1937

Agricultural Research Bulletins, Nos. 202-209

Agricultural Experiment Station, Iowa State College of Agriculture and Mechanic Arts

N. F. Waters  
Iowa State College

W. V. Lambert  
Iowa State College

R. H. Walker  
Iowa State College

P. E. Brown  
Iowa State College

See next page for additional authors

Follow this and additional works at: http://lib.dr.iastate.edu/ag_researchbulletins

Part of the Agricultural and Resource Economics Commons, Agricultural Economics Commons, Agricultural Science Commons, Agronomy and Crop Sciences Commons, Bioresource and Agricultural Engineering Commons, Botany Commons, Dairy Science Commons, Economics Commons, Genetics Commons, Plant Pathology Commons, Poultry or Avian Science Commons, and the Soil Science Commons

Recommended Citation


http://lib.dr.iastate.edu/ag_researchbulletins/18

This Book is brought to you for free and open access by the Iowa Agriculture and Home Economics Experiment Station at Iowa State University Digital Repository. It has been accepted for inclusion in Agricultural Research Bulletins by an authorized administrator of Iowa State University Digital Repository. For more information, please contact digirep@iastate.edu.
<table>
<thead>
<tr>
<th>Bul. No.</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>202</td>
<td>1</td>
</tr>
<tr>
<td>203</td>
<td>57</td>
</tr>
<tr>
<td>204</td>
<td>105</td>
</tr>
<tr>
<td>205</td>
<td>201</td>
</tr>
<tr>
<td>206</td>
<td>217</td>
</tr>
<tr>
<td>207</td>
<td>253</td>
</tr>
<tr>
<td>208</td>
<td>301</td>
</tr>
<tr>
<td>209</td>
<td>337</td>
</tr>
<tr>
<td>Inbreeding in the White Leghorn Fowl</td>
<td></td>
</tr>
<tr>
<td>By N. F. Waters and W. V. Lambert</td>
<td></td>
</tr>
<tr>
<td>Chemical Analyses of Iowa Soils for Phosphorus, Nitrogen and Carbon: A Statistical Study</td>
<td></td>
</tr>
<tr>
<td>By R. H. Walker and P. E. Brown</td>
<td></td>
</tr>
<tr>
<td>Genetic Aspects of the Danish System of Progeny-Testing Swine</td>
<td></td>
</tr>
<tr>
<td>By Jay L. Lush</td>
<td></td>
</tr>
<tr>
<td>The Oxidation of Acetymethylicarbinol to Diacetyl in Butter Cultures</td>
<td></td>
</tr>
<tr>
<td>By M. B. Michaelian and B. W. Hammer</td>
<td></td>
</tr>
<tr>
<td>Classification of the Organisms Important in Dairy Products I. Streptococcus Liquefaciens</td>
<td></td>
</tr>
<tr>
<td>By H. F. Long and B. W. Hammer</td>
<td></td>
</tr>
<tr>
<td>Masonry Barn Design and Construction</td>
<td></td>
</tr>
<tr>
<td>By Henry Giese, H. J. Barre and J. Brownlee Davidson</td>
<td></td>
</tr>
<tr>
<td>The Relation of Reserves to Cold Resistance in Alfalfa</td>
<td></td>
</tr>
<tr>
<td>By J. J. Mark</td>
<td></td>
</tr>
<tr>
<td>Economics of Agricultural Land Use Adjustments II. Methodology in Soil Conservation and Agricultural Adjustment Research</td>
<td></td>
</tr>
<tr>
<td>By Rainer Schickele</td>
<td></td>
</tr>
</tbody>
</table>
Inbreeding in the White Leghorn Fowl

By N. F. Waters and W. V. Lambert

AGRICULTURAL EXPERIMENT STATION
IOWA STATE COLLEGE OF AGRICULTURE
AND MECHANIC ARTS

R. E. Buchanan, Director

POULTRY HUSBANDRY SUBSECTION
and
GENETICS SECTION

AMES, IOWA
## CONTENTS

<table>
<thead>
<tr>
<th>Summary</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inbreeding in mammals and birds</td>
<td>5</td>
</tr>
<tr>
<td>General effects of inbreeding and crossbreeding</td>
<td>8</td>
</tr>
<tr>
<td>The problem</td>
<td>10</td>
</tr>
<tr>
<td>History and purpose</td>
<td>10</td>
</tr>
<tr>
<td>Methods</td>
<td>11</td>
</tr>
<tr>
<td>The effect of inbreeding on fertility</td>
<td>13</td>
</tr>
<tr>
<td>The effect of inbreeding on hatchability</td>
<td>15</td>
</tr>
<tr>
<td>The effect of inbreeding on days to first egg</td>
<td>18</td>
</tr>
<tr>
<td>The effect of inbreeding on egg production</td>
<td>21</td>
</tr>
<tr>
<td>The effect of inbreeding on egg size</td>
<td>24</td>
</tr>
<tr>
<td>The effect of inbreeding on rate of growth and on mature body weight</td>
<td>27</td>
</tr>
<tr>
<td>The effect of inbreeding on viability</td>
<td>30</td>
</tr>
<tr>
<td>Description of families</td>
<td>33</td>
</tr>
<tr>
<td>The effect of inbreeding on fertility in families 1 to 6</td>
<td>40</td>
</tr>
<tr>
<td>The effect of inbreeding on hatchability in families 1 to 6</td>
<td>42</td>
</tr>
<tr>
<td>The effect of inbreeding on age at first egg in families 1 to 6</td>
<td>44</td>
</tr>
<tr>
<td>The effect of inbreeding on egg production in families 1 to 6</td>
<td>47</td>
</tr>
<tr>
<td>The effect of inbreeding on egg weight in families 1 to 6</td>
<td>49</td>
</tr>
<tr>
<td>Discussion</td>
<td>50</td>
</tr>
<tr>
<td>Plate I</td>
<td>52</td>
</tr>
<tr>
<td>Plate II</td>
<td>53</td>
</tr>
<tr>
<td>Literature cited</td>
<td>54</td>
</tr>
</tbody>
</table>
A study, extending over a 10-year period, has been made of the effect of inbreeding in the White Leghorn breed of domestic fowl. The major object of this investigation was to study the effect of various intensities of inbreeding on the following characters: Fertility, hatchability, viability, days to first egg, egg production, egg size and body size.

In the present investigation the degree of inbreeding was, in general, less intense than that from brother and sister or parent and offspring matings. One intensely inbred family, however, with the equivalent of brother and sister mating, was maintained successfully for nine generations. Six more or less distinct families, each with a somewhat different type and intensity of inbreeding but with a similar foundation ancestry, were developed.

All individuals were selected primarily on the basis of high hatchability of their eggs, upon general vigor of the individual bird and of the offspring of each pair of birds. Other characters besides vigor and hatchability also were considered whenever practical.

The ancestry of all the birds in the present generation of these 6 families may be traced to four males and seven females. One of the four original males (No. 823), however, has a greater degree of relationship to the present generation than any of the other foundation birds. This relationship still averages approximately 55 percent, with the lowest degree of relationship being 29 percent and the highest 61 percent. The relationship of the present generation to the other three foundation males does not exceed 5 percent.

The relationship between brothers and sisters in the present generation chicks of the separate families ranges from 74 to 94 percent. The average inter-se relationship between the present chicks which are not sibs is above 50 percent.

The inbreeding coefficients of the present birds range from 41 percent for the least inbred to 82 percent for the most intensely inbred family.

There was no general decrease in percent of eggs fertile as the degree of inbreeding increased; in fact some inbred families have shown an increase in percent of eggs fertile.

There was a slow but gradual decline in the average percent hatchability of fertile eggs set for all inbreds as the inbreeding increased. The average hatchability for all inbreds, however, was in most cases well above 60 percent. In six of the families
studied there was no general decrease in hatchability, which
demonstrates that it is possible to maintain a reasonably safe
level of hatchability under a system of intense inbreeding.

There was a significant decrease in the number of days to
first egg. The most intensely inbred birds on the average
matured sexually 16 days earlier than the birds of the original
non-inbred foundation stock.

There was a general but not a consistent decrease in number
of eggs laid during a given period as the inbreeding increased.
An exception was observed for the 70 percent inbred group
which compared favorably with the original non-inbred founda-
tion birds in egg production. There was no marked decrease
in 200-day egg production for any one of the six separate fami-
lies as a result of the inbreeding.

The data on egg weight suggest no general decrease or in-
crease in average egg weight as a result of the inbreeding.

The results indicate that intensive inbreeding did not de-
crease materially the growth rate or adult body weight of the
birds used in this experiment.

With the exception of the 80 percent group, there was no in-
crease in mortality in any of the groups up to 24 weeks of age.
The pullet year mortality, however, showed a marked rise for
the more intensely inbred birds with the exception of that
group of birds having an inbreeding coefficient of 70 percent.
Inbreeding in the White Leghorn Fowl

BY N. F. WATERS AND W. V. LAMBERT

Among animal breeders as a whole there are few problems of more general interest than that of inbreeding. In the hands of some breeders it has proved a valuable tool; for others the outcome has been very unsatisfactory. These paradoxical results stimulated much research on the problem of inbreeding during the last 30 years. Some of this research has furnished the answer to many of the theoretical aspects of the inbreeding question. No very systematic attempts, however, have been made to use close inbreeding in a practical way for animal improvement. Many breeders have recognized the usefulness of the method as a tool for fixing traits but have avoided continued close inbreeding for fear of fixing undesirable characteristics in their animals.

In the agronomic field much more extensive use has been made of inbreeding in a practical way. Based on the pioneer researches of East (9) and Shull (26), an entirely new method of corn breeding is being evolved which is built around a plan of intensive inbreeding followed by cross-breeding. This program has resulted not only in marked increases in yield but it also holds great promise for the development of lines adapted for special purposes.

With the smaller mammals intensive inbreeding has been done with considerable success but relatively few intensive inbreeding experiments have been carried out with larger mammals. Continued close inbreeding in the fowl almost invariably has resulted in disaster. Hitherto, no experiment has been reported in which very close inbreeding has proceeded beyond the sixth generation; however, the number of attempts to inbreed the fowl closely has been small.

INBREEDING IN MAMMALS AND BIRDS

The older experiments on the inbreeding of animals have been so well reviewed by several writers, King (18, 19 and 20), Wright (29) and East and Jones (10), that no attempt will be made here to review the earlier experiments. On the whole, the results were unsatisfactory although exceptions to this general conclusion occurred.

1 Project No. 54 of the Iowa Agricultural Experiment Station.

2 The authors desire to thank Dr. J. L. Lush of the Animal Husbandry Department for his valuable criticism and Dr. A. E. Brandt of the Mathematics Department for his assistance on certain statistical phases of this bulletin.
The most extensive inbreeding in mammals has been done by King (21). Miss King has inbred two strains of rats, the famous Wistar A and B strains, by brother-sister mating for 93 generations, and reports that both strains are still in a flourishing condition. The success of the inbreeding in the Wistar rats is attributed to a good foundation stock and to the rigid selection of the best animals for breeders in each generation.

Another long-continued and intensive series of inbreeding experiments in mammals has been reported by Wright (30), Eaton (8) and McPhee and Eaton (22). Wright observed a decline in vigor in all characteristics for over twenty generations of brother-sister inbreeding in the guinea pig, although the decline in vigor was greater for some characters than for others. Distinct differentiation in the above respects was observed between the various inbred families, and the differences between families increased as inbreeding progressed. In this respect the families tended to keep a certain rank with respect to each character. Recently Eaton (8) has summarized the results of 25 years of inbreeding in the five remaining of the original twenty-three inbred families of guinea pigs with which the experiment was started. This summary includes the earlier results reported by Wright (29) for the five lines. These lines became clearly differentiated from one another early in the experiment. They have reacted differently to inbreeding or to environmental conditions, however, so that the ranking for the various families in the different measures of vigor has changed at times.

An average decline in all measures of vigor was observed but fertility suffered most as a result of the inbreeding. Since somewhat parallel declines, though at a higher level, were observed for the control stock, Eaton believes that general conditions rather than inbreeding have accounted for much of the decline observed in these families.

In the larger mammals most of the close inbreeding has been confined to swine. Several investigators have reported on the results of brother and sister or of half brother and sister matings in this species for several generations with somewhat varying results. The experiments of Hodgson (14) and Hughes (15) have been most successful. The former has inbred full brother by sister in three lines of Poland China swine, out of seven original lines in the beginning, for five, six and eight generations without great loss in vigor or change in conformation. The lines became clearly differentiated in other respects, however, particularly in temperamental and psychological reactions. Hughes, likewise, has been successful in inbreeding Berkshire swine for the equivalent of about six generations of brother and sister matings without any appreciable loss in size,
fertility or vigor. McPhee (23) and McPhee, Russell, and Zeller (24) have had less favorable results. An attempt on their part to establish an inbred strain of Poland China swine ended in the second generation because of poor fertility and high mortality in the inbreds. In the Tamworth and Chester White breeds the results were less disastrous, although some decline in general vigor of the inbreds was noted after four generations of brother-sister mating. The segregation of various anomalies, such as swirls, cleft palate, cryptorchidism and change in type, was observed. Craft (3) has inbred Duroc Jerseys by mating half brothers and sisters for five generations. The general vigor of this stock, as measured by size of litter, still-born young, rate of gain, efficiency of feed utilization and in losses after weaning, was lowered by the inbreeding although some good individuals were observed among the inbreds.

With the other large domestic animals little systematic inbreeding experimentation has been done. Some inbreeding has been practiced in the development of various breeds but most of this inbreeding has been relatively mild. The only other mammal that has been highly inbred is the mouse. At present a number of highly inbred strains of laboratory mice are in existence and some of these inbred strains compare favorably with good outbred stocks of mice.

In birds most inbreeding experiments have been unsuccessful, none having been reported thus far in which inbreeding progressed beyond the sixth generation of brother and sister mating. The most intense and long-continued inbreeding experiments for the fowl have been reported by Goodale (11) and Dunn (7). Both of these experiments, which were carried on by brother and sister matings, ended in disaster due to the rapid decline in hatchability of the inbred birds. In other respects, also, degeneration was observed, for the inbred birds were smaller, matured later, laid fewer eggs and were lower in viability than were outbred birds reared under comparable conditions. Dunn observed a differentiation among the various inbred families in bone length and in the proportion of the parts.

The experiments of most other students of inbreeding in the fowl, Cole and Halpin (1), Jull (16), Hays (12), Dumon (5), Dunkerly (6) and Dudley (4) agree in general with those reported above. The character most affected by inbreeding was hatchability although in most of the experiments reported a general decline in the vigor of the inbred stock was observed. In a second experiment by Cole and Halpin (2), where selection was based on hatchability, the writers state that the general vitality of the stock was raised although egg production was decreased.
Wriedt (28), contrary to the findings of most investigators, claims that good results were secured from inbreeding in the White Leghorns used at the Rogaland breeding station in Norway. The degree of inbreeding in this experiment was relatively low, however, the coefficient of inbreeding in no case probably exceeding 37.5 percent.

**GENERAL EFFECTS OF INBREEDING AND CROSSBREEDING**

Inbreeding may be defined broadly as the mating together of related individuals. Such a system of mating automatically brings about a general increase in the genetic purity or homozygosity of the inbred population, the rate of increase in homozygosity being dependent upon the closeness of relationship of the mates to each other. The genetic likeness is increased within each inbred family but at the same time the diversity from family to family is increased, even though these families start from common foundation stock. A population, therefore, is broken up into diverse groups as a result of inbreeding; some groups good in one respect and some in others. Unfortunately, however, inbreeding increases homozygosity for bad as well as for good factors and may fix combinations of genes that do not nick well, with the result that some deterioration usually occurs in those qualities generally found in a good vigorous stock. The inbreeding does not create the defective traits that appear but merely uncovers them by bringing to a homozygous condition the recessive genes that were present in the parent animals.

Some retardation in the fixation of undesirable genes or poor combinations of factors may be effected by rigid selection, but under intensive inbreeding the power of selection to check the fixation of such genes is relatively weak. With less intensive inbreeding, however, selection becomes a more important factor in preventing fixation of defective genes. In the latter case there is a less rapid approach toward homozygosity which allows for elimination of some of the defective factors before they become permanently fixed in the inbred population.

The outcome of inbreeding in either animals or plants depends much upon the type of genetic variability in the original population preceding inbreeding. Less degeneration takes place if the foundation stock is relatively free of heritable defects; if it carries many such defects, as seems to be true of most animals and plants, some degeneration is likely to occur in spite of rigid selection to the contrary.

Outbreeding, as contrasted with inbreeding, refers to the mating of unrelated individuals. This is a general definition
which may imply crosses within the breed, between breeds or even wider crosses. The effect of this system of mating is to maintain genetic impurity or heterozygosity. Any major changes occurring in a population in which outbreeding is carefully and regularly practiced, therefore, are due to the influence of selection and not to any great increase or decrease in the heterozygosity of the breeding stock. Rigid selection for certain characters results in the fixation of some genes and the shifting of the population in the desired direction. After a certain limit is reached, however, selection often becomes relatively powerless in producing further gains.

Outcrosses between non-inbred strains often produce superior $F_1$ or first generation hybrid progeny. This occurs because the set of hereditary factors contributed by one parent complement favorably the set contributed by the other parent, a phenomenon commonly known as "nicking." Where the parent animals are similar in their breeding there is less chance of getting hybrid vigor than from crosses in which there is little common relationship. Even two entirely unrelated strains, however, may give little increased vigor if they carry many common genes. The only certain means of determining the value of two strains for crossing lies in actually crossing them. Unfortunately the appearance of an animal is not a very reliable criterion of its breeding behavior; it is only from observing actual results as measured by the performance of their hybrids that the value of any given strains for crossbreeding can be determined.

In plants, especially in corn, it has been demonstrated that crossbreeding following inbreeding frequently gives an exceptional return of vigor in the individuals of the first crossbred generation. The inbreeding process produces homozygous strains but in the process of becoming homozygous many of the defective genes in the strain are eliminated. No two inbred lines are likely homozygous for the same combination of genes, but when the right combination of inbreds is crossed a marked increase in vigor results in the hybrid due to the favorable nicking of the genes in the two strains.

Because of the facts just discussed it would seem that the inbreeding method holds promise for animal improvement. It is improbable that inbred strains can be established which are equal to the better strains now existent, but because of the elimination of defective hereditary factors as a result of inbreeding, with the possibility of recombination of the desirable factors through crossbreeding, the plan holds real promise. It is, of course, a long time program and one which will probably necessitate the developing and testing of a good many inbred lines before the better combinations are found.
THE PROBLEM

From the foregoing discussion it is clear that the utilization of inbreeding as a means of animal improvement presents many difficult problems. The effectiveness of the method for fixing type and uniformity in animals and the well demonstrated value of the plan, when followed by crossbreeding, for corn improvement, however, certainly justifies an extensive test of an inbreeding program for animals based somewhat on the plan being used so successfully by corn breeders. For economic reasons the fowl would seem to be the animal best suited for such a test. The small cost of each bird, the short interval between generations and the ability to carry a large number of animals at relatively small cost make it possible to test the plan on a large scale. A final answer can be furnished only from critical experiments designed directly to answer the question.

Two distinct phases are involved in such a program. The first step is the development of good inbred lines. Once these have been developed they may be tested in various intercrosses, or by using inbred males for top crossing on non-inbred females or in various other ways, as well as for synthesizing new inbreds. It is not to be expected that all inbreds will be equally valuable for intercrossing and for other uses. An important part of any well planned experiment of this nature, therefore, will call for the continual development of new and better inbreds. These probably can be produced to best advantage by inbreeding the hybrids resulting from outcrosses of the superior inbred lines to the best non-inbred strains.

Such a program was undertaken at the Iowa Experiment Station in 1926 and the results obtained during the first phase of the experiment, namely the production of inbreds, have been remarkably successful in contrast with most experiments on close inbreeding so far reported for the fowl. In this paper the writers are reporting primarily on the effects of the various systems of inbreeding used to date upon those characters which are of greatest economic concern to the poultryman.

HISTORY AND PURPOSE*

The foundation birds used in this study were obtained from the flock of the Iowa State College in 1925. The pedigree records show that the birds were descended largely from a flock purchased by the College in 1923 from a breeder living near Ames.

The original object of this investigation was to study the

*The early phases of this investigation were planned by and under the supervision of Dr. C. W. Knox, now Senior Geneticist, U. S. D. A.
effect of different intensities of inbreeding, crossbreeding and outcrossing in the single comb White Leghorn fowl on the following characters: Fertility, hatchability, viability, days to first egg, egg production, egg size and body size. Another major object was to develop lines homozygous for a number of the characters of greatest economic usefulness to the poultry breeder since reasonably homozygous material would seem to be necessary before the geneticist can hope to make a critical analysis of such characters.

From the more strictly applied viewpoint, the plan was to develop inbred lines that would prove useful for intercrossing with other inbreds and for top-crossing with good non-inbred strains. At the outset of this investigation there was available ample evidence in the field of corn breeding to show the value of intercrossing and top crossing with corn, and, as the possibility of a similar use of inbreds seemed favorable in poultry, this has remained one of the main purposes of the experiment. And finally, inbred birds, or preferably F₁ hybrids between birds of different inbred lines, should furnish excellent material for nutrition and physiologic experiments due to the reduction of genetic variability in such material.

METHODS

The original plan of the experiment called for different intensities of inbreeding and, in general, the degree of inbreeding has been less intensive than that obtained from brother and sister or parent and offspring matings; this policy has been followed for the most part throughout the experiment. One intensely inbred family of parent-offspring and brother-sister mating, however, has been maintained successfully for nine generations. Throughout the investigation there was a rigid selection for high hatchability, large family size and good vigor. High hatchability was chosen as perhaps the most important character for, in order to maintain any line of poultry, it is imperative that the hatchability be maintained at or above a certain minimum level. Other characters besides vigor, size of family and hatchability were considered whenever practical, namely: Fertility, viability, early maturity, egg production, egg size and body size.

It should be made clear that there was no selection of birds on which records were to be obtained throughout the experiment. All birds that were able to stand after hatching were placed in the brooder houses, being forced to compete with other chicks until eliminated either by death or by discarding after all desirable records were obtained.

Pedigree records were kept for every bird used in the study. All birds were trapnested for at least 10 months during the first
5 years and for at least 12 months during the next 5 years. Each egg that was saved for incubation was weighed, the eggs from each hen were hatched in separate wire baskets and upon removal from the incubator each chick was wing banded. Hatchability and fertility records were kept for each individual hen.

The last 4 years all chicks were weighed at hatching time, at intervals of approximately 2 weeks during the first 3 months and at monthly intervals thereafter until maximum weight was attained, which occurs at approximately 10 months of age. It was not practical to weigh each bird exactly 2 weeks or 1 month after hatching, and so in many instances it was necessary to estimate the weights at the close of each 14-day or 30-day interval by interpolation between the weights actually taken.

Mortality records for the first 24 weeks include only those birds hatched in the years 1933 and 1934. Previous to this, accurate chick mortality records are not available. Records of pullet year mortality are available for all birds beginning with the year 1926.

Several changes in the management of the birds used in this investigation have been made during the past 10 years. These changes have been made in keeping with good poultry management practices but they have introduced environmental changes that need be considered in an analysis of the results. So far as possible, however, the conditions were as near optimum as could be provided at all times.

The ancestry of all the birds in the present generation may be traced to four males and seven females. One of the four original males (No. 823), however, has a distinctly higher degree of relationship to the present generation than any other of the foundation birds. This relationship still averages approximately 55 percent, ranging from 29 percent to 61 percent. The relationship of the present generation to the other three foundation males does not exceed 8 percent. The relationship between brothers and sisters in the present generation ranges from 74 percent to 94 percent. The average inter-se relationship between the present chicks which are not sibs is above 50 percent. The inbreeding coefficients of the present birds range from 41 percent to 82 percent. This is equivalent to a trifle more than two generations of brother and sister matings for the least inbred family while the inbreeding coefficient for the highest inbred family is equivalent to that obtained from eight generations of brother and sister matings.

The measurement of inbreeding and relationship has been calculated according to the method suggested by Wright (31). The inbreeding coefficient furnishes a measure of the probable decrease in heterozygosity in any given animal while the rela-
The relationship coefficient furnishes an estimate of the extent to which the given animals have common genes.

**THE EFFECT OF INBREEDING ON FERTILITY**

The investigations of Pearl and Surface (25) and of Hays and Sanborn (13) would indicate that fertility is not inherited. Recent studies by Jull (17), however, indicate that fertility is inherited and he suggests that the selection of yearling dams based on the results of their first year’s record is a worth while practice. While unquestionably there are genes that affect fertility, it should be recognized that many environmental conditions, preferential mating and other things may greatly affect this character. Obviously this renders a genetic analysis difficult.

While there has been no intentional selection primarily for high fertility in this experiment, there has been a high incidental selection for this character, for, in general, those birds that produced a large number of chicks during the hatching season had both high fertility and high hatchability of their eggs.

Figure 1 shows the influence upon fertility that was observed in this experiment. The average percent of eggs fertile is shown for all inbreds and for those birds chosen to be parents. Figure 2 gives the percentage distribution of eggs fertile for all the inbreds used for breeding purposes. The trend for fertility would indicate that there has been a decrease in fertility for those inbreds having the equivalent of more than one brother-sister generation of inbreeding, namely, 25 percent. In no instance, however, did the mean fertility drop below 78 percent. Table 1 shows the mean fertility by years for the different inbred groups. Fertility was consistently low for the year 1934 for all groups except the 11-20.9 percent group. There is no indication of consistently low fertility for any of

---

*It should be emphasized here that the data shown in figs. 1 to 8 are grouped together by inbreeding percent and that birds hatched in several different years may be placed in similar inbreeding groups.*

---

![Fig. 1. Trends showing percent of fertile eggs for all inbreds and for those inbreds chosen to be parents, together with the number of hens in each group.](image-url)
Fig. 2. Histograms showing variation in percent of fertile eggs for all inbreds used for breeding, with the mean and standard deviation for each group. Mean fertility for each inbred group is indicated by the arrow.
TABLE 1. PERCENTAGE FERTILITY BY YEARS FOR THE DIFFERENT INBRED GROUPS.

<table>
<thead>
<tr>
<th>Year</th>
<th>0</th>
<th>1-10.9</th>
<th>11-20.9</th>
<th>21-30.9</th>
<th>31-40.9</th>
<th>41-50.9</th>
<th>51-60.9</th>
<th>61-70.9</th>
<th>71-80.9</th>
</tr>
</thead>
<tbody>
<tr>
<td>1926</td>
<td>88</td>
<td></td>
<td></td>
<td></td>
<td>83</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1927</td>
<td>93</td>
<td>87</td>
<td>98</td>
<td>78</td>
<td>64</td>
<td>90</td>
<td>97</td>
<td>97</td>
<td></td>
</tr>
<tr>
<td>1928</td>
<td>87</td>
<td>90</td>
<td>99</td>
<td>65</td>
<td>71</td>
<td>99</td>
<td>88</td>
<td>88</td>
<td>80</td>
</tr>
<tr>
<td>1929</td>
<td>87</td>
<td>90</td>
<td>79</td>
<td>90</td>
<td>89</td>
<td>90</td>
<td>76</td>
<td>82</td>
<td>96</td>
</tr>
<tr>
<td>1930</td>
<td>90</td>
<td>89</td>
<td>75</td>
<td>89</td>
<td>82</td>
<td>96</td>
<td>67</td>
<td>67</td>
<td>96</td>
</tr>
<tr>
<td>1931</td>
<td>98</td>
<td>90</td>
<td>79</td>
<td>84</td>
<td>83</td>
<td>78</td>
<td>82</td>
<td>88</td>
<td>96</td>
</tr>
<tr>
<td>1932</td>
<td>98</td>
<td>96</td>
<td>96</td>
<td>84</td>
<td>83</td>
<td>78</td>
<td>82</td>
<td>88</td>
<td>96</td>
</tr>
<tr>
<td>1933</td>
<td>98</td>
<td>96</td>
<td>96</td>
<td>84</td>
<td>83</td>
<td>78</td>
<td>82</td>
<td>88</td>
<td>96</td>
</tr>
<tr>
<td>1934</td>
<td>98</td>
<td>96</td>
<td>96</td>
<td>84</td>
<td>83</td>
<td>78</td>
<td>82</td>
<td>88</td>
<td>96</td>
</tr>
</tbody>
</table>

The fertility for the chosen parents, with but one exception, has been above 80 percent. Since, as previously pointed out, there was a high incidental selection for fertility throughout the experiment, fertility for the chosen parents has been maintained at a high level.

In these studies it is evident that inbreeding has not had a serious effect on fertility and from the results it would seem possible for the breeder to practice mild inbreeding without seriously decreasing fertility, providing he continually practices careful selection for high fertility.

THE EFFECT OF INBREEDING ON HATCHABILITY

In the several attempts that have been made to inbreed the fowl heretofore, almost invariably there has been a rapid decrease in hatchability as the inbreeding coefficient increased, this decrease in hatchability leading in most cases to termination of the experiment. Since it is clear that no inbreeding experiment in the fowl can be continued successfully unless a reasonable hatchability is maintained, it, therefore, becomes necessary to practice rigid selection for high hatchability.

Throughout this experiment there has been a constant selection in all families for high hatchability and for large families from each dam. Such a program does not necessarily insure that all birds selected as breeders possessed the best genotype for high hatchability, since the genetic basis for this character is certainly complex and the character is greatly influenced by
environmental conditions. Since the environmental influence, however, is probably not greatly, if at all, selective between genotypes, it seems that a breeding program based on the selection of the highest hatching females would eventually insure the isolation of birds with good combinations of genes for hatchability.

In the present experiment there has been a slow but gradual decline in the average percent hatchability of fertile eggs set for all inbreds as the inbreeding coefficient has increased. From fig. 3 it will be observed, however, that the average hatchability for all inbreds has been above 60 percent, with the exception of those birds having an inbreeding coefficient of 70 percent.

In fig. 4 is shown the distribution for percentage hatchability for the different degrees of inbreeding. A few birds in all groups have given very low hatchability but many have hatched as high as 100 percent; thus there has been ample opportunity to select as breeders those birds which were produced from high hatching dams. The average hatchability of the chosen parents has been above 80 percent and no birds were chosen as parents whose dams hatched less than 60 percent of their fertile eggs.

Table 2 presents the statistics for mean hatchability by years for the different inbred groups. It is well known that the ability of fertile eggs to hatch is dependent to a high degree on the environment. Therefore, it is very difficult to suggest that the consistently low hatchability observed in certain years is due entirely to genetic causes. The years 1928, 1930, 1932, and 1933 all seem to suggest that hatchability generally decreased as inbreeding increased. On the other hand, the years 1931 and 1934 do not show such a relationship. Comparing the years 1933 and 1934 it is clear that the birds having the same degree of inbreeding hatched much better in 1934.

An analysis of variance in hatchability for the different degrees of inbreeding shows that there was a highly significant difference between groups. Most of the families are highly re-
Fig. 4. Histograms showing variation in percent of fertile eggs hatched for all inbreds used for breeding, with the mean and standard deviation for each group. The mean hatchability is indicated by the arrow.
TABLE 2. PERCENTAGE HATCHABILITY BY YEARS FOR THE DIFFERENT INBRED GROUPS.

<table>
<thead>
<tr>
<th>Year</th>
<th>0</th>
<th>1-10.9</th>
<th>11-20.9</th>
<th>21-30.9</th>
<th>31-40.9</th>
<th>41-50.9</th>
<th>51-60.9</th>
<th>61-70.9</th>
<th>71-80.9</th>
</tr>
</thead>
<tbody>
<tr>
<td>1926</td>
<td>76</td>
<td>82</td>
<td>85</td>
<td>84</td>
<td>60</td>
<td>61</td>
<td>76</td>
<td>61</td>
<td>59</td>
</tr>
<tr>
<td>1927</td>
<td>73</td>
<td>80</td>
<td>90</td>
<td>85</td>
<td>81</td>
<td>60</td>
<td>61</td>
<td>76</td>
<td>59</td>
</tr>
<tr>
<td>1928</td>
<td>73</td>
<td>74</td>
<td>77</td>
<td>77</td>
<td>66</td>
<td>68</td>
<td>67</td>
<td>61</td>
<td>60</td>
</tr>
<tr>
<td>1929</td>
<td>74</td>
<td>71</td>
<td>90</td>
<td>85</td>
<td>81</td>
<td>60</td>
<td>61</td>
<td>57</td>
<td>59</td>
</tr>
<tr>
<td>1930</td>
<td>93</td>
<td>88</td>
<td>84</td>
<td>60</td>
<td>61</td>
<td>76</td>
<td>61</td>
<td>59</td>
<td>75</td>
</tr>
<tr>
<td>1931</td>
<td>74</td>
<td>71</td>
<td>77</td>
<td>69</td>
<td>68</td>
<td>67</td>
<td>61</td>
<td>57</td>
<td>59</td>
</tr>
<tr>
<td>1932</td>
<td>74</td>
<td>71</td>
<td>77</td>
<td>69</td>
<td>68</td>
<td>67</td>
<td>61</td>
<td>57</td>
<td>59</td>
</tr>
<tr>
<td>1933</td>
<td>73</td>
<td>71</td>
<td>71</td>
<td>62</td>
<td>67</td>
<td>67</td>
<td>61</td>
<td>57</td>
<td>59</td>
</tr>
<tr>
<td>1934</td>
<td>86</td>
<td>86</td>
<td>70</td>
<td>85</td>
<td>71</td>
<td>71</td>
<td>71</td>
<td>71</td>
<td>75</td>
</tr>
</tbody>
</table>

lated to one another, as will be pointed out later, but, it is to be expected under an intense system of inbreeding that different families will diverge and show different means and distributions, as, in fact, they do.

This investigation has demonstrated that it is possible to maintain a reasonably safe level for hatchability under a system of intense inbreeding. It should be stressed again, however, that there has been a very rigid selection for high hatchability based upon a large number of progeny. In some instances it was necessary to discard entire families having other desirable characters because of low hatchability.

THE EFFECT OF INBREEDING ON DAYS TO FIRST EGG

It is desirable to have a pullet lay its first egg as early in life as possible, for it has been demonstrated repeatedly that the earlier in life a pullet lays her first egg, or matures sexually, the greater will be her first year’s egg production. It has been reported by Hays (12) and Jull (16) that inbreeding tends to increase the number of days to first egg. It should be emphasized that throughout this experiment there has been no conscious selection for early sexual maturity.

In fig. 5 the average number of days to first egg for all inbreds and for those birds chosen to be parents is shown. The data from the birds upon which this figure is based were grouped by percent inbreeding, regardless of the year in which they were hatched. Figure 6 gives the distribution for days to first egg for all inbreds. No increase in the mean number of days to first egg was observed for the various inbred groups as the inbreeding coefficient increased. From the 0 percent to 60 percent groups there was little change in the average days to first egg. There was, however, a drop of 22 days in sexual maturity between the 60 percent and 80 percent groups. It will be observed that the number of birds in the various inbred groups upon which these results are based is fairly large.
The number of days to first egg is shown by years for the different groups in table 3. No marked yearly differences in days to sexual maturity are indicated from these data. With two exceptions, namely, 1930 and 1932, the highly inbred groups are the earliest maturing, regardless of the year in which they were hatched. It would seem to be of some genetic significance that the more highly inbred groups matured sexually earlier, while the less intensely inbred birds hatched in the same year and receiving the same management, in general, matured sexually much later, regardless of the year in which they were hatched. This would seem to indicate that the birds in the more highly inbred groups are homozygous for more of the genes for early maturity.

All data considered, there was a decrease in number of days to sexual maturity as the inbreeding increased. An analysis of variance in sexual maturity among the progeny with different degrees of inbreeding shows that there is a highly significant difference between the various groups.

<table>
<thead>
<tr>
<th>Year</th>
<th>0</th>
<th>1-10.9</th>
<th>11-20.9</th>
<th>21-30.9</th>
<th>31-40.9</th>
<th>41-50.9</th>
<th>51-60.9</th>
<th>61-70.9</th>
<th>71-80.9</th>
</tr>
</thead>
<tbody>
<tr>
<td>1926</td>
<td>211</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1927</td>
<td>212</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1928</td>
<td>220</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1929</td>
<td>217</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1930</td>
<td>215</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1931</td>
<td>205</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1932</td>
<td>202</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1933</td>
<td>215</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1934</td>
<td>207</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**TABLE 3. AVERAGE NUMBER OF DAYS TO FIRST EGG FOR THE DIFFERENT INBRED GROUPS AS OBSERVED IN DIFFERENT YEARS OF THE EXPERIMENT.**
Fig. 6. Histograms showing the variation in days to first egg for all inbreds, with the mean and standard deviation for each group. The average days to first egg for each group is indicated by the arrow.

Among the chosen parents the average days to sexual maturity is lower than the average for all inbreds for the 0 percent to 50 percent groups. From the 50 percent to 80 percent
groups the average days to sexual maturity is somewhat erratic.
In this experiment, then, there is no indication that intense inbreeding has increased the number of days to first egg. On the contrary, the more intensely inbred birds have matured sexually 16 days earlier on the average than the birds of the original non-inbred foundation stock.

EFFECT OF INBREEDING ON EGG PRODUCTION

In fig. 7, the effects of inbreeding on egg production are presented. Because of the high mortality occurring during the
first laying year it seemed desirable to consider the number of
eggs laid for different intervals during the first year of pro-
duction as well as for the total first year production. There-
fore, three periods of production are reported, namely: Janu-
ary to March egg production, first 200 days egg production
and annual egg production.

It should be remembered that there was no conscious selection
for egg production throughout the experiment. There was,
however, a possible incidental selection for, if birds were se-
lected for high hatchability and for large numbers of progeny,
it is clear that they were laying at a rapid rate during the
hatching season.

The trend of the January to March egg production for the
chosen inbred parents and for all inbreds is shown in fig. 7.
There is no clear evidence that ability to lay eggs during the
winter months has been greatly reduced as a result of continued
inbreeding. True, there was a slow decrease in winter egg
production as the inbreeding coefficient increased from 0 to
50.9 percent, but the birds in the group 61 to 70.9 percent
showed a high rate of production during the 3 winter months,
even higher than that found in the foundation birds. These re-
sults demonstrate the possibility for high egg production in the
more highly inbred groups. The 80 percent inbreds showed a
decided drop in winter egg production. The winter egg pro-
duction for the birds chosen to be parents is in general slightly
higher than that for all inbreds.

A more thorough analysis was made for 200-day egg produc-
tion than for either January to March or annual egg produc-
tion. The trend for 200-day egg production for the different in-
bred groups is shown likewise in fig. 7. This figure also shows
the trend of the parent birds. The distribution of 200-day egg
production for the different inbred groups is presented in fig. 8.

Egg production for the first 200 days of laying unquestion-
ably decreased for the birds with inbreeding coefficients from
0 to 50 percent. For the 60 and 70 percent groups, however,
an increase in production was noted but the birds of the 80
percent group again showed a marked decrease. Table 4 gives
the statistics for 200-day egg production by years for the dif-
ferent inbred groups. Environmental causes probably were
responsible in considerable part for the variation in egg pro-
duction observed between the different groups although these
statistics do not show marked yearly differences. Each year
certain groups were low but there were other groups in the
same year which were high. On the whole, however, the pro-
duction was a little lower for the more highly inbred birds.
This is most apparent in the last 3 years.

An analysis of variance in the 200-day production shows a
Fig. 8. Histograms showing variation in 200-day egg production for all inbreds, with the respective means and standard deviations. The average production is indicated by the arrow.

highly significant difference between the various groups. Certain of the groups show a marked variability as measured by the standard deviation. The 0 percent inbred birds showed the lowest variability while the 30 and 60 percent inbreds showed the highest variability. Much of the variability in the inbred groups can be attributed, no doubt, to the fact that inbreds from several different families have been grouped together in computing this variability.

The trend for annual egg production shows a decrease similar to that observed for January to March and for 200-day egg production (fig. 7). There was a marked drop in annual egg production for the 60 percent inbred group that was not ob-
TABLE 4. AVERAGE NUMBER OF EGGS LAID DURING THE FIRST 200 DAYS OF PRODUCTION FOR THE DIFFERENT INBRED GROUPS.

<table>
<thead>
<tr>
<th>Percent inbreeding</th>
<th>Year</th>
<th>0</th>
<th>1-10.9</th>
<th>11-20.9</th>
<th>21-30.9</th>
<th>31-40.9</th>
<th>41-50.9</th>
<th>51-60.9</th>
<th>61-70.9</th>
<th>71-80.9</th>
</tr>
</thead>
<tbody>
<tr>
<td>1926</td>
<td></td>
<td>115</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1927</td>
<td></td>
<td>111</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1928</td>
<td></td>
<td>107</td>
<td>114</td>
<td>101</td>
<td>105</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1929</td>
<td></td>
<td>102</td>
<td>114</td>
<td>68</td>
<td>119</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1930</td>
<td></td>
<td>103</td>
<td>96</td>
<td>100</td>
<td>90</td>
<td>77</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1931</td>
<td></td>
<td></td>
<td>111</td>
<td></td>
<td>105</td>
<td>95</td>
<td>96</td>
<td>117</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1932</td>
<td></td>
<td>87</td>
<td>143</td>
<td></td>
<td>84</td>
<td>78</td>
<td>84</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1933</td>
<td></td>
<td>84</td>
<td>104</td>
<td>92</td>
<td>62</td>
<td>73</td>
<td>105</td>
<td>70</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1934</td>
<td></td>
<td>84</td>
<td>93</td>
<td>103</td>
<td>58</td>
<td>63</td>
<td></td>
<td></td>
<td>54</td>
<td></td>
</tr>
</tbody>
</table>

served for either the January to March or 200-day egg production. With the exception of this 60 percent group the trends for January to March, 200-day and annual egg production coincide rather closely.

The fact that the 70 percent inbreds could compete favorably with the original non-inbred foundation birds shows clearly that the ability to lay a reasonable number of eggs has not been lost in the birds of the more intensely inbred groups.

THE EFFECT OF INBREEDING ON EGG SIZE

It is well established that the ultimate size of a hen’s egg is related to the ultimate size of the bird. Growth is relative to time; therefore the reproductive organs will increase in size when the body as a whole increases in size. Accordingly, the mean annual egg weight of a bird is not necessarily its genetic egg size, for if a pullet starts to lay early in life she will lay a larger number of small eggs before attaining maximum growth than will the hen that starts to lay much later in life. An early sexual maturing bird, therefore, will have a lower mean annual egg weight than will the late sexual maturing bird, although they may both be genetically the same with reference to egg weight. Accordingly, the size of egg for the individual bird was obtained for this study only after a bird had attained full growth, or at approximately 10 months of age.

During the early phases of this project egg weights were obtained only during the hatching period, and then only for those birds chosen to be parents. A study of the age of these birds showed all of them to be approximately 10 months of age or older and therefore the egg weights from these birds were used in this study. For 4 years the eggs from all inbreds were weighed at least 1 week each month and nearly all of them were weighed daily.

In fig. 9 is presented the trend for average egg weight for the various coefficients of inbreeding, while the distribution of
Fig. 9. Trends showing average egg weight for all inbreds and for those inbreds chosen to be parents, together with the number of birds in each group.

egg weight for all the inbreds is shown in fig. 10. An analysis of variance in egg weights shows a significant difference between the groups when classed according to the intensity of their inbreeding. This difference, however, does not come from any steady decrease or increase in average egg weight paralleling the changes in inbreeding. The lowest egg weights were in the 10 percent and the 80 percent groups, almost at the two extremes of the inbreeding. The other groups differed very little in average egg weight. At present it is not clear why these groups differed significantly in egg weight. The absence of a steady trend makes it unlikely that the differences were a direct result of the inbreeding. There were no highly inbred birds in the early years and no mildly inbred birds in the later years. Any environmental conditions which possibly might have influenced egg weight peculiarly in one or more years, therefore, would not have affected all the inbreeding groups equally.

The birds that were chosen to be parents showed relatively little increase in egg size although the egg weight is slightly greater in the chosen groups than for the entire inbred group. The standard deviation for the birds in fig. 10 indicates that the greatest amount of variability occurred in the 20, 30, 40, 50, and 80 percent groups, while the lowest variability was observed in the 60 percent group. Table 5 shows the statistics for egg weights by years. The eggs for the years 1926 to 1931 were weighed only during the hatching season, while those for the years 1932 to 1934 were weighed at least once a week throughout the year. It is questionable whether there are any significant differences from year to year that might be traced to the environment. The lowest average egg size was observed in the years 1929 and 1934; however, there were many groups within each year that were equally as low.

The results as a whole certainly suggest no general decrease in average egg size as a result of the inbreeding. The cause of marked variability observed from group to group is not entirely clear but a probable source of much of this variability is the segregation of various egg size factors into the more or less
Fig. 10. Histograms showing average egg weight for all inbreds and for those inbreds chosen to be parents, with the respective means and standard deviations.

TABLE 5. AVERAGE WEIGHT OF EGGS LAID BY THE DIFFERENT INBRED GROUPS, FOR EACH YEAR OF THE EXPERIMENT.

<table>
<thead>
<tr>
<th>Year</th>
<th>0</th>
<th>1-10.9</th>
<th>11-20.9</th>
<th>21-30.9</th>
<th>31-40.9</th>
<th>41-50.9</th>
<th>51-60.9</th>
<th>61-70.9</th>
<th>71-80.9</th>
</tr>
</thead>
<tbody>
<tr>
<td>1926</td>
<td>58</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1927</td>
<td>56</td>
<td>53</td>
<td>56</td>
<td>57</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1928</td>
<td>65</td>
<td>54</td>
<td>54</td>
<td>55</td>
<td>55</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1929</td>
<td>52</td>
<td>54</td>
<td>56</td>
<td>57</td>
<td>57</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1930</td>
<td>52</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1931</td>
<td>56</td>
<td>56</td>
<td>58</td>
<td>58</td>
<td>56</td>
<td>56</td>
<td>57</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1932</td>
<td>57</td>
<td>57</td>
<td>57</td>
<td>56</td>
<td>56</td>
<td>56</td>
<td>56</td>
<td>53</td>
<td></td>
</tr>
<tr>
<td>1933</td>
<td>51</td>
<td>53</td>
<td>56</td>
<td>52</td>
<td>53</td>
<td>55</td>
<td>53</td>
<td>53</td>
<td>50</td>
</tr>
<tr>
<td>1934</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
separate families resulting from the continued inbreeding. A further consideration of this question will be given when the different families are discussed.

THE EFFECT OF INBREEDING ON RATE OF GROWTH AND ON MATURE BODY WEIGHT

Body weights were not obtained for any inbreds until 1932. For the last 3 years each chick was weighed at hatching time and at intervals of 2 weeks during the first 4 months and at monthly intervals thereafter, until maximum weight was attained.

Fig. 11 presents a comparison of the average growth curves for all inbred females for the various degrees of inbreeding; fig. 12 shows the average growth curves for the inbred males. With the exception of the 20 percent inbred females, very little difference was observed in the growth rate for the various degrees of inbreeding. The 20 percent inbred males and females grew faster and attained a greater weight than the rest of the inbreds. A large number of non-inbred Leghorns both males and females were weighed each year for comparison. The average growth curve for the non-inbred Leghorns is not shown in figs. 11 and 13 because the curve coincides nearly exactly with the 30 to 80 percent curves. Considering the wide range of environmental conditions that exists when birds are hatched.

Fig. 11. Comparison of growth curves for all inbred females having different degrees of inbreeding for the years 1932 to 1934.
at different months and during different years, these inbred birds showed remarkably little change as the inbreeding coefficient increased.

Figs. 13 and 14 show the observed distributions for maximum body weight, which weight was reached at approximately 10 months of age for both males and females. There was some fluctuation in mean adult body weight for the different inbred groups in both males and females, but there was no progressive increase or decrease in weight as the percent of inbreeding increased. An analysis of variance for the different inbred groups, both male and female, however, showed that there was a significant difference in body weight between the groups. The greatest amount of variation occurred in the 30, 40, and 50 percent groups, while the smallest amount was found in the 60 and 80 percent groups.

Table 6 shows the statistics for body weight by years for both males and females. There is no indication that the birds
were consistently larger or smaller because they were grown in different years.

These results would indicate that intensive inbreeding did not decrease materially the growth rate or adult body weight of the birds used in this experiment.

![Histograms showing the weight variation at 10 months of age for all inbred females for the years 1932 to 1934, with the respective means and standard deviations.](image-url)
Fig. 14. Histograms showing the weight variation at 10 months of age for all inbred males for the years 1932 to 1934, with the respective means and standard deviations.

THE EFFECT OF INBREEDING ON VIABILITY

Figure 15 gives the percentage mortality for all inbreds for the following periods: 1 to 8 weeks, 8 to 16 weeks, 16 to 24 weeks, for the first 24 weeks and for the pullet, or first-year mortality. There was no general increase in the first 8 weeks’ mortality as
the inbreeding increased, although the 80 percent group does show an increase. Likewise, there was no increase in the 8 to 16 weeks’ or in the 16 to 24 weeks’ mortality as inbreeding increased. Considering the total percentage mortality for the first 24 weeks it is observed that there is, in fact, a decrease in mortality for those birds with an inbreeding coefficient ranging from 20 to 70 percent.

The pullet-year mortality showed a rapid increase as the inbreeding increased with the exception of those birds having an inbreeding coefficient of 70 percent. The 80 percent inbred birds were nearly all dead before the end of the first pullet

**TABLE 6. AVERAGE BODY WEIGHT IN GRAMS AT 10 MONTHS OF AGE FOR THE DIFFERENT INBRED GROUPS.**

**MALES**

<table>
<thead>
<tr>
<th>Year</th>
<th>11-20.9</th>
<th>21-30.9</th>
<th>31-40.9</th>
<th>41-50.9</th>
<th>51-60.9</th>
<th>61-70.9</th>
<th>71-80.9</th>
</tr>
</thead>
<tbody>
<tr>
<td>1932</td>
<td>1.993</td>
<td>1.738</td>
<td>1.802</td>
<td>1.719</td>
<td>1.749</td>
<td>1.779</td>
<td>1.779</td>
</tr>
<tr>
<td>1933</td>
<td>1.850</td>
<td>1.749</td>
<td>1.890</td>
<td>1.974</td>
<td>1.718</td>
<td>1.883</td>
<td>1.654</td>
</tr>
<tr>
<td>1934</td>
<td>1.764</td>
<td>1.950</td>
<td>1.722</td>
<td>1.613</td>
<td>1.710</td>
<td>1.883</td>
<td>1.654</td>
</tr>
</tbody>
</table>

**FEMALES**

<table>
<thead>
<tr>
<th>Year</th>
<th>11-20.9</th>
<th>21-30.9</th>
<th>31-40.9</th>
<th>41-50.9</th>
<th>51-60.9</th>
<th>61-70.9</th>
<th>71-80.9</th>
</tr>
</thead>
<tbody>
<tr>
<td>1932</td>
<td>2.293</td>
<td>2.325</td>
<td>2.256</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1933</td>
<td>2.413</td>
<td>2.368</td>
<td>2.138</td>
<td>1.929</td>
<td>2.017</td>
<td>2.185</td>
<td>2.199</td>
</tr>
<tr>
<td>1934</td>
<td>2.066</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### FIGURE 16. PEDIGREE AND STATISTICS FOR FAMILY 1.

<table>
<thead>
<tr>
<th>Inbreeding Coefficient, percent</th>
<th>82</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of chicks hatched</td>
<td>9</td>
</tr>
<tr>
<td>Fertile eggs, percent</td>
<td>81</td>
</tr>
<tr>
<td>Fertile eggs hatched, percent</td>
<td>62</td>
</tr>
<tr>
<td>Days to first egg</td>
<td>160</td>
</tr>
<tr>
<td>Jan. to Mar. egg production</td>
<td>21</td>
</tr>
<tr>
<td>200 day egg production</td>
<td>101</td>
</tr>
<tr>
<td>Annual egg production</td>
<td>54</td>
</tr>
<tr>
<td>Egg weight, grams</td>
<td>54</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>79</th>
<th>73</th>
<th>67</th>
<th>59</th>
<th>50</th>
<th>35</th>
<th>34</th>
<th>25</th>
<th>0</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>39</td>
<td>46</td>
<td>20</td>
<td>25</td>
<td>25</td>
<td>23</td>
<td>28</td>
<td>69</td>
<td>94</td>
<td></td>
</tr>
<tr>
<td>81</td>
<td>83</td>
<td>93</td>
<td>84</td>
<td>96</td>
<td>97</td>
<td>100</td>
<td>79</td>
<td>93</td>
<td>88</td>
<td></td>
</tr>
<tr>
<td>62</td>
<td>87</td>
<td>85</td>
<td>77</td>
<td>93</td>
<td>76</td>
<td>89</td>
<td>61</td>
<td>90</td>
<td>83</td>
<td></td>
</tr>
<tr>
<td>160</td>
<td>192</td>
<td>202</td>
<td>234</td>
<td>195</td>
<td>243</td>
<td>205</td>
<td>215</td>
<td>204</td>
<td>227</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>52</td>
<td>53</td>
<td>35</td>
<td>52</td>
<td>50</td>
<td>48</td>
<td>43</td>
<td>55</td>
<td>37</td>
<td></td>
</tr>
<tr>
<td>101</td>
<td>129</td>
<td>148</td>
<td>110</td>
<td>102</td>
<td>110</td>
<td>110</td>
<td>105</td>
<td>133</td>
<td>116</td>
<td></td>
</tr>
<tr>
<td>54</td>
<td>97</td>
<td>97</td>
<td>81</td>
<td>81</td>
<td>55</td>
<td>55</td>
<td>56</td>
<td>56</td>
<td>56</td>
<td></td>
</tr>
</tbody>
</table>
year. Fortunately a large number of progeny was obtained from the 80 percent inbred birds during the breeding season, and thus this high mortality did not eliminate the more highly inbred families.

The mortality record for the first 24 weeks included only the birds hatched in the years 1933 and 1934. A record of pullet-year mortality was available for all birds excepting those for the year 1925.

DESCRIPTION OF FAMILIES

The pedigrees of families 1 to 6 are shown in figs. 16 to 21, respectively, together with the data obtained from the birds of these families for the various characters studied.

Family 1 (fig. 16) represents the most intensely inbred family developed during the course of the experiment. The chicks which were hatched in 1935 had an inbreeding coefficient of 82 percent which is equivalent to eight generations of continuous brother and sister matings. At the present time the ancestry of all the birds in family 1 may be traced to one male, 823, and two females, 3784 and 3774. The present birds have a relationship coefficient of 60 percent to the original foundation male, 823. The relationship coefficient between birds of the present generation is 94 percent.

The chicks in family 2 (fig. 17) which were hatched during 1935 have an inbreeding coefficient of 58 percent, equivalent to slightly more than four generations of continuous brother and sister matings. The ancestry of this family may be traced to four males and five females. The highest relationship, however, is to male 823, it being approximately 54 percent for the present birds while the relationship to each of the other three males does not exceed 5 percent. The inter-se relationship between the birds of the present generation in this family is 84 percent.

Family 3 (fig. 18) is inbred to approximately the same extent as family 2. An examination of the pedigrees for these two families shows some differences after the fourth generation, however. As in family 2, the ancestry of the present generation of family 3 may be traced to the same four males and five females. The relationship of the present birds to male 823 is approximately 53 percent while the relationship to each of the other three males does not exceed 5 percent. The inter-se relationship between the birds of the present generation is 86 percent.

Family 4 (fig. 19) is inbred to approximately the same extent as family 2. An examination of the pedigrees for these two families shows some differences after the fourth generation, however. As in family 2, the ancestry of the present generation of family 3 may be traced to the same four males and five females. The relationship of the present birds to male 823 is approximately 53 percent while the relationship to each of the other three males does not exceed 5 percent. The inter-se relationship between the birds of the present generation is 86 percent.

The birds in the present generation of family 4 (fig. 19) have an inbreeding coefficient of 50 percent which is equivalent to approximately four generations of brother and sister matings. As in the other three families the influence of male 823 is pre-
**FIGURE 17. PEDIGREE AND STATISTICS FOR FAMILY 2.**

<table>
<thead>
<tr>
<th>Inbreeding Coefficient, percent</th>
<th>58</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of chicks hatched</td>
<td>40</td>
</tr>
<tr>
<td>Fertile eggs, percent</td>
<td>93</td>
</tr>
<tr>
<td>Fertile eggs hatched, percent</td>
<td>93</td>
</tr>
<tr>
<td>Days to first egg</td>
<td>201</td>
</tr>
<tr>
<td>Jan. to Mar. egg production</td>
<td>36</td>
</tr>
<tr>
<td>200 day egg production</td>
<td>135</td>
</tr>
<tr>
<td>Annual egg production</td>
<td>197</td>
</tr>
<tr>
<td>Egg weight, grams</td>
<td>50</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>50</th>
<th>49</th>
<th>47</th>
<th>33</th>
<th>19</th>
<th>13</th>
<th>25</th>
<th>0</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of chicks hatched</td>
<td>40</td>
<td>30</td>
<td>34</td>
<td>32</td>
<td>52</td>
<td>61</td>
<td>118</td>
<td>194</td>
<td>185</td>
</tr>
<tr>
<td>Fertile eggs, percent</td>
<td>60</td>
<td>81</td>
<td>97</td>
<td>93</td>
<td>98</td>
<td>98</td>
<td>88</td>
<td>95</td>
<td>91</td>
</tr>
<tr>
<td>Fertile eggs hatched, percent</td>
<td>93</td>
<td>88</td>
<td>87</td>
<td>91</td>
<td>85</td>
<td>75</td>
<td>68</td>
<td>90</td>
<td>77</td>
</tr>
<tr>
<td>Days to first egg</td>
<td>201</td>
<td>160</td>
<td>165</td>
<td>180</td>
<td>224</td>
<td>211</td>
<td>195</td>
<td>212</td>
<td>233</td>
</tr>
<tr>
<td>Jan. to Mar. egg production</td>
<td>60</td>
<td>38</td>
<td>37</td>
<td>38</td>
<td>49</td>
<td>43</td>
<td>47</td>
<td>29</td>
<td>25</td>
</tr>
<tr>
<td>200 day egg production</td>
<td>135</td>
<td>106</td>
<td>98</td>
<td>95</td>
<td>118</td>
<td>122</td>
<td>111</td>
<td>121</td>
<td>110</td>
</tr>
<tr>
<td>Annual egg production</td>
<td>197</td>
<td>197</td>
<td>197</td>
<td>196</td>
<td>236</td>
<td>199</td>
<td>183</td>
<td>183</td>
<td>183</td>
</tr>
<tr>
<td>Egg weight, grams</td>
<td>50</td>
<td>62</td>
<td>64</td>
<td>55</td>
<td>60</td>
<td>55</td>
<td>57</td>
<td>57</td>
<td>57</td>
</tr>
</tbody>
</table>
FIGURE 18. PEDIGREE AND STATISTICS FOR FAMILY 3.

<table>
<thead>
<tr>
<th>Inbreeding Coefficient, percent</th>
<th>62</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of enicks hatched</td>
<td>55</td>
</tr>
<tr>
<td>Fertile eggs, percent</td>
<td>95</td>
</tr>
<tr>
<td>Fertile eggs hatched, percent</td>
<td>92</td>
</tr>
<tr>
<td>Days to first egg</td>
<td>186</td>
</tr>
<tr>
<td>Jan. to Mar. egg production</td>
<td>42</td>
</tr>
<tr>
<td>200 day egg production</td>
<td>95</td>
</tr>
<tr>
<td>Annual egg production</td>
<td>58</td>
</tr>
<tr>
<td>Egg weight, grams</td>
<td>188</td>
</tr>
</tbody>
</table>
FIGURE 19. PEDIGREE AND STATISTICS FOR FAMILY 4.
ponderant and the relationship of this male to the birds of the present generation is 61 percent. The relationship of the other three original males to the present generation does not exceed 5 percent. The relationship coefficient between birds of the present generation in this family is 88 percent. The pedigrees of family 4 and family 3 are very similar up to the sixth generation when the two pedigrees diverge somewhat. In the tenth generation, the rather distinct lines developed after the sixth generation were crossed again.

The birds in the present generation of family 5 (fig. 20) have an inbreeding coefficient of 42 percent which is equivalent to slightly more than two generations of brother and sister matings. Up to the sixth generation of this family the foundation ancestry consisted of two males and five females. After the sixth generation an unrelated Leghorn male, number B438, was crossed with a female having an inbreeding coefficient of 31 percent. After the seventh generation brother with sister and half brother with half sister matings were made. The relationship of the present birds to male 823 is 29 percent and 45 percent to male B438. The inter-se relationship between birds of the present generation is 77 percent.

Family 6 (fig. 21) is the least intensely inbred family studied. The present birds have an inbreeding coefficient of 41 percent which is equal to a little more than two generations of continuous brother and sister matings. The ancestry of the present generation may be traced to three males and six females. Again in this family, the influence of male 823 is preponderant as he bears a relationship of approximately 58 percent to the birds hatched in 1935. The relationship of the other two original males to the present generation does not exceed 5 percent. A study of the pedigree of family 6 shows that after the second generation the pedigree diverged in three rather different ways but that the diverged lines were crossed again in the fifth and sixth generation.

Up to the present time it has been possible to inbreed brother and sister for eight generations. This does not mean, however, that a system of brother and sister matings necessarily will continue to be successful, although the results to date would indicate that this will be possible. If continued close inbreeding within each family does not prove possible, however, inter-crossing of the different families, which all show a rather high inter-se relationship, should insure indefinitely the perpetuation of the present inbred strain of Leghorns.

There are a number of highly inbred families still living which have not been reported separately in this study because of the high relationship they bear to certain of the six families whose pedigrees are shown.
FIGURE 20. PEDIGREE AND STATISTICS FOR FAMILY 5.

<table>
<thead>
<tr>
<th>Inbreeding Coefficient, percent</th>
<th>36</th>
<th>25</th>
<th>0</th>
<th>31</th>
<th>29</th>
<th>21</th>
<th>20</th>
<th>13</th>
<th>0</th>
<th>42</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of chicks hatched</td>
<td>24</td>
<td>64</td>
<td>40</td>
<td>64</td>
<td>13</td>
<td>71</td>
<td>54</td>
<td>115</td>
<td>173</td>
<td>220</td>
</tr>
<tr>
<td>Fertile eggs, percent</td>
<td>84</td>
<td>94</td>
<td>76</td>
<td>90</td>
<td>100</td>
<td>98</td>
<td>98</td>
<td>94</td>
<td>94</td>
<td>86</td>
</tr>
<tr>
<td>Fertile eggs hatched, percent</td>
<td>89</td>
<td>92</td>
<td>93</td>
<td>93</td>
<td>77</td>
<td>93</td>
<td>75</td>
<td>72</td>
<td>92</td>
<td>80</td>
</tr>
<tr>
<td>Days to first egg</td>
<td>158</td>
<td>210</td>
<td>143</td>
<td>218</td>
<td>225</td>
<td>228</td>
<td>185</td>
<td>202</td>
<td>200</td>
<td>282</td>
</tr>
<tr>
<td>Jan. to Mar. egg production</td>
<td>36</td>
<td>43</td>
<td>65</td>
<td>51</td>
<td>76</td>
<td>59</td>
<td>45</td>
<td>46</td>
<td>47</td>
<td>35</td>
</tr>
<tr>
<td>200 day egg production</td>
<td>139</td>
<td>124</td>
<td>166</td>
<td>138</td>
<td>118</td>
<td>115</td>
<td>124</td>
<td>108</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual egg production</td>
<td>285</td>
<td>191</td>
<td>199</td>
<td>190</td>
<td>190</td>
<td>190</td>
<td>188</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Egg weight, grams</td>
<td>52</td>
<td>57</td>
<td>51</td>
<td>56</td>
<td>48</td>
<td>56</td>
<td>58</td>
<td>55</td>
<td>99</td>
<td></td>
</tr>
</tbody>
</table>
In table 7 statistics on the inbreeding coefficients and the relationships of the present birds of the six families to each other and of these birds to their respective sires are presented. In all families the inbreeding exceeds 41 percent. The relationship of full sibs in all families ranges from approximately 74 for the least inbred to 94 percent for the most inbred family. Inasmuch as the relationship coefficient is a measure of genetic likeness, it is evident that all the individuals in the present generation of each family studied are highly like each other.

The relationship of each different family to the original foundation sire, 823, is, with the exception of family 5, above 53 percent which means that the birds of these different families carry more of the genes of sire 823 than did the original first generation hybrids of which he was the sire. Therefore, the influence of sire 823 on each of these birds in the different families, with the exception of family 5, is very high as might be expected with the restricted ancestry of all families. Family 1 and family 4 have the highest relationship to each other—approximately 82 percent. In no instance does the relationship of family 5 to the other five families exceed 24 percent.

EFFECT OF INBREEDING ON FERTILITY IN FAMILIES 1 TO 6

The statistics for fertility in relation to the pedigree and inbreeding coefficient given in figs. 16 to 21 were based only upon those birds shown in these particular pedigrees. A more detailed analysis of fertility for the six families is presented in fig. 22, which shows the average trend for fertility with each increase in inbreeding percentage, not only for the birds chosen to be parents but also the average trend for fertility of all birds used for breeding purposes in each family. The figures, likewise, show the number of birds upon which the mean is based.

TABLE 7. STATISTICS SHOWING THE COEFFICIENTS OF INBREEDING AND VARIOUS RELATIONSHIPS IN THE SIX FAMILIES STUDIED.

Only the inter-se relationship and the inbreeding coefficients for the last generation birds in the different families are shown.

<table>
<thead>
<tr>
<th>Coefficient of inbreeding</th>
<th>Families</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>F106</td>
<td>F177</td>
</tr>
<tr>
<td>Coefficient of inbreeding</td>
<td>82</td>
</tr>
<tr>
<td>Relationship to full sibs</td>
<td>94</td>
</tr>
<tr>
<td>Relationship to 823</td>
<td>60</td>
</tr>
<tr>
<td>Inter-se relationship to family 1 (F106)</td>
<td>59</td>
</tr>
<tr>
<td>Inter-se relationship to family 2 (F177)</td>
<td>65</td>
</tr>
<tr>
<td>Inter-se relationship to family 3 (F96)</td>
<td>62</td>
</tr>
<tr>
<td>Inter-se relationship to family 4 (F110)</td>
<td>21</td>
</tr>
<tr>
<td>Inter-se relationship to family 5 (F226)</td>
<td>53</td>
</tr>
</tbody>
</table>


Fig. 22. Trends showing the percent of eggs fertile for families one to six for all inbreds and for those inbreds chosen to be parents in each family. The observed range in fertility for the different families is shown by the dots and circles, and the figures show the number of birds upon which the average was based.
In general, there was no progressive decrease in fertility for the chosen parents as the inbreeding increased. The lowest fertility, 60 percent, was observed in family 2 for the ninth generation but with the exception of this one generation the fertility remained above 79 percent for all families. The average trend line for the chosen parents of each family shows that with the exception of families 2 and 4 the average percentage fertility for these birds was above 80 percent. The average trend line for each family for the chosen parents, plus their sibs, shows that in general there was a decrease in fertility for families 2 and 3 with each increase in the inbreeding coefficient above 22 percent. In family 4 there was a large decrease in the fourth inbred generation but no great decrease thereafter. While families 1, 5, and 6 show erratic changes in fertility from generation to generation there was no significant decrease in fertility as the inbreeding increased. With the exception of family 2 the average percentage fertility was not below 75 percent for any of the generations in the six families studied.

THE EFFECT OF INBREEDING ON HATCHABILITY IN FAMILIES 1 TO 6

The statistics for hatchability for each family were shown in figs. 16 to 21 in relation to the pedigree and inbreeding coefficient, but the data shown therein are based only upon those birds shown in the pedigree. A more detailed analysis of hatchability based upon all breeding females used in each of these families is presented in fig 23, which shows the average trend for hatchability with each increase in inbreeding, not only for the birds selected to be parents but also the average trend for hatchability of the selected parents plus their sibs, together with the range in hatchability observed for each family. The figures show the number of birds upon which the mean is based.

From a study of fig. 23 it will be seen immediately that the highest hatching birds were not always selected as breeders. As previously stated, birds were selected for vigor and because they came from large families as well as for high hatchability. It also should be pointed out that not all of the sibs of the selected birds were used as breeders, although in most cases the birds used constituted a fair sample.

It will be observed, in general, that the hatchability of the selected birds in all families was higher than that of their sibs. Also, the hatchability for the selected birds in each family was maintained at a fairly high level, averaging with few exceptions above 75 percent. In no family did the hatchability of
Fig. 23. Trends showing the percent hatchability in six inbred families, for all inbreds and for those inbreds chosen to be parents in each family. The dots and circles show the observed range in hatchability for all sibs and the figures give the number of birds upon which the average was based.
the selected birds drop below 62 percent and it was possible by constant selection to maintain high hatchability in each of these families as the inbreeding increased.

It is interesting to observe, however, that a constant selection for high hatchability in all six families failed to increase the average hatchability for all sibs. This may be partly explained by the fact that the hatchability in this strain was high before selection was begun and any marked progress in raising average hatchability would not be expected. On the other hand, there was no significant decrease in average hatchability for any of the families as the intensity of the inbreeding increased, this being in marked contrast to most of the inbreeding results so far reported for the fowl.

There was considerable variation in the hatchability range of all sibs for nearly all the families studied. It is extremely unlikely, however, that this variability was entirely genetic. Environmental differences during the incubation period may occur from year to year as well as from month to month which may decrease hatchability.

The statistics for these six families demonstrate the possibility of maintaining a reasonably high average hatchability even under the most intensive type of inbreeding. Furthermore, the results suggest that it may be possible to fix this character in strains of the fowl by a system of judicious inbreeding combined with careful selection. Because of the great economic importance of this character it is highly desirable to devise some system of breeding that will give assurance of reasonably high hatchability. Therefore, such a system combined with a subsequent use of crossbreeding may prove a very useful tool for the improvement of average hatchability in our flocks as well as for improving the performance of flocks in other respects. Before such a program is adopted generally, however, more experimental work must be done to test it at every step. The adequate testing of such a program would appear to be one of the greatest needs in poultry breeding at the present time and it is a program worth a cooperative attack by many institutions.

THE EFFECT OF INBREEDING ON AGE AT FIRST EGG IN FAMILIES 1 TO 6

Figure 24 presents the average trend for number of days to first egg for each increase in inbreeding for the chosen parents and the average trend for number of days to first egg for all sibs in each family, together with their range in distribution, for families 1 to 6. It should be emphasized that there was no conscious selection for early maturity throughout this investigation.
Fig. 24. Trends showing a comparison of days to sexual maturity in six inbred families for those females chosen to be parents and for the chosen females plus their sibs. The observed range in days to first egg for all sibs is shown by dots and circles, and the figures show the number of birds upon which the average was based.
In the most intensely inbred family, number 1, there was an erratic but slow decrease in days to first egg for the chosen parents as the intensity of inbreeding increased. The intense system of inbreeding practiced in this family seems to have had little effect on sexual maturity. Actually the average days to sexual maturity for the first 5 years is 20 days above the average for the last 5 years, though the genetic significance of this is doubtful because of the great influence of the environment on this character. There has also been a decrease in age at first egg for the chosen parents plus their sibs in family 1 as the inbreeding increased.

In family 2, as in the more intensely inbred family 1, there was no marked change in days to first egg for the chosen parents, plus their sibs, as the inbreeding intensity increased. There was a slow decrease in days to first egg after the fifth year and a continued decrease until the eighth year for the chosen parents in family 2. By referring to the pedigree in fig. 17, however, it will be seen that this decrease was due to the results obtained from a single early maturing bird used in each of the three years.

Family 3 showed no significant change in age at first egg for either group after the third inbred generation. It will be observed by referring to fig. 19 that the inbreeding coefficient in family 4 represents an average obtained from two different but highly related families which were later crossed; consequently, there was little change in the inbreeding coefficient after the sixth inbred generation, but a slight decrease was observed in days to sexual maturity.

There was little change in age at first egg in family 5 up to the fifth inbred generation. After the fifth generation an unrelated Leghorn male B438 was mated with female B3337, as shown in fig. 20. Following this top cross there was an immediate drop in age at first egg for the first generation hybrids. The first inbred generation following this top cross resulted in an increase in age at first egg but this was followed by a decrease in the second inbred generation.

Family 6 showed no significant change in age at first egg for either the chosen parents or for all the sibs throughout the entire course of the experiment.

A comparison of the six families studied, then, fails to demonstrate that intense inbreeding necessarily increases the number of days to first egg, although this effect has been observed in some inbreeding experiments. It will be noticed that considerable variation in the age at sexual maturity occurred in all six of the families studied. The more intensely inbred birds
in family 1, however, showed less variability for the last 4 years than did the birds of the other five families.

It is extremely difficult to obtain an absolute genetic measurement of sexual maturity since the environment has a pronounced influence on sexual maturity. It is probable that because of the homozygosity produced as a result of the inbreeding the influence of the environment has become relatively more important as a cause of variability in the inbred birds than the genetic influence. In order to determine the relative importance of heredity and environment, however, highly inbred families will be indispensable not only for a study of sexual maturity but for a genetic analysis of many of the other characters of great economic importance.

THE EFFECT OF INBREEDING ON EGG PRODUCTION IN FAMILIES 1 TO 6

The effect of inbreeding on the first 200 days’ egg production is shown for families 1 to 6 in fig. 25. Because of the high mortality occurring during the first laying year, and because of the fact that some females were discarded in the early phases of the experiment before their first laying year was completed, it seemed desirable to consider the number of eggs laid for the first 200-day interval rather than the total year’s production. The total year’s production and January to March egg production, however, had been considered and the statistics for these periods, for the chosen parents only, are shown in figs. 16 to 21 for the six families considered.

The average trend is shown in fig. 25 for the first 200 days’ production for each increase in inbreeding for both the chosen parents and for all sibs, together with the range in distribution for families 1 to 6.

It is immediately clear that there was no decrease in 200-day egg production for the chosen parents in any of the six families as the inbreeding intensity increased. There was a decrease in the trend for 200-day egg production for all sibs in family 1 after the fifth inbred generation. There was, also, a slight decrease for all sibs in family 4 as the inbreeding increased. In families 2, 3, 5, and 6, however, there was no marked decrease in 200-day egg production as the inbreeding increased.

Family 1 showed remarkably little variation in 200-day egg production from the very start of the investigation. True, the number of individuals in each family whose records for this character are available is few but they do give, nevertheless, some indication of the progeny for each inbred generation. A somewhat greater variability was observed in 200-day egg pro-
Fig. 25. The effect of inbreeding on 200-day egg production in six inbred families of the fowl. The trend of egg production as inbreeding increased is shown for both those females chosen to be parents and the average trend for all sibs. The observed range in production for all sibs is shown by the dots and circles, and the figures show the number of birds upon which the average was based.

duction for the less intensely inbred birds in the other five families but as the inbreeding increased the variability for this character apparently decreased. Figs. 16 to 21 show there was no significant change in the January to March, or in the annual egg production for the parents of the six families as the inbreeding increased.

It would appear from these results that there was no marked
decrease in egg production for the six inbred families as a result of the inbreeding.

THE EFFECT OF INBREEDING ON EGG WEIGHT IN FAMILIES 1 TO 6

In figs. 16 to 21 statistics for egg weight in relation to the pedigree and inbreeding coefficient are given for a few birds in families 1 to 6. These statistics are based upon only those birds shown in the pedigree, however. A more detailed analysis of egg weight for these families is presented in fig. 26, which gives the average trend with each increase in inbreed-

Fig. 26. Trends showing the effect of inbreeding on egg weight in six inbred families for all inbreds and for those inbreds chosen to be parents in each family. The observed range in egg weight for all sibs is shown by the dots and circles, and the figures give the number of birds upon which the average was based.
ing, not only for the birds selected to be parents but also the average trend for egg weight of the selected parents plus their sibs, together with the range observed for each family. The figures show the number of birds upon which the means were based.

While all families showed changes in egg weight as the inbreeding increased there was no significant trend towards either large or small egg weight in these six families for either the chosen parents or for all sibs.

There was but little variation in egg weight for any of the six families studied. As previously stated, there was no selection for egg weight throughout the experiment. It might be expected, nevertheless, that if the original foundation birds were heterozygous for major genes affecting egg weight a greater divergence in egg weight would have occurred between some of the lines than was actually observed.

**DISCUSSION**

The results of inbreeding the fowl that have been presented clearly demonstrate that close inbreeding may be practiced in the domestic fowl, providing careful and rigid selection for certain characters is maintained at all times, particularly for high hatchability. While in contrast with most of the inbreeding results so far reported for the fowl, this experiment does bring the problem of inbreeding in this species more into line with the results that have been obtained for several other species of animals. It is obvious that there has been a decline in some characteristics that denote vitality as a result of inbreeding, but, as indicated by the high coefficients of inbreeding, the birds in most of the families should be homozygous for so many of their genes that no further large decrease in vitality is to be expected from further inbreeding. For most characteristics they have retained to a remarkable degree the excellent qualities possessed by the foundation birds.

The data from the several families do not indicate that more favorable results were obtained from the less intensive as contrasted with the more intensive type of inbreeding—one of the questions which the experiment was designed to answer. This is not surprising, however, in view of the high relationship of all birds to one of the foundation sires, number 823. Had the breeding program been directed less toward a concentration of the heredity of one individual more information on this point no doubt would have been obtained.

One point of especial interest has been the freedom of defects
and abnormalities of all types in the inbred families. Aside from one embryonic lethal [Upp and Waters (27)] no definite evidence of other defective genes in these families has been obtained. This is somewhat surprising in view of the large number of plumage and morphological defects of various kinds that have been observed in the fowl. It does show, however, that some individuals carry relatively few of the genetic defects observed in this species.

In spite of the high inter-se relationship between the various families certain of them become rather clearly differentiated in some respects, such as in body conformation and type of comb. A tendency toward the development of a salmon or light red coloration in the breast plumage of the females of certain families likewise was observed. Any fixation of color genes is, of course, masked by the inhibitor gene (I).

It is hoped that the favorable results obtained from the close inbreeding practiced in these families will encourage other investigators to undertake the development of good inbreds. If the problem of the utilization of inbreds for poultry improvement is to be tested adequately it is likely that a good many different inbred lines must be developed and intercrossed before superior combinations are found. It is hardly to be expected that the greatest hybrid vigor would result from intercrosses between the six families reported here since they are so highly inter-related. Several other less intensely but quite distinctly inbred families have been developed at this station in the course of a study of the inheritance of disease resistance in the fowl, and various crosses between these lines and the inbred families here reported are now being made.

The present study suggests a practical application of the principle of inbreeding. The poultry breeder is often in a quandary to know how much inbreeding may be practiced without decreasing the efficiency of his flock. In general, the advanced breeder desires to confine his breeding program to his own flock, thus reducing the dangers involved when unrelated birds are introduced. Inbreeding tends to increase uniformity within the flock, not only for type and general conformation but for all other characters, both good and bad. The inbreeding provides a mechanism by which the good results of right crosses and the bad results of wrong choices in selection are much more apt to be retained in the flock and fixed permanently on it than if no inbreeding accompanied the selection; therefore, the breeder who is inbreeding must be exceptionally cautious in his choice of birds for breeding if he is to avoid the fixation of undesirable characteristics in his flock.
Fig. 1. Male F106 and female F106 in family 1, hatched 1935.

Fig. 2. Male F177 and female F177 in family 2, hatched 1935.

Fig. 3. Male F96 and female F96 in family 3, hatched 1935.
Plate II.

Fig. 1. Male F110 and female F110 in family 4, hatched 1935.

Fig. 2. Male F226 and female F226 in family 5, hatched 1935.

Fig. 3. Male F84 and female F84 in family 6, hatched 1935.
LITERATURE CITED


(21) King, H. D. (Personal communication with the Junior author.) 1935.


Chemical Analyses of Iowa Soils for Phosphorus, Nitrogen and Carbon: a Statistical Study

By R. H. Walker and P. E. Brown

AGRICULTURAL EXPERIMENT STATION
IOWA STATE COLLEGE OF AGRICULTURE AND MECHANIC ARTS
R. E. Buchanan, Director

SOILS SUBSECTION
AGRONOMY SECTION

AMES, IOWA
## CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summary</td>
<td>59</td>
</tr>
<tr>
<td>Methods</td>
<td>62</td>
</tr>
<tr>
<td>Results for the drift soils</td>
<td>66</td>
</tr>
<tr>
<td>Comparison of surface and subsoils</td>
<td>71</td>
</tr>
<tr>
<td>The influence of texture</td>
<td>72</td>
</tr>
<tr>
<td>Comparison of soils of uniform texture</td>
<td>77</td>
</tr>
<tr>
<td>Results for the loess soils</td>
<td>79</td>
</tr>
<tr>
<td>Relation of soil composition to soil color</td>
<td>82</td>
</tr>
<tr>
<td>Comparison of loess silt loams</td>
<td>84</td>
</tr>
<tr>
<td>Results for the terrace and bottomland soils</td>
<td>85</td>
</tr>
<tr>
<td>Relationship of texture to composition</td>
<td>85</td>
</tr>
<tr>
<td>Comparison of soils of uniform texture</td>
<td>91</td>
</tr>
<tr>
<td>Comparison of upland and terrace and bottomland soils</td>
<td>91</td>
</tr>
<tr>
<td>Carbon-nitrogen ratio</td>
<td>93</td>
</tr>
<tr>
<td>Discussion</td>
<td>100</td>
</tr>
<tr>
<td>Factors affecting the phosphorus, nitrogen and carbon content of Iowa soils</td>
<td>100</td>
</tr>
<tr>
<td>Literature cited</td>
<td>103</td>
</tr>
</tbody>
</table>
SUMMARY

1. Data concerning the phosphorus, nitrogen and carbon content of Iowa soils, as published in the various Iowa Soil Survey reports, have been assembled, summarized and analyzed statistically for the purpose of characterizing the various soil types for the state as a whole.

2. The mean phosphorus, nitrogen and carbon content of each soil type is recorded, and the variability within the types is pointed out.

3. In spite of the variability within soil types, the differences among types, in most cases, were found to be significant or highly significant. Certain soil types were found to be similar in their phosphorus, nitrogen and carbon content, but significantly different from other soils.

4. In general, surface soils contained larger quantities of phosphorus, nitrogen and carbon than subsoils.

5. Dark colored loess soils contained larger quantities of phosphorus, nitrogen and carbon than light colored loess soils.

6. Fine textured soil types contained larger quantities of phosphorus, nitrogen and carbon than the coarser textured types of the same series or of different series. A high or low phosphorus, nitrogen or carbon content, however, seems to be a series characteristic entirely apart from the textural influence. This appears to be related to the topography and native vegetation factors.

7. The loess soils as a group do not differ from the drift soils either in their phosphorus, nitrogen or carbon content nor in their carbon-nitrogen ratio. The bottomland soils, however, contain significantly larger amounts of phosphorus, nitrogen and carbon than the terrace soils, but the two groups do not differ in their carbon-nitrogen ratio. The terrace and bottomland soils as a group contain significantly larger quantities of phosphorus and nitrogen than the loess and drift soils, but the difference in carbon is hardly large enough to be significant. There is little, if any, difference in the carbon-nitrogen ratio.

8. The mean carbon-nitrogen ratio for all soils of Iowa was found to be 12.15:1, but the largest number of soils had a ratio slightly lower, the mode of the frequency distribution curve being at 12:1.
9. The close relation between the nitrogen and carbon content of Iowa soils is shown by the high correlation coefficients, which were found to be 0.95 for the drift soils and 0.93 for the loess soils.

10. Although the temperature and humidity factors are of primary importance in determining the nitrogen and carbon content of soils, it appears that within the comparatively narrow range of variation of these factors within the state of Iowa, the factors of topography, soil texture and type of vegetation have been of greatest importance in the differentiation of soil types.

11. In general, the results of this study support the soil type concept now in use in soil classification.
The Iowa soil survey was begun in 1913 for the purpose of mapping, classifying and determining the pedological and fertility characteristics of Iowa soils. In connection with this work chemical analyses have been made to determine the phosphorus, nitrogen and carbon content of representative samples of the various soil types mapped. Analyses of the soils of each county have been published in their respective soil survey reports and data now are available for the soils in 77 counties.

It is the chief purpose of the study reported here to assemble all of the analytical data on the various soil types as given in the county soil survey reports, and analyze them for the state as a whole in an attempt to characterize the soils with respect to their content of phosphorus, nitrogen and organic carbon. The average content of these constituents in the different soil types was estimated in order that correlations with other soil characteristics might be studied, and also that a more definite basis for estimating the productivity of the various soils and for making recommendations for their proper management might be established.

It has long been established that there is a direct relation between the inherent productivity of soils and their content of the essential plant nutrients. Although this relationship may not hold in the case of the current productivity of a particular soil, it is bound to appear over a period of years and the total plant nutrient content is one of the factors determining the permanence of soil fertility.

The entire quantity of any of the nutrient elements in soils is never in a form available for the use of growing plants. In fact the percentage of nutrients available in the soil at any particular time is usually rather low. But from the unavailable nutrients the available forms are constantly being produced by the biological, chemical and physical processes. Proper soil management and treatment may encourage the production of available nutrients from the unavailable forms to such an ex-

---

1 Project 228 of the Iowa Agricultural Experiment Station.
2 The authors are indebted to the various members of the staff who have assisted in taking the soil samples and in making the chemical analyses during the progress of the Iowa soil survey. Appreciation is also expressed for the suggestions and criticisms offered by Prof. George W. Snedecor of the Statistical Laboratory.
tent that there may seem to be no relation between the total supply and the quantity available for the nutrition of plants. The quantity of plant nutrients made available in a soil over a period of years, however, is dependent mainly upon the total content of these constituents in the soil.

**METHODS**

At the completion of the soil survey field work in all of the counties, samples of the surface, subsurface and subsoil of each soil type in the county were sent to the soils laboratory for analysis. The chemical analyses reported here were made on these samples.

The more extensive soil types in each county were sampled in three different areas where they were typically developed. The minor soil types were sampled in only one location in each county. The samples were taken with care in order that they would be entirely representative of the types and in order that there would not be any abnormal condition in the samples owing to previous treatments of the area or to peculiarities of the soil in the particular location. In all cases the samples were taken from cultivated fields. This was done because, except in rare cases, it was found impossible to locate virgin areas representative of the types from which samples could be obtained.

Inasmuch as the soil survey and study of soil types were carried on for some time before the development of the present method of characterizing soil types the samples were taken, as in the earlier work, at definite depths from the surface. This method was continued throughout the work. The surface samples were taken from 0 to 6½ inches; the subsurface samples from 6½ to 20 inches; and the subsoil samples from 20 to 40 inches. The surface samples corresponded more or less closely to what is known as the A horizon. The subsurface samples, in most cases, were probably a mixture of the soil of the A and B horizons. For this reason the data obtained from the study of the subsurface samples were not considered here. The subsoil samples were somewhat representative of the C horizon, or the parent material from which the A and B horizons have been developed through the soil-forming processes. The data obtained in the chemical analysis of the subsoil samples of the upland drift and loess soils were included in this study, but the results on the terrace and bottomland subsoils were omitted.

In this study attention was centered largely upon the data obtained from the analyses of the surface soils of the state.

The chemical determinations for phosphorus, nitrogen, and total and inorganic carbon were made according to the method of the Association of Official Agricultural Chemists (2). The
organic carbon was estimated by deducting the quantity of inorganic carbon from the total carbon.

These determinations were made over a period of 20 years, and a number of different analysts have worked on the project. All have used the same methods, however. Determinations have been made for phosphorus and nitrogen on duplicate portions of each soil sample after grinding and mixing. The total carbon determinations were usually made on only one portion of each sample, but in many cases these analyses were also made in duplicate. A study of the data from the duplicate determinations has shown that the error resulting from the variance of portions of individual samples is extremely low and that they may be considered as two observations of the same thing. There is ample justification from the statistical viewpoint for using either determination alone, or an average of the duplicates. This indicates the comparatively small degree of error in the chemical determinations that have been made, but it does not lessen the desirability of making determinations on duplicate portions of the samples. In this work the averages of the duplicate determinations have been used in the analysis of the data.

In order to make the desired comparisons and yet give full consideration to the variability between samples of individual soil types from different locations, it was necessary to employ statistical methods. In most instances the analysis of variance
method was used (18). In other cases Student’s “t test” for the significance of mean differences, and correlation methods (25) were employed.

At the time this study was initiated data giving the phosphorus, nitrogen and organic carbon content of the soils of the state were available for 72 counties. These counties are well distributed over the state, as shown in Fig. 1.

Reference to the soil area and the soil type maps of the state in figs. 2 and 3 shows that the counties from which samples were taken are well distributed among the various soil areas, and also that the principal soil type groups were adequately sampled for this study. Many of the individual soil types, and particularly the more extensive ones, occur in several of the counties and samples were taken in each county. For example, Carrington loam was sampled in 36 counties, O’Neill loam in 30, Waukesha silt loam in 40, and Wabash silt loam in 58 counties.

On the other hand, some of the soil types had been mapped in only one county, hence data on chemical analyses were available for only one sample. Usually these soils were of relatively little importance from the standpoint of total area, although they may be of considerable importance on individual farms. The Clarion fine sand, Dodgeville sandy loam and LaCrosse sandy loam are representative of this group of soils.

It is obvious that data on the chemical composition of a soil which has been sampled from 20 to 40 different counties would give a better idea of the variability within the type and would

---

**Fig. 2.** The location of the principal soil areas of Iowa.
Fig. 3. The location of the principal soil types of Iowa.

offer a more reliable basis upon which to make comparisons between types than one which has been sampled in only one or two locations. The data reported here are entirely adequate for the characterization of most of the soils of the state with respect to their phosphorus, nitrogen and carbon content, and particularly for the more important or extensive soils. The data for the less extensive or minor types cannot be considered so satisfactory but they were included as they have proved to be of some interest.

Reference may be made to the soil survey reports for the individual counties (20) (4) for information concerning the chemical composition of the soil types in any particular county. In this work, however, the data from the individual counties were combined and summarized on the soil type basis for the state as a whole.

It has been convenient in this study to arrange the soils into three groups on the basis of their geological origin and location, namely: drift soils, loess soils and terrace and bottomland soils.
RESULTS FOR THE DRIFT SOILS

The mean phosphorus, nitrogen and carbon content of the drift soils in the surface 62½ inches is shown in table 1, the results being reported in pounds per 2 million pounds of soil per acre. The carbon-nitrogen ratios for the individual samples of each soil have been calculated and their means are also shown in the table. The number of counties from which samples of each soil type were obtained for this study is also indicated in the table. Similar data for the subsoil samples of the same soils are shown in table 2.

The mean phosphorus, nitrogen and carbon content of a particular soil, as shown in table 1, provides a summary of the data obtained from the individual samples of that soil. As to the variability of the phosphorus, nitrogen or carbon content of different samples of a particular soil, it was found, for example, that the nitrogen content of the individual samples of Carrington sandy loam varied from 1,280 pounds per acre for the sample taken in Clayton County to 2,840 pounds for the sample obtained in Worth County. The mean of the 11 different samples taken of this soil is 2,000 pounds per acre. Similarly it may be noted that the mean nitrogen content of Webster loam is 5,681 pounds per acre, whereas the individual samples varied from 4,360 pounds per acre in Greene County to 8,200 pounds in Sac County. The standard deviation has been computed for representative types of the drift soils and recorded in table 3. This table also shows the coefficient of variability. These values serve to indicate the extent and character of the variability of the individual observations about the mean.

In view of the large variability of the phosphorus, nitrogen and carbon content of different samples within soil types, it seemed desirable to determine whether or not the differences between types as indicated by the means were significant. DeTurk (6) made a somewhat similar study on three soil types in Illinois. He states that "the extreme range of values indicated by individual analyses would completely obliterate all chemical boundary lines between soil types." He adds further that, "a study of the means, while it shows in general the differences between types, does not give a reliable indication of the existence or non-existence of boundary lines between types with respect to chemical composition." In making this study, however, DeTurk considered only the range between the extremes of the data and it is doubtful if due consideration was given to the character of the variability. For example, it is possible that the extremes for different types may overlap, but at the same time the majority of the values, as indicated by the standard deviation, may fall into sufficiently different ranges to warrant a differentiation of the types.
<table>
<thead>
<tr>
<th>Soil type</th>
<th>Number of samples</th>
<th>Phosphorus</th>
<th>Nitrogen</th>
<th>Carbon</th>
<th>C:N ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carrington sand</td>
<td>2</td>
<td>800</td>
<td>550</td>
<td>8,000</td>
<td>14.05</td>
</tr>
<tr>
<td>Carrington fine sand</td>
<td>2</td>
<td>750</td>
<td>850</td>
<td>11,500</td>
<td>14.50</td>
</tr>
<tr>
<td>Carrington very fine sandy loam</td>
<td>1</td>
<td>700</td>
<td>600</td>
<td>8,000</td>
<td>14.10</td>
</tr>
<tr>
<td>Carrington sandy loam</td>
<td>11</td>
<td>864</td>
<td>2,000</td>
<td>25,000</td>
<td>12.50</td>
</tr>
<tr>
<td>Carrington fine sandy loam</td>
<td>21</td>
<td>895</td>
<td>2,133</td>
<td>26,380</td>
<td>12.54</td>
</tr>
<tr>
<td>Carrington loam</td>
<td>36</td>
<td>1,147</td>
<td>3,756</td>
<td>44,300</td>
<td>12.24</td>
</tr>
<tr>
<td>Carrington loam (steep phase)</td>
<td>6</td>
<td>1,117</td>
<td>3,688</td>
<td>43,800</td>
<td>12.97</td>
</tr>
<tr>
<td>Carrington loam (rolling phase)</td>
<td>1</td>
<td>1,100</td>
<td>3,900</td>
<td>46,000</td>
<td>11.70</td>
</tr>
<tr>
<td>Carrington silt loam</td>
<td>24</td>
<td>1,288</td>
<td>4,606</td>
<td>53,580</td>
<td>11.66</td>
</tr>
<tr>
<td>Clarion fine sand</td>
<td>1</td>
<td>1,600</td>
<td>2,200</td>
<td>28,000</td>
<td>12.60</td>
</tr>
<tr>
<td>Clarion sandy loam</td>
<td>1</td>
<td>1,100</td>
<td>2,800</td>
<td>32,000</td>
<td>11.30</td>
</tr>
<tr>
<td>Clarion fine sandy loam</td>
<td>6</td>
<td>1,100</td>
<td>3,083</td>
<td>38,670</td>
<td>12.28</td>
</tr>
<tr>
<td>Clarion loam</td>
<td>19</td>
<td>1,205</td>
<td>4,368</td>
<td>48,840</td>
<td>11.22</td>
</tr>
<tr>
<td>Clarion loam (rolling phase)</td>
<td>5</td>
<td>1,180</td>
<td>4,160</td>
<td>47,800</td>
<td>11.60</td>
</tr>
<tr>
<td>Clarion loam (shallow phase)</td>
<td>1</td>
<td>900</td>
<td>2,600</td>
<td>29,000</td>
<td>11.20</td>
</tr>
<tr>
<td>Clarion loam (steep phase)</td>
<td>5</td>
<td>1,060</td>
<td>2,840</td>
<td>43,000</td>
<td>18.48</td>
</tr>
<tr>
<td>Clarion silt loam</td>
<td>7</td>
<td>1,237</td>
<td>4,986</td>
<td>60,570</td>
<td>12.18</td>
</tr>
<tr>
<td>Clyde silt loam</td>
<td>1</td>
<td>1,642</td>
<td>7,157</td>
<td>80,070</td>
<td>12.50</td>
</tr>
<tr>
<td>Clyde silty clay loam</td>
<td>1</td>
<td>1,735</td>
<td>7,929</td>
<td>91,290</td>
<td>11.72</td>
</tr>
<tr>
<td>Conover silt loam</td>
<td>2</td>
<td>700</td>
<td>2,150</td>
<td>27,000</td>
<td>12.45</td>
</tr>
<tr>
<td>Dickinson loamy sand</td>
<td>1</td>
<td>500</td>
<td>900</td>
<td>8,300</td>
<td>9.40</td>
</tr>
<tr>
<td>Dickinson sandy loam</td>
<td>5</td>
<td>1,060</td>
<td>1,860</td>
<td>27,600</td>
<td>14.54</td>
</tr>
<tr>
<td>Dickinson loamy fine sand</td>
<td>1</td>
<td>900</td>
<td>800</td>
<td>26,000</td>
<td>32.00</td>
</tr>
<tr>
<td>Dickinson fine sandy loam</td>
<td>10</td>
<td>870</td>
<td>2,310</td>
<td>22,000</td>
<td>16.19</td>
</tr>
<tr>
<td>Dickinson loam</td>
<td>8</td>
<td>1,175</td>
<td>3,475</td>
<td>36,620</td>
<td>10.80</td>
</tr>
<tr>
<td>Dodgeville sandy loam</td>
<td>1</td>
<td>600</td>
<td>1,700</td>
<td>23,000</td>
<td>13.80</td>
</tr>
<tr>
<td>Dodgeville loam</td>
<td>5</td>
<td>1,080</td>
<td>4,060</td>
<td>37,600</td>
<td>9.96</td>
</tr>
<tr>
<td>Dodgeville silt loam</td>
<td>7</td>
<td>1,043</td>
<td>4,357</td>
<td>49,140</td>
<td>11.24</td>
</tr>
<tr>
<td>Dodgeville silt loam (shallow phase)</td>
<td>1</td>
<td>1,000</td>
<td>3,900</td>
<td>51,000</td>
<td>12.90</td>
</tr>
<tr>
<td>Floyd silt loam</td>
<td>5</td>
<td>1,540</td>
<td>6,420</td>
<td>51,800</td>
<td>13.32</td>
</tr>
<tr>
<td>Lakeville sandy loam</td>
<td>1</td>
<td>1,300</td>
<td>4,300</td>
<td>36,000</td>
<td>8.50</td>
</tr>
<tr>
<td>Lindley sand</td>
<td>1</td>
<td>1,000</td>
<td>700</td>
<td>8,000</td>
<td>11.50</td>
</tr>
<tr>
<td>Lindley fine sand</td>
<td>6</td>
<td>733</td>
<td>782</td>
<td>10,830</td>
<td>14.37</td>
</tr>
<tr>
<td>Lindley sandy loam</td>
<td>4</td>
<td>600</td>
<td>850</td>
<td>9,250</td>
<td>10.43</td>
</tr>
<tr>
<td>Lindley fine sandy loam</td>
<td>9</td>
<td>789</td>
<td>1,733</td>
<td>21,550</td>
<td>12.44</td>
</tr>
<tr>
<td>Lindley very fine sandy loam</td>
<td>2</td>
<td>1,000</td>
<td>2,550</td>
<td>31,000</td>
<td>12.65</td>
</tr>
<tr>
<td>Lindley loam</td>
<td>21</td>
<td>852</td>
<td>2,033</td>
<td>24,470</td>
<td>11.86</td>
</tr>
<tr>
<td>Lindley silt loam</td>
<td>19</td>
<td>847</td>
<td>2,226</td>
<td>26,840</td>
<td>12.20</td>
</tr>
<tr>
<td>Pierce sandy loam</td>
<td>4</td>
<td>1,025</td>
<td>2,775</td>
<td>28,500</td>
<td>12.55</td>
</tr>
<tr>
<td>Pierce fine sandy loam</td>
<td>2</td>
<td>1,400</td>
<td>4,950</td>
<td>53,500</td>
<td>11.35</td>
</tr>
<tr>
<td>Pierce loam</td>
<td>2</td>
<td>1,100</td>
<td>3,400</td>
<td>43,500</td>
<td>12.75</td>
</tr>
<tr>
<td>Rogers silt loam</td>
<td>3</td>
<td>2,033</td>
<td>17,330</td>
<td>235,670</td>
<td>14.40</td>
</tr>
<tr>
<td>Roseville silt loam</td>
<td>1</td>
<td>500</td>
<td>3,000</td>
<td>29,000</td>
<td>9.90</td>
</tr>
<tr>
<td>Shelby loamy fine sand</td>
<td>1</td>
<td>400</td>
<td>900</td>
<td>8,000</td>
<td>8.60</td>
</tr>
<tr>
<td>Shelby sandy loam</td>
<td>1</td>
<td>600</td>
<td>1,200</td>
<td>7,000</td>
<td>6.10</td>
</tr>
<tr>
<td>Shelby fine sandy loam</td>
<td>4</td>
<td>725</td>
<td>2,300</td>
<td>23,750</td>
<td>10.02</td>
</tr>
<tr>
<td>Shelby loam</td>
<td>17</td>
<td>985</td>
<td>3,023</td>
<td>34,765</td>
<td>11.58</td>
</tr>
<tr>
<td>Shelby silt loam</td>
<td>6</td>
<td>883</td>
<td>3,150</td>
<td>35,170</td>
<td>10.98</td>
</tr>
<tr>
<td>Thurston loamy sand</td>
<td>1</td>
<td>1,000</td>
<td>900</td>
<td>12,000</td>
<td>12.70</td>
</tr>
<tr>
<td>Thurston sandy loam</td>
<td>3</td>
<td>1,000</td>
<td>1,600</td>
<td>20,000</td>
<td>13.53</td>
</tr>
<tr>
<td>Thurston loam</td>
<td>1</td>
<td>1,000</td>
<td>1,900</td>
<td>23,000</td>
<td>12.00</td>
</tr>
<tr>
<td>Webster loam</td>
<td>16</td>
<td>1,244</td>
<td>5,681</td>
<td>66,190</td>
<td>11.82</td>
</tr>
<tr>
<td>Webster silt loam</td>
<td>6</td>
<td>1,567</td>
<td>8,633</td>
<td>102,000</td>
<td>12.23</td>
</tr>
<tr>
<td>Webster silty clay loam</td>
<td>19</td>
<td>3,084</td>
<td>4,158</td>
<td>54,890</td>
<td>14.35</td>
</tr>
<tr>
<td>Webster clay loam</td>
<td>8</td>
<td>1,788</td>
<td>6,762</td>
<td>82,620</td>
<td>12.50</td>
</tr>
<tr>
<td>Weighted average for all soils</td>
<td>1,215</td>
<td>3,720</td>
<td>45,742</td>
<td>12.34</td>
<td></td>
</tr>
</tbody>
</table>
### TABLE 2. THE MEAN PHOSPHORUS, NITROGEN AND CARBON CONTENT OF THE DRIFT SOILS OF IOWA.

Pounds per acre of 6 million pounds of subsoil; 20–40 inches.

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Number of samples</th>
<th>Phosphorus</th>
<th>Nitrogen</th>
<th>Carbon</th>
<th>C:N ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carrington sand</td>
<td>2</td>
<td>1,600</td>
<td>850</td>
<td>12,000</td>
<td>15.75</td>
</tr>
<tr>
<td>Carrington fine sand</td>
<td>2</td>
<td>1,400</td>
<td>1,800</td>
<td>21,500</td>
<td>11.45</td>
</tr>
<tr>
<td>Carrington very fine sandy loam</td>
<td>1</td>
<td>1,300</td>
<td>1,000</td>
<td>19,000</td>
<td>18.50</td>
</tr>
<tr>
<td>Carrington sandy loam</td>
<td>11</td>
<td>1,900</td>
<td>2,310</td>
<td>25,039</td>
<td>12.15</td>
</tr>
<tr>
<td>Carrington fine sandy loam</td>
<td>21</td>
<td>2,019</td>
<td>2,576</td>
<td>33,520</td>
<td>13.24</td>
</tr>
<tr>
<td>Carrington loam</td>
<td>36</td>
<td>2,200</td>
<td>3,703</td>
<td>41,440</td>
<td>19.93</td>
</tr>
<tr>
<td>Carrington loam (steep phase)</td>
<td>6</td>
<td>2,450</td>
<td>2,617</td>
<td>34,000</td>
<td>14.56</td>
</tr>
<tr>
<td>Carrington loam (rolling phase)</td>
<td>1</td>
<td>2,000</td>
<td>2,900</td>
<td>20,000</td>
<td>7.10</td>
</tr>
<tr>
<td>Carrington silt loam</td>
<td>24</td>
<td>2,271</td>
<td>3,802</td>
<td>39,670</td>
<td>10.61</td>
</tr>
<tr>
<td>Clarion fine sand</td>
<td>1</td>
<td>5,000</td>
<td>1,700</td>
<td>26,000</td>
<td>15.40</td>
</tr>
<tr>
<td>Clarion sandy loam</td>
<td>1</td>
<td>2,700</td>
<td>2,520</td>
<td>24,870</td>
<td>9.87</td>
</tr>
<tr>
<td>Clarion fine sandy loam</td>
<td>6</td>
<td>2,700</td>
<td>2,567</td>
<td>39,830</td>
<td>15.40</td>
</tr>
<tr>
<td>Clarion loam</td>
<td>19</td>
<td>2,763</td>
<td>3,774</td>
<td>45,580</td>
<td>14.56</td>
</tr>
<tr>
<td>Clarion loam (rolling phase)</td>
<td>5</td>
<td>2,800</td>
<td>3,150</td>
<td>22,760</td>
<td>7.15</td>
</tr>
<tr>
<td>Clarion loam (shallow phase)</td>
<td>1</td>
<td>2,700</td>
<td>2,000</td>
<td>15,000</td>
<td>7.40</td>
</tr>
<tr>
<td>Clarion loam (steep phase)</td>
<td>5</td>
<td>3,160</td>
<td>3,360</td>
<td>24,200</td>
<td>7.50</td>
</tr>
<tr>
<td>Clarion silt loam</td>
<td>7</td>
<td>3,457</td>
<td>3,871</td>
<td>42,860</td>
<td>12.71</td>
</tr>
<tr>
<td>Clyde silt loam</td>
<td>13</td>
<td>2,554</td>
<td>2,324</td>
<td>34,714</td>
<td>10.87</td>
</tr>
<tr>
<td>Clyde silty clay loam</td>
<td>17</td>
<td>3,238</td>
<td>4,205</td>
<td>49,705</td>
<td>11.83</td>
</tr>
<tr>
<td>Conover silt loam</td>
<td>2</td>
<td>2,000</td>
<td>2,550</td>
<td>30,000</td>
<td>11.55</td>
</tr>
<tr>
<td>Dickinson loamy sand</td>
<td>1</td>
<td>1,200</td>
<td>500</td>
<td>7,000</td>
<td>15.20</td>
</tr>
<tr>
<td>Dickinson sandy loam</td>
<td>5</td>
<td>1,900</td>
<td>2,020</td>
<td>22,000</td>
<td>10.52</td>
</tr>
<tr>
<td>Dickinson loamy fine sand</td>
<td>1</td>
<td>1,700</td>
<td>1,200</td>
<td>18,000</td>
<td>14.70</td>
</tr>
<tr>
<td>Dickinson fine sandy loam</td>
<td>10</td>
<td>1,850</td>
<td>2,990</td>
<td>24,800</td>
<td>9.43</td>
</tr>
<tr>
<td>Dickinson loam</td>
<td>8</td>
<td>2,375</td>
<td>2,375</td>
<td>22,850</td>
<td>11.59</td>
</tr>
<tr>
<td>Dodgeville sandy loam</td>
<td>1</td>
<td>1,200</td>
<td>3,200</td>
<td>35,000</td>
<td>10.90</td>
</tr>
<tr>
<td>Dodgeville loam</td>
<td>2</td>
<td>2,181</td>
<td>3,365</td>
<td>50,593</td>
<td>14.65</td>
</tr>
<tr>
<td>Dodgeville silt loam</td>
<td>5</td>
<td>1,960</td>
<td>4,740</td>
<td>54,000</td>
<td>11.66</td>
</tr>
<tr>
<td>Dodgeville silt loam (shallow phase)</td>
<td>1</td>
<td>1,900</td>
<td>3,700</td>
<td>40,000</td>
<td>11.00</td>
</tr>
<tr>
<td>Floyd silt loam</td>
<td>5</td>
<td>2,540</td>
<td>1,900</td>
<td>20,200</td>
<td>7.88</td>
</tr>
<tr>
<td>Lakeville sandy loam</td>
<td>1</td>
<td>2,400</td>
<td>3,500</td>
<td>8,000</td>
<td>2.30</td>
</tr>
<tr>
<td>Lindley sand</td>
<td>1</td>
<td>1,700</td>
<td>780</td>
<td>7,065</td>
<td>10.17</td>
</tr>
<tr>
<td>Lindley fine sand</td>
<td>6</td>
<td>1,200</td>
<td>1,033</td>
<td>13,000</td>
<td>10.97</td>
</tr>
<tr>
<td>Lindley sandy loam</td>
<td>4</td>
<td>1,450</td>
<td>1,625</td>
<td>14,500</td>
<td>10.85</td>
</tr>
<tr>
<td>Lindley fine sandy loam</td>
<td>9</td>
<td>2,076</td>
<td>2,000</td>
<td>16,220</td>
<td>9.79</td>
</tr>
<tr>
<td>Lindley very fine sandy loam</td>
<td>2</td>
<td>2,300</td>
<td>2,100</td>
<td>29,500</td>
<td>13.50</td>
</tr>
<tr>
<td>Lindley loam</td>
<td>21</td>
<td>2,195</td>
<td>1,971</td>
<td>23,619</td>
<td>13.37</td>
</tr>
<tr>
<td>Lindley silt loam</td>
<td>19</td>
<td>2,215</td>
<td>2,084</td>
<td>19,780</td>
<td>10.47</td>
</tr>
<tr>
<td>Pierce fine sandy loam</td>
<td>2</td>
<td>3,200</td>
<td>1,700</td>
<td>19,000</td>
<td>11.10</td>
</tr>
<tr>
<td>Pierce loam</td>
<td>2</td>
<td>2,600</td>
<td>3,500</td>
<td>30,000</td>
<td>8.70</td>
</tr>
<tr>
<td>Rogers silt loam</td>
<td>3</td>
<td>4,333</td>
<td>43,133</td>
<td>457,330</td>
<td>10.60</td>
</tr>
<tr>
<td>Roseville silt loam</td>
<td>1</td>
<td>300</td>
<td>1,300</td>
<td>12,000</td>
<td>9.20</td>
</tr>
<tr>
<td>Shelby loamy fine sand</td>
<td>1</td>
<td>500</td>
<td>4,300</td>
<td>19,000</td>
<td>10.00</td>
</tr>
<tr>
<td>Shelby sandy loam</td>
<td>1</td>
<td>1,100</td>
<td>1,300</td>
<td>13,000</td>
<td>10.00</td>
</tr>
<tr>
<td>Shelby fine sandy loam</td>
<td>4</td>
<td>1,675</td>
<td>3,375</td>
<td>28,500</td>
<td>8.58</td>
</tr>
<tr>
<td>Shelby loam</td>
<td>17</td>
<td>2,170</td>
<td>2,817</td>
<td>28,940</td>
<td>10.50</td>
</tr>
<tr>
<td>Shelby silt loam</td>
<td>6</td>
<td>1,316</td>
<td>2,950</td>
<td>28,000</td>
<td>9.76</td>
</tr>
<tr>
<td>Thurston loamy sand</td>
<td>1</td>
<td>1,400</td>
<td>1,200</td>
<td>10,000</td>
<td>8.80</td>
</tr>
<tr>
<td>Thurston sandy loam</td>
<td>3</td>
<td>2,567</td>
<td>2,867</td>
<td>20,670</td>
<td>11.23</td>
</tr>
<tr>
<td>Thurston loam</td>
<td>1</td>
<td>1,400</td>
<td>600</td>
<td>13,000</td>
<td>21.00</td>
</tr>
<tr>
<td>Webster loam</td>
<td>16</td>
<td>2,544</td>
<td>4,219</td>
<td>45,750</td>
<td>10.68</td>
</tr>
<tr>
<td>Webster silt loam</td>
<td>6</td>
<td>3,183</td>
<td>5,150</td>
<td>79,670</td>
<td>14.27</td>
</tr>
<tr>
<td>Webster silty clay loam</td>
<td>19</td>
<td>3,084</td>
<td>4,158</td>
<td>54,890</td>
<td>14.35</td>
</tr>
<tr>
<td>Webster clay loam</td>
<td>8</td>
<td>3,150</td>
<td>3,112</td>
<td>36,620</td>
<td>13.47</td>
</tr>
</tbody>
</table>

Weighted average for all soils: 2,373, 3,691, 37,700, 11.49
TABLE 3. THE MEAN, STANDARD DEVIATION AND COEFFICIENT OF VARIABILITY OF THE PHOSPHORUS, NITROGEN AND CARBON CONTENT OF REPRESENTATIVE DRIFT SOILS OF IOWA.

Code: P and N + 100; C + 1,000.

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Number of determinations</th>
<th>Phosphorus</th>
<th>Nitrogen</th>
<th>Carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>Standard deviation</td>
<td>Coefficient of variability</td>
</tr>
<tr>
<td>Carrington sandy loam</td>
<td>11</td>
<td>864</td>
<td>157</td>
<td>18.1</td>
</tr>
<tr>
<td>Clarion loam</td>
<td>19</td>
<td>1,303</td>
<td>297</td>
<td>24.6</td>
</tr>
<tr>
<td>Webster loam</td>
<td>16</td>
<td>1,244</td>
<td>233</td>
<td>20.3</td>
</tr>
<tr>
<td>Carrington silt loam</td>
<td>24</td>
<td>1,288</td>
<td>225</td>
<td>17.4</td>
</tr>
<tr>
<td>Clyde silty clay loam</td>
<td>17</td>
<td>1,735</td>
<td>404</td>
<td>23.2</td>
</tr>
<tr>
<td>Webster silty clay loam</td>
<td>19</td>
<td>3,084</td>
<td>868</td>
<td>28.1</td>
</tr>
<tr>
<td>All drift soils (55 types)</td>
<td>384</td>
<td>1,215</td>
<td>610</td>
<td>50.2</td>
</tr>
</tbody>
</table>

Bizzell (3) studied the chemical composition of New York soils and among other things he reported the nitrogen and phosphorus content for 101 soils. There was a wide variation in chemical composition between samples of one type taken from different localities, and the variations were frequently greater than the differences between averages of different types. He concluded that in total nitrogen and phosphorus the types are neither distinct nor are the soils within each type closely similar. Owing to the relatively small number of samples in most of the soil types, no attempt was made to analyze the data statistically, as it was considered impossible to give a satisfactory mathematical expression to this variation.

Walker (24) studied the chemical composition of Louisiana soils and came to the conclusion that there are usually wider variations within a given series or class than there are between averages of series or classes.

In analyzing the data for the drift soils of Iowa, the results obtained from all of the individual samples within a soil type were employed; hence all of the variability within types was given full consideration. The results are shown in table 4.

Before making the analysis the figures reported in the soil survey reports were coded by dividing the pounds per acre of phosphorus and nitrogen by 100 and the pounds per acre of carbon by 1,000. The mean square figures shown in the analysis of variance tables were not decoded, but wherever the means for phosphorus, nitrogen or carbon content are shown, as in tables 1, 2, 11, etc., the figures are decoded and the values shown are of the proper magnitude.

There are 384 individual samples of soil distributed among
the 55 types considered in this analysis. The data of table 4 indicate that in spite of the large variability within types the differences among types are highly significant. This is true for the phosphorus, nitrogen and carbon content of both the surface and subsoil samples. The variability of the samples is not great enough to conceal the actual differences among the type means for these constituents.

The above conclusions apply to the drift soil types as a whole, and not to the difference between any two soil types that may be singled out for direct comparison. In order to make an independent comparison of two soils it would be necessary to make a "t test" of the mean difference. For example, in comparing the Clarion and Webster silt loams in their nitrogen contents it may be observed from table 1 that the means are 4,986 and 8,633 pounds per acre, respectively. The mean difference is 3,647 pounds which was found to be significant. Hence the difference in nitrogen content of these two soils is real and cannot be accounted for on the basis of random sampling.

Similarly the Carrington silt loam and Webster silt loam with mean nitrogen contents of 4,606 and 8,633 pounds per acre, respectively, are found to be highly significantly different. On the other hand, the mean difference between the Carrington and Clarion silt loams is only 380 pounds of nitrogen per acre, which is not significant. Thus it is shown that although the analysis of variance in table 4 indicates that there are real and significant differences among types, certain soils may not differ materially in nitrogen, phosphorus or carbon.

The Clarion and Webster soils of the Wisconsin Drift area

---

**TABLE 4. ANALYSIS OF VARIANCE OF THE PHOSPHORUS, NITROGEN AND CARBON CONTENT OF THE VARIOUS TYPES OF DRIFT SOILS OF IOWA.**

**Code: P and N+100; C+1,000**

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Degrees of freedom</th>
<th>Phosphorus</th>
<th>Nitrogen</th>
<th>Carbon</th>
<th>C:N ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Surface: 0 to 6 2/3 inches</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>383</td>
<td>37</td>
<td>526</td>
<td>977</td>
<td>18</td>
</tr>
<tr>
<td>Between soil types</td>
<td>54</td>
<td>190**</td>
<td>2,496**</td>
<td>5,279**</td>
<td>26*</td>
</tr>
<tr>
<td>Within soil types</td>
<td>329</td>
<td>12</td>
<td>203</td>
<td>272</td>
<td>17</td>
</tr>
<tr>
<td><strong>Subsoil: 20 to 40 inches</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>370</td>
<td>71</td>
<td>1,673</td>
<td>2,250</td>
<td>55</td>
</tr>
<tr>
<td>Between soil types</td>
<td>52</td>
<td>380**</td>
<td>8,216**</td>
<td>11,419**</td>
<td>135**</td>
</tr>
<tr>
<td>Within soil types</td>
<td>318</td>
<td>21</td>
<td>602</td>
<td>754</td>
<td>41</td>
</tr>
</tbody>
</table>

*Significant difference  
**Highly significant difference
probably were similarly supplied with phosphorus, nitrogen and carbon when they were laid down by the glacier. Owing to the topographic position of the Webster soils, however, and their occurrence in somewhat depressed and poorly-drained locations, they have supported a greater abundance of plant growth than the Clarion soils which are rolling in topography and naturally well drained. The rate of organic matter decomposition also has been less in the wetter soils, and these two conditions have favored a larger accumulation of organic matter which is shown by the higher content of carbon and nitrogen. Furthermore, the topographic conditions have favored the leaching of nutrients from the higher-lying Clarion soils and their accumulation in the depressed areas of Webster soils. Similar comparisons may be made of the Carrington and Clyde soils of the Iowan Drift area. The mean contents of phosphorus, nitrogen and carbon of the Clyde soils are higher and apparently significantly higher in most cases, than in the rolling Carrington soils.

Soils having considerably smaller mean phosphorus, nitrogen and carbon contents than those referred to above are the Shelby and Lindley loams of southern Iowa. These soils may have contained quite different amounts of phosphorus, nitrogen and carbon than the soils of northern Iowa when they were laid down by glacial action, but in addition to that they have been subjected to somewhat different environmental conditions during the period of soil formation. They are older soils; they have been formed under conditions of greater rainfall, and in general they are steeper in topography than the soils of northern Iowa previously referred to.

COMPARISON OF SURFACE AND SUBSOILS

A number of investigators have found that the percentage content of nitrogen and carbon is considerably less in the subsoil than it is in the surface layer. Naturally the differences in phosphorus content have not been so pronounced as those for nitrogen and carbon. The data recorded in table 1 show the pounds of the various constituents per acre to a depth of 6\% inches which is considered to be equivalent to 2,000,000 pounds of soil. The data representing the subsoils recorded in table 2 are based on a soil depth from 20 to 40 inches below the surface, or a layer three times the thickness of the surface layer. In order to make a direct comparison of the content of the surface and subsoil horizons of these soils, therefore, it would be necessary first to divide the figures for the subsoils by 3. The composition of both soil layers would then be expressed on the basis of pounds per 2 million pounds of soil. In this way a comparison may be made between the surface and subsoil layers.
of any soil type. In the case of the Webster loam for example, the mean phosphorus, nitrogen and carbon content of the surface soil, as shown in table 1, is 1,244, 5,681, and 66,190 pounds per acre, whereas the corresponding values for the subsoil when calculated to an equivalent basis would be 848, 1,406 and 15,250 pounds per acre, respectively. In order to make a more generalized comparison between the two soil layers the mean content for all the soil types in the drift group was computed and found to be 1,215, 3,720, and 45,742 pounds, whereas for the subsoils the corresponding figures were 791, 1,230, and 12,566 pounds, respectively.

It is apparent from these means that there is a real difference in the nitrogen and carbon content of the two horizons, and this is to be expected. It is in the surface horizon that organic matter has accumulated from plant remains during the ages through which the soils have developed.

It also appears that the difference in phosphorus content in the two horizons is significant. It seems reasonable to assume that the phosphorus content of the surface and subsoil layers was practically the same when the soil material was deposited by glacial action. It follows, therefore, that factors must have been in operation since that time to increase the phosphorus content of the surface layer, or to decrease it in the subsoil, or both. This change may be explained, undoubtedly, on the basis of the assimilation of phosphorus by plant roots in the subsoil, and the subsequent translocation of a portion of it to the stems and leaves of the plants. Thus as organic matter accumulated in the surface soil there was also an accumulation of phosphorus in this soil horizon, although to a lesser degree than in the case of nitrogen and carbon.

THE INFLUENCE OF TEXTURE

It has been commonly recognized that the total plant nutrient content of soils varies widely with the texture. In order to determine whether or not this is true for the drift soils of Iowa the data of table 1 were studied further.

The relationship of texture to composition within a single series is shown in table 5. In this table the available classes of soils belonging to the Carrington series are listed according to their increasing degree of fineness of texture, and their corresponding phosphorus, nitrogen and carbon contents are shown. It is evident that there is a rather definite and consistent relationship between the texture of the soil and the content of these constituents.

The limitations of this type of comparison are not to be overlooked. In the first place the comparison has been confined to a small group of similar soils. This objection may be met by
TABLE 5. THE AVERAGE PHOSPHORUS, NITROGEN AND CARBON CONTENT OF SOIL TYPES OF DIFFERENT CLASSES OF THE CARRINGTON SERIES.

<table>
<thead>
<tr>
<th>Soil types ranked in order of texture</th>
<th>Pounds per acre</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Phosphorus</td>
</tr>
<tr>
<td>Carrington sand</td>
<td>800</td>
</tr>
<tr>
<td>Carrington fine sand</td>
<td>750</td>
</tr>
<tr>
<td>Carrington sandy loam</td>
<td>864</td>
</tr>
<tr>
<td>Carrington fine sandy loam</td>
<td>895</td>
</tr>
<tr>
<td>Carrington loam</td>
<td>1,147</td>
</tr>
<tr>
<td>Carrington silt loam</td>
<td>1,288</td>
</tr>
</tbody>
</table>

analyzing the data from a larger number of soils. This has been done and the results are reported below. Another objection is the fact that the type designation, although it is an expression of the texture, is not a very specific designation. For example there is some range of texture among soils that fall into the loam class. If a single mathematical expression could be used to express the specific texture of a soil it would be much easier to make a correlation between texture and composition and the results would more nearly approach the ideal. Russell and McRuer (15) used the hygroscopic coefficient as an expression of soil texture in their studies. Unfortunately in the work reported here no data are available to provide a single value expression of soil texture.

In order to overcome partially the limitations pointed out, and make more reliable comparisons of the phosphorus, nitrogen and carbon content of the various textural groups, a statistical analysis was made for the individual soils within the groups, and then comparisons were made between groups. The textural groups studied, and the soils included in each group are shown in table 6. This table also gives the low and high means for the various constituents for the soils within each textural group.

In the first place an analysis of variance was made of the data for the soils listed in each textural group. These analyses are recorded in table 7.

It was found that in the group of sandy loam soils the different types differ among themselves significantly or highly significantly in phosphorus, nitrogen and carbon. They also differ in carbon-nitrogen ratio. The fine sandy loam soils differ significantly in nitrogen and carbon-nitrogen ratio, but the differences in their phosphorus and carbon contents are not sufficiently large to be significant. The various types within the loam, silt loam, silty clay loam, and clay loam classes differ significantly in content of all constituents in all cases.

In general, it appears that the different soils within a specific textural group differ among themselves in content of phos-
TABLE 6. THE HIGH AND LOW MEAN NITROGEN, PHOSPHORUS AND CARBON CONTENT OF TEXTURAL GROUPS OF DRIFT SOILS USED IN TEXTURAL COMPARISONS.

<table>
<thead>
<tr>
<th>Textural group</th>
<th>Soil type</th>
<th>No. of samples</th>
<th>Phosphorus</th>
<th>Nitrogen</th>
<th>Carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>low</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>Sandy loams</td>
<td>Thureton</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pierce</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Carrington</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dickinson</td>
<td>5</td>
<td>1.175</td>
<td></td>
<td>3.756</td>
</tr>
<tr>
<td></td>
<td>Lindley</td>
<td>4</td>
<td>600</td>
<td>850</td>
<td>9,250</td>
</tr>
<tr>
<td>Fine sandy loams</td>
<td>Shelby</td>
<td>4</td>
<td>1,100</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Carrington</td>
<td>21</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Clarion</td>
<td>6</td>
<td>3,083</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lindley</td>
<td>9</td>
<td>1,733</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loams</td>
<td>Shelby</td>
<td>17</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Carrington</td>
<td>(steep phase)</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Clarion</td>
<td>(rolling phase)</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Clarion</td>
<td>(steep phase)</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Carrington</td>
<td>36</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dodgeville</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dickinson</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lindley</td>
<td>21</td>
<td>1,244</td>
<td>2,033</td>
<td>5,681</td>
</tr>
<tr>
<td></td>
<td>Webster</td>
<td>16</td>
<td></td>
<td>1,244</td>
<td>5,681</td>
</tr>
<tr>
<td>Silt loams</td>
<td>Webster</td>
<td>6</td>
<td></td>
<td>2,033</td>
<td>17,330</td>
</tr>
<tr>
<td></td>
<td>Rogers</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Clarion</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Carrington</td>
<td>24</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dodgeville</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Conover</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Clyde</td>
<td>13</td>
<td>700</td>
<td>2,150</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Floyd</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lindley</td>
<td>19</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shelby</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silty clay loams</td>
<td>Clyde s.c.</td>
<td>17</td>
<td>1,735</td>
<td>7,962</td>
<td>91,940</td>
</tr>
<tr>
<td>and clay loam</td>
<td>Webster s.c.</td>
<td>19</td>
<td>3,084</td>
<td>4,158</td>
<td>54,890</td>
</tr>
<tr>
<td></td>
<td>Webster c.</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

phorus, nitrogen and carbon. In view of this fact the question then arises whether or not the differences between the means of groups are sufficiently large to be significant in spite of the variability within the various groups.

To answer this question the data were analyzed by the analysis of variance with the results shown in table 8. It may be noted that the mean square within soil types is considerably less than that between textural groups in the ease of phosphorus, nitrogen and carbon. Just the opposite is true for the carbon-nitrogen ratio. These results may be interpreted to mean that the observed differences in the means of the phosphorus, nitrogen and carbon content of the textural groups of soils are real and of sufficient magnitude that they are not obscured by the variability within the types of the various textural groups. In
TABLE 7. ANALYSIS OF VARIANCE OF THE PHOSPHORUS, NITROGEN AND CARBON CONTENT OF DIFFERENT SOIL TYPES IN THE TEXTURAL GROUPS OF DRIFT SOILS LISTED IN TABLE 6.
Code: \(P\) and \(N+100\); \(C+1,000\).

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Degrees of freedom</th>
<th>Mean square</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Phosphorus</td>
<td>Nitrogen</td>
</tr>
<tr>
<td><strong>Sandy loams</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between soil types</td>
<td>4</td>
<td>14.9*</td>
</tr>
<tr>
<td>Within soil types</td>
<td>22</td>
<td>5.1</td>
</tr>
<tr>
<td><strong>Fine sandy loams</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between soil types</td>
<td>4</td>
<td>11.7</td>
</tr>
<tr>
<td>Within soil types</td>
<td>45</td>
<td>5.6</td>
</tr>
<tr>
<td><strong>Loams</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between soil types</td>
<td>9</td>
<td>25.5**</td>
</tr>
<tr>
<td>Within soil types</td>
<td>116</td>
<td>7.0</td>
</tr>
<tr>
<td><strong>Silt loams</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between soil types</td>
<td>9</td>
<td>104.2**</td>
</tr>
<tr>
<td>Within soil types</td>
<td>76</td>
<td>7.1</td>
</tr>
<tr>
<td><strong>Silty clay loams and clay loam</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between soil types</td>
<td>2</td>
<td>999.4**</td>
</tr>
<tr>
<td>Within soil types</td>
<td>40</td>
<td>47.2</td>
</tr>
</tbody>
</table>

*Significant  
**Highly significant

Code: \(P\) and \(N+100\); \(C+1,000\).

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Degrees of freedom</th>
<th>Mean square</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Phosphorus</td>
<td>Nitrogen</td>
</tr>
<tr>
<td>Between textural groups</td>
<td>4</td>
<td>1,574**</td>
</tr>
<tr>
<td>Within soil types</td>
<td>327</td>
<td>21</td>
</tr>
</tbody>
</table>

**Highly significant

view of this conclusion it appears from the data of table 6 that the soils classified in the finer textural groups contain significantly larger amounts of phosphorus, nitrogen and carbon than the soils of coarser texture. This general relationship is illustrated by the graph in fig. 4 where the mean phosphorus, nitrogen and carbon content of the various textural groups is shown.
The mean phosphorus, nitrogen and carbon content of various textural groups of drift soils is illustrated in Fig. 4. The graph also indicates that the correlation between texture and nitrogen and carbon content is probably larger than it is between texture and phosphorus content. The results of this analysis show that the soils of different texture either contained different amounts of phosphorus before they were acted upon by the weathering processes or, owing to their textural differences, they have lost phosphorus at different rates through drainage, crop removal or other means, or the present difference in phosphorus content may be the resultant of both of these factors. In the case of nitrogen and carbon, however, the situation is somewhat different. Considerable amounts of each of these elements have been added to the soil from outside sources during the process of soil formation. The nitrogen content has undoubtedly been increased as a result of the growth and the fixation of atmospheric nitrogen by the nitrogen fixing bacteria of the soil. The carbon content has been increased through the photosynthetic process and the subsequent accumulation of organic debris in the soil. The comparative phosphorus, nitrogen and carbon contents of the surface and subsoils substantiate these conclusions. Hence the results of table 8 indicate that the soil texture has had a real influence either on the factors tending toward an increase or a decrease in soil nitrogen and carbon, or on both.

Walker (24) did not find this type of relationship between soil texture and the content of phosphorus and nitrogen for Louisiana soils. In his studies on 67 samples of 27 soil types he found rather wide variations between extremes in phosphorus...
and nitrogen content but he concluded that the results were so uniform for most of the soils that the averages for each series or textural group were practically the same. No attempt was made to analyze the data statistically.

On the other hand, in their studies on Nebraska soils, Russell and McRuer (16) concluded that texture is the outstanding factor determining nitrogen content in any soil type, and since all soil types show considerable variation in texture, they exhibit a corresponding variation in nitrogen content.

In studying the chemical composition of the soils of New York, Bizzell (3) arranged them on the basis of fineness of division or texture, beginning with the coarsest and ending with the finest textural group. He found that nitrogen and potassium have a distinct tendency to increase with an increase of fineness of the soil. Phosphorus, magnesium and sulfur exhibited the same general trend, although the differences were not so pronounced. These observations are in complete agreement with those reported here.

Some question may arise as to the significance of the differences between two closely related textural groups. Inasmuch as there is a natural continuity of textural change from the coarsest to the finest textured soil in the field without sharp lines of demarcation appearing such as have been artificially and arbitrarily set up in the laboratory, and also since the method of establishing soil class as used in the field by the soil surveyor is not one of specific measurement, it is natural that borderline cases may be interpreted differently by different observers. This is a possible source of error in this type of comparison and it serves to emphasize the fact that if absolute measurements of soil texture were available the relationship of texture to composition would undoubtedly be more pronounced.

Another possible explanation of the fact that statistically significant differences in phosphorus, nitrogen and carbon content may not occur between two specific textural groups whereas there would be differences between other groups, lies in the fact that the actual difference in texture between the two groups may be very slight. The sandy loam and fine sandy loam groups, for example, may be much more closely related in specific texture, if it were possible to make such a measurement, than the fine sandy loam and loam classes, or the loam and silt loam classes.

**COMPARISON OF SOILS OF UNIFORM TEXTURE**

A convenient and interesting comparison of the various soils as affected by factors other than texture may be obtained by ranking those soils of a certain textural class according to their content of phosphorus, nitrogen and carbon. This has been
TABLE 9. LOAM SOILS IN THE DRIFT AREAS RANKED IN ORDER OF INCREASING PHOSPHORUS, NITROGEN AND CARBON CONTENT.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Phosphorus</th>
<th>Nitrogen</th>
<th>Carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Lindley</td>
<td>Thurston</td>
<td>Thurston</td>
</tr>
<tr>
<td>2</td>
<td>Shelby</td>
<td>Lindley</td>
<td>Lindley</td>
</tr>
<tr>
<td>3</td>
<td>Thurston</td>
<td>Shelby</td>
<td>Shelby</td>
</tr>
<tr>
<td>4</td>
<td>Dodgeville</td>
<td>Pierce</td>
<td>Dickinson</td>
</tr>
<tr>
<td>5</td>
<td>Pierce</td>
<td>Dickinson</td>
<td>Dodgeville</td>
</tr>
<tr>
<td>6</td>
<td>Carrington</td>
<td>Carrington</td>
<td>Pierce</td>
</tr>
<tr>
<td>7</td>
<td>Dickinson</td>
<td>Dodgeville</td>
<td>Carrington</td>
</tr>
<tr>
<td>8</td>
<td>Clarion</td>
<td>Clarion</td>
<td>Clarion</td>
</tr>
<tr>
<td>9</td>
<td>Webster</td>
<td>Webster</td>
<td>Webster</td>
</tr>
</tbody>
</table>

TABLE 10. SILT LOAM SOILS IN THE DRIFT AREAS RANKED IN ORDER OF INCREASING PHOSPHORUS, NITROGEN AND CARBON CONTENT.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Phosphorus</th>
<th>Nitrogen</th>
<th>Carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Roseville</td>
<td>Conover</td>
<td>Lindley</td>
</tr>
<tr>
<td>2</td>
<td>Conover</td>
<td>Lindley</td>
<td>Conover</td>
</tr>
<tr>
<td>3</td>
<td>Lindley</td>
<td>Roseville</td>
<td>Roseville</td>
</tr>
<tr>
<td>4</td>
<td>Dodgeville</td>
<td>Dodgeville</td>
<td>Carrington</td>
</tr>
<tr>
<td>5</td>
<td>Clarion</td>
<td>Carrington</td>
<td>Clarion</td>
</tr>
<tr>
<td>6</td>
<td>Carrington</td>
<td>Clarion</td>
<td>Clarion</td>
</tr>
<tr>
<td>7</td>
<td>Floyd</td>
<td>Floyd</td>
<td>Clyde</td>
</tr>
<tr>
<td>8</td>
<td>Webster</td>
<td>Clyde</td>
<td>Webster</td>
</tr>
<tr>
<td>9</td>
<td>Clyde</td>
<td>Webster</td>
<td>Rogers</td>
</tr>
<tr>
<td>10</td>
<td>Rogers</td>
<td>Rogers</td>
<td>Rogers</td>
</tr>
</tbody>
</table>

done for the loam and silt loam soils and the results are shown in tables 9 and 10, respectively. The mean phosphorus, nitrogen and carbon contents of these soils, as recorded in table 1, have been employed in making this classification.

The relative phosphorus, nitrogen and carbon content of the various soils is shown in these tables. It may be noted that soils which rank high in one constituent have a tendency to have approximately the same ranking in the other two constituents. The same tendency appears for the low ranking soils.

It may also be observed from these tables that the series which rank the highest in the various constituents in one texture also tend to rank high in other textural classes. The same observation may be made for the low ranking soils. In other words, a high or low phosphorus, nitrogen or carbon content seems to be a series characteristic entirely apart from the textural influence. It is only natural that this should be the case for it is the individual and combined characteristics of soils, other than texture, that differentiate them into series.

Undoubtedly the soil-forming processes that have operated on soils of similar inherent characteristics to produce types having entirely different acquired characteristics have also had a profound influence upon their phosphorus, nitrogen and carbon content. Indeed the content of phosphorus, nitrogen
and carbon of a soil is an important characteristic of that soil, and it is reflected either directly or indirectly in other profile characteristics. The fact that significant differences occur in the phosphorus, nitrogen and carbon contents of soil types, and also between series of similar classes, is strong evidence in support of the soil type theory of soil classification. In other words the chemical analysis of soils supports and substantiates the differentiation of soils into series and classes in the field by the soil surveyor. Although this is true in general when a large number of soils is considered, it should not be misinterpreted to mean that it may be possible to differentiate soils merely by making analyses for their phosphorus or nitrogen content. It must be kept in mind that the phosphorus or nitrogen content of a soil is only one of its many characteristics, and that a knowledge of one character cannot be used to determine the other characters. There is a close relationship, however, between this characteristic and the others that are employed in differentiating soils.

RESULTS FOR THE LOESS SOILS

The mean phosphorus, nitrogen and carbon content of the loess soils of Iowa is shown in table 11. In order to indicate the extent of the variability within types in this group of soils, the standard deviation of the phosphorus, nitrogen and carbon for three of the more important soils and for the loess soils as a whole has been computed and is shown in table 12. From this table it appears that the loess soils show approximately the same degree of variability as the drift soils. For example, the nitrogen content of the Tama silt loam varied from 3,360 pounds per acre in the sample from Fayette County to 6,010 pounds in the sample from Marshall County. The mean is 4,269 pounds per acre, and the standard deviation is 700 pounds, which is 16.3 percent of the mean. Somewhat larger variability is indicated for the nitrogen content of the Clinton and Marshall silt loams and for the loess soils as a group. The variability in the phosphorus and carbon content of these soils is also indicated by the data of table 12.

As in the case of the drift soils an analysis of variance of the data for all of the individual samples of each soil has been made for the purpose of determining whether the variability within soils is so large as to obscure differences between types. The results of this analysis are shown in table 13.

It was found that the variance within types was considerably and significantly less than that between types in the case of phosphorus, nitrogen and carbon for the surface samples. Hence the differences between means of types are highly significant. There is no significant difference, however, between
<table>
<thead>
<tr>
<th>Soil type</th>
<th>Number of samples</th>
<th>Surface Soil: 0—6 2/3 inches</th>
<th>Subsoil: 20—40 inches</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Phosphorus</td>
<td>Nitrogen</td>
</tr>
<tr>
<td>Afton silt loam</td>
<td>1</td>
<td>1,200</td>
<td>7,000</td>
</tr>
<tr>
<td>Clinton sand</td>
<td>1</td>
<td>500</td>
<td>800</td>
</tr>
<tr>
<td>Clinton fine sand</td>
<td>4</td>
<td>875</td>
<td>750</td>
</tr>
<tr>
<td>Clinton loamy fine sand</td>
<td>1</td>
<td>600</td>
<td>500</td>
</tr>
<tr>
<td>Clinton fine sandy loam</td>
<td>4</td>
<td>750</td>
<td>1,075</td>
</tr>
<tr>
<td>Clinton very fine sandy loam</td>
<td>4</td>
<td>825</td>
<td>2,050</td>
</tr>
<tr>
<td>Clinton silt loam</td>
<td>36</td>
<td>1,019</td>
<td>2,506</td>
</tr>
<tr>
<td>Clinton silt loam (steep phase)</td>
<td>3</td>
<td>1,200</td>
<td>1,200</td>
</tr>
<tr>
<td>Edina silt loam</td>
<td>4</td>
<td>1,200</td>
<td>3,500</td>
</tr>
<tr>
<td>Fayette sand</td>
<td>1</td>
<td>500</td>
<td>300</td>
</tr>
<tr>
<td>Fayette fine sand</td>
<td>1</td>
<td>600</td>
<td>1,200</td>
</tr>
<tr>
<td>Fayette very fine sandy loam</td>
<td>1</td>
<td>800</td>
<td>2,200</td>
</tr>
<tr>
<td>Fayette silt loam</td>
<td>7</td>
<td>943</td>
<td>2,300</td>
</tr>
<tr>
<td>Fayette silt loam (steep phase)</td>
<td>1</td>
<td>500</td>
<td>1,300</td>
</tr>
<tr>
<td>Grundy silt loam</td>
<td>10</td>
<td>1,268</td>
<td>4,253</td>
</tr>
<tr>
<td>Grundy silt loam</td>
<td>1</td>
<td>553</td>
<td>4,800</td>
</tr>
<tr>
<td>Knox silt loam</td>
<td>6</td>
<td>1,283</td>
<td>2,117</td>
</tr>
<tr>
<td>Marcus silt loam</td>
<td>1</td>
<td>1,300</td>
<td>6,000</td>
</tr>
<tr>
<td>Marion silt loam</td>
<td>7</td>
<td>957</td>
<td>2,229</td>
</tr>
<tr>
<td>Marshall silt loam</td>
<td>14</td>
<td>1,329</td>
<td>4,029</td>
</tr>
<tr>
<td>Marshall silt loam (level phase)</td>
<td>3</td>
<td>1,800</td>
<td>5,600</td>
</tr>
<tr>
<td>Marshall silt loam (shallow phase)</td>
<td>4</td>
<td>1,350</td>
<td>3,375</td>
</tr>
<tr>
<td>Muscatine silt loam</td>
<td>13</td>
<td>1,500</td>
<td>4,415</td>
</tr>
<tr>
<td>Muscatine silt loam</td>
<td>2</td>
<td>1,500</td>
<td>4,750</td>
</tr>
<tr>
<td>Putnam silt loam</td>
<td>6</td>
<td>1,150</td>
<td>3,083</td>
</tr>
<tr>
<td>Scott silt loam</td>
<td>2</td>
<td>1,350</td>
<td>3,550</td>
</tr>
<tr>
<td>Tama sand</td>
<td>1</td>
<td>500</td>
<td>400</td>
</tr>
<tr>
<td>Tama loamy fine sand</td>
<td>1</td>
<td>1,000</td>
<td>2,100</td>
</tr>
<tr>
<td>Tama silt loam</td>
<td>29</td>
<td>1,297</td>
<td>4,210</td>
</tr>
<tr>
<td>Tama silt loam (rolling phase)</td>
<td>1</td>
<td>1,100</td>
<td>3,000</td>
</tr>
<tr>
<td>Tama silt loam (shallow phase)</td>
<td>4</td>
<td>1,075</td>
<td>3,350</td>
</tr>
<tr>
<td>Tama silt loam (light colored phase)</td>
<td>4</td>
<td>975</td>
<td>2,600</td>
</tr>
<tr>
<td>Weighted average</td>
<td></td>
<td>1,436</td>
<td>3,201</td>
</tr>
</tbody>
</table>
TABLE 12. THE MEAN, STANDARD DEVIATION AND COEFFICIENT OF VARIABILITY OF THE PHOSPHORUS, NITROGEN AND CARBON CONTENT OF REPRESENTATIVE LOESS SOILS OF IOWA.

Code: \( P \) and \( N + 100; \ C + 1,000. \)

<table>
<thead>
<tr>
<th>Soil types</th>
<th>Number of determinations</th>
<th>Phosphorus</th>
<th>Nitrogen</th>
<th>Carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>Standard deviation</td>
<td>Coefficient of variability</td>
</tr>
<tr>
<td>Tama silt loam</td>
<td>29</td>
<td>1,348</td>
<td>277</td>
<td>22.2</td>
</tr>
<tr>
<td>Clinton silt loam</td>
<td>36</td>
<td>1,019</td>
<td>221</td>
<td>21.6</td>
</tr>
<tr>
<td>Marshall silt loam</td>
<td>14</td>
<td>1,329</td>
<td>120</td>
<td>9.0</td>
</tr>
<tr>
<td>All loess soils</td>
<td>(36 types)</td>
<td>229</td>
<td>1,435</td>
<td>793</td>
</tr>
</tbody>
</table>

TABLE 13. ANALYSIS OF VARIANCE OF THE PHOSPHORUS, NITROGEN AND CARBON CONTENT OF THE LOESS SOILS OF IOWA.

Code: \( P \) and \( N + 100; \ C + 1,000. \)

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Degrees of freedom</th>
<th>Mean square</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Phosphorus</td>
<td>Nitrogen</td>
</tr>
<tr>
<td>Total</td>
<td>229</td>
<td>63</td>
</tr>
<tr>
<td>Between soil types</td>
<td>35</td>
<td>309**</td>
</tr>
<tr>
<td>Within soil types</td>
<td>194</td>
<td>18</td>
</tr>
</tbody>
</table>

| Total               | 191                | 78          | 357        | 423       | 18.8 |
| Between soil types  | 32                 | 156**       | 1,098**    | 1,315**   | 34.8** |
| Within soil types   | 159                | 63          | 208        | 243       | 15.6 |

**Highly significant difference.

In the case of the subsoil samples the variance within types with respect to their carbon-nitrogen ratio.

In the case of the subsoil samples the variance within types was considerably less than that between types for each of the constituents and also for carbon-nitrogen ratio. Hence it may be concluded that the subsoils of the various types are significantly different in their phosphorus, nitrogen and carbon content and also in their carbon-nitrogen ratio. This may be interpreted as meaning that these soils were endowed originally with different amounts of these constituents, or that there has been infiltration into them from the A and B horizons of certain soils or losses by drainage from others.

In comparing the surface samples against the subsoil samples it is necessary again to reduce the data to a uniform basis and it is convenient to make the computation on the basis of pounds of phosphorus, nitrogen or carbon per 2 million pounds of soil. In the surface samples of Clinton silt loam the mean phos-
phorus, nitrogen and carbon content, respectively, is 1,019, 2,506, and 30,030 pounds per 2 million pounds of soil, whereas in the subsoil the corresponding figures are 986, 847, and 8,473 pounds. A similar situation is shown by the means for the Marshall silt loam where the mean phosphorus, nitrogen and carbon content of the surface soils is 1,329, 4,029 and 63,860 pounds, respectively, while for the subsoils the corresponding values are 1,148, 1,771 and 15,787 pounds per 2 million of soil. It is evident that there is a larger percentage of phosphorus, nitrogen and also of carbon in the surface than in the subsoil samples of the loess soils just as was shown earlier to be the case with the drift soils. Although it is not surprising that the surface soils are richer in nitrogen and carbon it is rather interesting to find that they also are richer in phosphorus.

**RELATION OF SOIL COMPOSITION TO SOIL COLOR**

A rather wide range of color variation is exhibited by the loess soils of Iowa. The lightest colored soil of all those mapped in the state is the Marion silt loam. This soil in the virgin state has a very light gray layer in the lower portion of the A horizon, whereas the upper portion is somewhat darkened by the accumulated organic matter. In cultivated fields, however, where the light gray layer has been turned up in the plowing process the entire soil has an unusually light color. This soil occurs in areas of rather rough topography and under forest conditions. The Clinton silt loam is another comparatively light colored soil that has developed under forest conditions. It is rather variable in color, ranging from a light gray in areas adjacent to the Marion soils to a light or even a dark brown in other areas. Somewhat lighter in color than most of the Clinton soils are the Fayette soils of northeastern Iowa. In other respects these two soils are very similar in the surface layer, both having developed under a forest growth. The Knox soils that occur along the Missouri River bluffs are also rather light colored as compared with the other soils of the state.

The darker colored loess soils have developed under prairie grasses rather than under forest conditions. Among this group may be listed soils of the Marshall, Tama, Muscatine and Grundy series. The Grundy and Muscatine soils are somewhat darker in color than the Marshall and Tama. There is also appreciable variability in the depth of the color in the latter two soils.

In analyzing the data for the phosphorus, nitrogen and carbon content of these soils it seemed desirable to determine whether or not the various light colored soils differed significantly among themselves, whether the dark colored soils differed from each other, and whether there is a significant differ-
TABLE 14. ANALYSIS OF VARIANCE OF THE PHOSPHORUS, NITROGEN AND CARBON CONTENT OF FOUR TYPES OF LIGHT COLORED SOILS AND FOUR TYPES OF DARK COLORED SOILS.

Code: P and N÷100; C÷1,000.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Degrees of freedom</th>
<th>Mean square</th>
<th>Phosphorus</th>
<th>Nitrogen</th>
<th>Carbon</th>
<th>C:N ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light colored soils, Clinton, Marion, Fayette and Knox silt loams</td>
<td></td>
<td></td>
<td>3</td>
<td>52</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between types</td>
<td></td>
<td>15.98*</td>
<td>38.6</td>
<td>211*</td>
<td>14.39*</td>
<td></td>
</tr>
<tr>
<td>Within types</td>
<td></td>
<td>5.23</td>
<td>39.4</td>
<td>65</td>
<td>3.10</td>
<td></td>
</tr>
<tr>
<td>Dark colored soils, Marshall, Tama, Muscatine and Grundy silt loams</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between types</td>
<td></td>
<td>2.12</td>
<td>24.6</td>
<td>250*</td>
<td>8.02*</td>
<td></td>
</tr>
<tr>
<td>Within types</td>
<td></td>
<td>6.79</td>
<td>61.4</td>
<td>81</td>
<td>2.60</td>
<td></td>
</tr>
</tbody>
</table>

*Significant difference.

ence in composition between the light colored soils as a group and the dark colored soils as a group. Hence the data for the Clinton, Marion, Fayette and Knox silt loams were analyzed and the results are shown in table 14. It is found that these soils differ significantly in their phosphorus and carbon contents but not in their nitrogen content. They also show a significant difference in carbon-nitrogen ratio.

Similarly the data for the Marshall, Tama, Muscatine and Grundy silt loams were analyzed and the results are also shown in table 14. These soils do not show a significant difference in phosphorus or nitrogen content but they are different in carbon content and in carbon-nitrogen ratio. These results may be interpreted to mean that the various soils were probably somewhat similarly supplied originally with phosphorus, nitrogen and carbon, but that due to the different conditions under which they have developed, such as topography, rainfall, temperature, etc., they have become distinctly different in chemical

TABLE 15. THE t TEST OF THE MEAN DIFFERENCES BETWEEN THE PHOSPHORUS, NITROGEN AND CARBON CONTENT OF LIGHT AND DARK COLORED LOESS SILT LOAM SOILS.

Dark soils: Marshall, Tama, Muscatine and Grundy silt loams.
Light soils: Clinton, Marion, Fayette and Knox silt loams.

<table>
<thead>
<tr>
<th></th>
<th>Phosphorus</th>
<th>Nitrogen</th>
<th>Carbon</th>
<th>C:N ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean—dark soils</td>
<td>1.294</td>
<td>4.250</td>
<td>49.650</td>
<td>11.78</td>
</tr>
<tr>
<td>Mean—light soils</td>
<td>1.030</td>
<td>2.403</td>
<td>27.940</td>
<td>11.64</td>
</tr>
<tr>
<td>Mean difference</td>
<td>264</td>
<td>1.847</td>
<td>21.710</td>
<td>0.14</td>
</tr>
<tr>
<td>t value</td>
<td>5.47**</td>
<td>14.14**</td>
<td>13.72**</td>
<td>0.43</td>
</tr>
</tbody>
</table>

**Highly significant difference.

$t = \frac{\text{Mean difference}}{\text{standard error of the mean difference}}.$
characteristics, particularly in carbon content, for this is the constituent that is influenced to the greatest extent by the type of vegetation.

The results of testing whether there is a significant difference between the light and dark colored soils as groups are shown in table 15. It may be seen that the dark colored soils are richer in all three constituents and that the difference between the two groups is highly significant in each case. There is no difference, however, in the carbon-nitrogen ratio of the two groups. This substantiates, by chemical analyses on a large scale, the observations by farmers for many years that the darker colored soils are the more fertile.

COMPARISON OF LOESS SILT LOAMS

Inasmuch as most of the loess soils have a silt loam texture, it was not possible to make a study of the influence of texture on composition within this group of soils. In order to show the combined effects of all other profile differential factors on the different soils the various series of the silt loam class have been ranked according to their increasing phosphorus, nitrogen and carbon content and the ranking is shown in table 16.

It is apparent that in general, soils having a high content of one constituent are also high in the other two. One notable exception to this generalization is the Knox soil. It has a relatively high phosphorus content but the lowest content of nitrogen and carbon of all the soils in the group. This condition may be explained by the fact that although this soil was probably as well supplied with these constituents originally as the adjacent and closely related Marshall soils, it has a characteristic topography which has prevented the growth of all but a very sparse vegetation while the topography of the other soils has permitted a dense growth of grass or trees and brush.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Phosphorus</th>
<th>Nitrogen</th>
<th>Carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fayette</td>
<td>Knox</td>
<td>Knox</td>
</tr>
<tr>
<td>2</td>
<td>Marion</td>
<td>Marion</td>
<td>Fayette</td>
</tr>
<tr>
<td>3</td>
<td>Clinton</td>
<td>Fayette</td>
<td>Marion</td>
</tr>
<tr>
<td>4</td>
<td>Putnam</td>
<td>Clinton</td>
<td>Clinton</td>
</tr>
<tr>
<td>5</td>
<td>Edina</td>
<td>Putnam</td>
<td>Putnam</td>
</tr>
<tr>
<td>6</td>
<td>Tama</td>
<td>Edina</td>
<td>Edina</td>
</tr>
<tr>
<td>7</td>
<td>Grundy</td>
<td>Scott</td>
<td>Scott</td>
</tr>
<tr>
<td>8</td>
<td>Knox</td>
<td>Marshall</td>
<td>Marshall</td>
</tr>
<tr>
<td>9</td>
<td>Marcus</td>
<td>Grundy</td>
<td>Tama</td>
</tr>
<tr>
<td>10</td>
<td>Marshall</td>
<td>Tama</td>
<td>Muscatine</td>
</tr>
<tr>
<td>11</td>
<td>Scott</td>
<td>Muscatine</td>
<td>Grundy</td>
</tr>
<tr>
<td>12</td>
<td>Muscatine</td>
<td>Marcus</td>
<td>Marcus</td>
</tr>
</tbody>
</table>
has prevented the accumulation of organic matter, and, of course, of organic carbon and nitrogen in the surface soil. This is an illustration of the influence topography may have on the quantity of nitrogen and carbon a soil may contain.

RESULTS FOR THE TERRACE AND BOTTOMLAND SOILS

The mean phosphorus, nitrogen and carbon content of the various terrace and bottomland soils is shown in table 17. It may be observed that these soils exhibit a wide range of composition. For example the lowest mean nitrogen content is 440 pounds per acre in the case of the Sarpy very fine sand, and the highest mean nitrogen content is 8,720 pounds in the case of the Fargo clay. This range includes all the mineral soils but does not take into consideration the peat and muck soils which have considerably larger mean nitrogen contents than even the Fargo clay as is shown in the table. The mean phosphorus content varies from 457 pounds per acre in the Sarpy sand to 2,745 in the Judson fine sandy loam.

It should also be noted that several of these soils have been sampled in only a few counties or, in some cases, in only one. Obviously the latter soils have not been sampled sufficiently to obtain a reliable indication of their composition. Most of them are restricted to rather small areas, and in many cases they occur to the extent of only a few acres in one or more counties. Although they may be of considerable importance on an individual farm they are not of great importance as compared with the major soil types of the state. In making an analysis of variance of the data representing the terrace and bottomland soils, those soils that have been sampled in less than three counties were omitted from the study. The analysis for the more extensive soils of this group is summarized in table 18. In this analysis 567 individual samples of soil, representing 42 types, were considered. The results are practically the same as those obtained in the analysis of the data from the drift and loess soils.

RELATIONSHIP OF TEXTURE TO COMPOSITION

Inasmuch as there is considerable variability in texture among the terrace and bottomland soils, an excellent opportunity is afforded for comparing the composition of soils of various textural groups. Hence soils of sandy loam, fine sandy loam, loam, silt loam and silty clay loam texture have been considered. The soils belonging to these textural groups are shown in table 19, which also shows the lowest and highest mean phosphorus, nitrogen and carbon content for each textural group.
<table>
<thead>
<tr>
<th>Soil type</th>
<th>Number of samples</th>
<th>Phosphorus</th>
<th>Nitrogen</th>
<th>Carbon</th>
<th>C:N ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benoit loam</td>
<td>1</td>
<td>1,037</td>
<td>5,600</td>
<td>55,568</td>
<td>9.92</td>
</tr>
<tr>
<td>Benoit silt loam</td>
<td>1</td>
<td>1,575</td>
<td>8,160</td>
<td>14,466</td>
<td>1.77</td>
</tr>
<tr>
<td>Bertrand loam</td>
<td>1</td>
<td>848</td>
<td>1,460</td>
<td>16,934</td>
<td>11.50</td>
</tr>
<tr>
<td>Bertrand silt loam</td>
<td>3</td>
<td>821</td>
<td>1,840</td>
<td>17,775</td>
<td>11.28</td>
</tr>
<tr>
<td>Bremer fine sandy loam</td>
<td>1</td>
<td>1,060</td>
<td>1,980</td>
<td>25,120</td>
<td>12.68</td>
</tr>
<tr>
<td>Bremer loam</td>
<td>1</td>
<td>1,482</td>
<td>4,640</td>
<td>55,262</td>
<td>12.04</td>
</tr>
<tr>
<td>Bremer silt loam</td>
<td>1</td>
<td>1,600</td>
<td>5,130</td>
<td>60,090</td>
<td>12.04</td>
</tr>
<tr>
<td>Bremer silty clay loam</td>
<td>1</td>
<td>1,436</td>
<td>5,682</td>
<td>65,910</td>
<td>11.97</td>
</tr>
<tr>
<td>Bremer clay</td>
<td>3</td>
<td>2,480</td>
<td>5,826</td>
<td>69,653</td>
<td>12.01</td>
</tr>
<tr>
<td>Buckner coarse sand</td>
<td>1</td>
<td>880</td>
<td>660</td>
<td>7,840</td>
<td>11.87</td>
</tr>
<tr>
<td>Buckner fine sand</td>
<td>2</td>
<td>2,446</td>
<td>2,412</td>
<td>14,008</td>
<td>6.20</td>
</tr>
<tr>
<td>Buckner loamy sand</td>
<td>1</td>
<td>935</td>
<td>1,336</td>
<td>15,135</td>
<td>11.94</td>
</tr>
<tr>
<td>Buckner loamy fine sand</td>
<td>1</td>
<td>1,723</td>
<td>3,360</td>
<td>43,789</td>
<td>13.03</td>
</tr>
<tr>
<td>Buckner gravelly sandy loam</td>
<td>1</td>
<td>1,190</td>
<td>1,900</td>
<td>18,800</td>
<td>9.89</td>
</tr>
<tr>
<td>Buckner coarse sandy loam</td>
<td>1</td>
<td>1,080</td>
<td>1,860</td>
<td>4,246</td>
<td>2.28</td>
</tr>
<tr>
<td>Buckner sandy loam</td>
<td>6</td>
<td>999</td>
<td>1,722</td>
<td>20,738</td>
<td>12.55</td>
</tr>
<tr>
<td>Buckner fine sandy loam</td>
<td>13</td>
<td>1,692</td>
<td>2,102</td>
<td>20,940</td>
<td>10.54</td>
</tr>
<tr>
<td>Buckner very fine sandy loam</td>
<td>2</td>
<td>508</td>
<td>1,861</td>
<td>18,560</td>
<td>9.26</td>
</tr>
<tr>
<td>Buckner loam</td>
<td>15</td>
<td>1,333</td>
<td>3,400</td>
<td>41,130</td>
<td>12.08</td>
</tr>
<tr>
<td>Buckner loam (colluvial phase)</td>
<td>1</td>
<td>1,020</td>
<td>2,860</td>
<td>31,480</td>
<td>11.00</td>
</tr>
<tr>
<td>Buckner silt loam</td>
<td>8</td>
<td>1,615</td>
<td>4,159</td>
<td>48,937</td>
<td>12.08</td>
</tr>
<tr>
<td>Buckner silt loam (colluvial phase)</td>
<td>2</td>
<td>1,963</td>
<td>4,202</td>
<td>51,284</td>
<td>12.28</td>
</tr>
<tr>
<td>Calhoun silt loam</td>
<td>18</td>
<td>1,366</td>
<td>3,220</td>
<td>38,220</td>
<td>12.15</td>
</tr>
<tr>
<td>Cass sand</td>
<td>2</td>
<td>900</td>
<td>500</td>
<td>11,570</td>
<td>22.08</td>
</tr>
<tr>
<td>Cass sandy loam</td>
<td>11</td>
<td>1,200</td>
<td>2,590</td>
<td>29,540</td>
<td>11.85</td>
</tr>
<tr>
<td>Cass fine sandy loam</td>
<td>1</td>
<td>1,337</td>
<td>1,900</td>
<td>23,370</td>
<td>12.44</td>
</tr>
<tr>
<td>Case very fine sandy loam</td>
<td>2</td>
<td>1,737</td>
<td>2,820</td>
<td>28,283</td>
<td>10.36</td>
</tr>
<tr>
<td>Cass loam</td>
<td>14</td>
<td>1,550</td>
<td>4,692</td>
<td>49,420</td>
<td>10.83</td>
</tr>
<tr>
<td>Cass silt loam</td>
<td>9</td>
<td>1,600</td>
<td>4,422</td>
<td>62,645</td>
<td>16.88</td>
</tr>
<tr>
<td>Cass silt loam (colluvial phase)</td>
<td>2</td>
<td>1,963</td>
<td>4,202</td>
<td>51,284</td>
<td>12.28</td>
</tr>
<tr>
<td>Calhoun silt loam</td>
<td>18</td>
<td>1,366</td>
<td>3,220</td>
<td>38,220</td>
<td>12.15</td>
</tr>
<tr>
<td>Davenport clay loam</td>
<td>1</td>
<td>1,508</td>
<td>4,360</td>
<td>47,611</td>
<td>10.91</td>
</tr>
<tr>
<td>Davenport silt loam</td>
<td>1</td>
<td>1,210</td>
<td>3,640</td>
<td>23,450</td>
<td>6.44</td>
</tr>
<tr>
<td>Davenport silt loam (colluvial phase)</td>
<td>3</td>
<td>1,233</td>
<td>4,700</td>
<td>52,073</td>
<td>10.83</td>
</tr>
<tr>
<td>Fargo loam</td>
<td>2</td>
<td>1,241</td>
<td>6,320</td>
<td>78,309</td>
<td>12.14</td>
</tr>
<tr>
<td>Fargo silt loam</td>
<td>3</td>
<td>2,243</td>
<td>8,052</td>
<td>180,300</td>
<td>14.64</td>
</tr>
<tr>
<td>Fargo silty clay loam</td>
<td>11</td>
<td>1,800</td>
<td>8,418</td>
<td>91,090</td>
<td>11.25</td>
</tr>
<tr>
<td>Fargo clay</td>
<td>11</td>
<td>2,020</td>
<td>8,720</td>
<td>91,373</td>
<td>10.47</td>
</tr>
<tr>
<td>Genesee fine sandy loam</td>
<td>4</td>
<td>1,036</td>
<td>2,098</td>
<td>22,573</td>
<td>11.25</td>
</tr>
<tr>
<td>Genesee very fine sandy loam</td>
<td>4</td>
<td>825</td>
<td>1,650</td>
<td>16,253</td>
<td>10.64</td>
</tr>
<tr>
<td>Genesee silt loam</td>
<td>11</td>
<td>1,254</td>
<td>2,556</td>
<td>28,540</td>
<td>11.21</td>
</tr>
<tr>
<td>Genesee silty clay loam</td>
<td>2</td>
<td>1,272</td>
<td>2,560</td>
<td>26,021</td>
<td>10.07</td>
</tr>
<tr>
<td>Hancock silt loam</td>
<td>2</td>
<td>1,975</td>
<td>3,090</td>
<td>36,052</td>
<td>11.68</td>
</tr>
<tr>
<td>Hancock fine sandy loam</td>
<td>1</td>
<td>1,388</td>
<td>1,840</td>
<td>13,742</td>
<td>7.46</td>
</tr>
<tr>
<td>Hancock very fine sandy loam</td>
<td>2</td>
<td>1,467</td>
<td>2,552</td>
<td>33,462</td>
<td>12.33</td>
</tr>
<tr>
<td>Hancock loam</td>
<td>2</td>
<td>1,225</td>
<td>4,455</td>
<td>45,400</td>
<td>10.24</td>
</tr>
<tr>
<td>Hancock very fine sandy loam (shallow)</td>
<td>1</td>
<td>1,306</td>
<td>1,880</td>
<td>18,326</td>
<td>9.75</td>
</tr>
<tr>
<td>Hancock fine sand (shallow phase)</td>
<td>1</td>
<td>1,711</td>
<td>1,080</td>
<td>13,843</td>
<td>12.81</td>
</tr>
<tr>
<td>Hancock silty clay</td>
<td>3</td>
<td>1,900</td>
<td>4,350</td>
<td>52,428</td>
<td>11.96</td>
</tr>
<tr>
<td>Jackson silt loam</td>
<td>14</td>
<td>1,092</td>
<td>2,771</td>
<td>31,140</td>
<td>11.23</td>
</tr>
<tr>
<td>Judson silt loam</td>
<td>12</td>
<td>1,588</td>
<td>4,130</td>
<td>48,427</td>
<td>11.91</td>
</tr>
<tr>
<td>Judson silt loam (light colored)</td>
<td>1</td>
<td>2,300</td>
<td>3,880</td>
<td>46,340</td>
<td>11.94</td>
</tr>
<tr>
<td>Judson loamy sand</td>
<td>2</td>
<td>962</td>
<td>1,020</td>
<td>9,823</td>
<td>9.72</td>
</tr>
<tr>
<td>Judson fine sandy loam</td>
<td>1</td>
<td>2,745</td>
<td>3,360</td>
<td>58,248</td>
<td>17.33</td>
</tr>
<tr>
<td>Judson loam</td>
<td>3</td>
<td>1,582</td>
<td>3,780</td>
<td>44,314</td>
<td>11.70</td>
</tr>
<tr>
<td>La Crosse sandy loam</td>
<td>1</td>
<td>1,697</td>
<td>1,880</td>
<td>18,898</td>
<td>10.05</td>
</tr>
<tr>
<td>Lamoure loam</td>
<td>6</td>
<td>1,583</td>
<td>4,913</td>
<td>71,834</td>
<td>11.34</td>
</tr>
<tr>
<td>Lamoure silt loam</td>
<td>1</td>
<td>1,924</td>
<td>6,350</td>
<td>87,095</td>
<td>14.35</td>
</tr>
<tr>
<td>Lamoure silt loam (colluvial phase)</td>
<td>1</td>
<td>1,220</td>
<td>7,460</td>
<td>78,100</td>
<td>10.46</td>
</tr>
<tr>
<td>Lamoure silty clay loam</td>
<td>22</td>
<td>1,725</td>
<td>7,550</td>
<td>79,567</td>
<td>10.77</td>
</tr>
<tr>
<td>Lamoure clay loam</td>
<td>1</td>
<td>1,124</td>
<td>3,390</td>
<td>29,126</td>
<td>8.59</td>
</tr>
<tr>
<td>Soil type</td>
<td>Number of samples</td>
<td>Phosphorus</td>
<td>Nitrogen</td>
<td>Carbon</td>
<td>C:N ratio</td>
</tr>
<tr>
<td>---------------------------------</td>
<td>-------------------</td>
<td>------------</td>
<td>----------</td>
<td>--------</td>
<td>-----------</td>
</tr>
<tr>
<td>Lamoure silty clay</td>
<td>2</td>
<td>2.006</td>
<td>4.100</td>
<td>49.512</td>
<td>13.00</td>
</tr>
<tr>
<td>Lamoure clay</td>
<td>2</td>
<td>1.642</td>
<td>2.540</td>
<td>30.981</td>
<td>12.27</td>
</tr>
<tr>
<td>Millside silt loam</td>
<td>1</td>
<td>1.623</td>
<td>4.760</td>
<td>55.806</td>
<td>11.74</td>
</tr>
<tr>
<td>Millside fine sandy loam</td>
<td>1</td>
<td>956</td>
<td>2.360</td>
<td>25.415</td>
<td>10.76</td>
</tr>
<tr>
<td>Millside loam</td>
<td>5</td>
<td>1.464</td>
<td>3.488</td>
<td>47.036</td>
<td>14.43</td>
</tr>
<tr>
<td>O'Neill sand</td>
<td>2</td>
<td>1.372</td>
<td>2.628</td>
<td>27.560</td>
<td>11.33</td>
</tr>
<tr>
<td>O'Neill fine sand</td>
<td>3</td>
<td>909</td>
<td>1.917</td>
<td>10.662</td>
<td>13.72</td>
</tr>
<tr>
<td>O'Neill loamy fine sand</td>
<td>1</td>
<td>740</td>
<td>1.840</td>
<td>21.840</td>
<td>11.86</td>
</tr>
<tr>
<td>O'Neill coarse sandy loam</td>
<td>2</td>
<td>1.262</td>
<td>1.497</td>
<td>19.185</td>
<td>12.65</td>
</tr>
<tr>
<td>O'Neill fine sandy loam</td>
<td>13</td>
<td>1.272</td>
<td>3.414</td>
<td>38.234</td>
<td>11.14</td>
</tr>
<tr>
<td>O'Neill sandy loam</td>
<td>15</td>
<td>1.040</td>
<td>2.346</td>
<td>28.070</td>
<td>12.39</td>
</tr>
<tr>
<td>O'Neill loam (deep phase)</td>
<td>1</td>
<td>1.104</td>
<td>3.650</td>
<td>37.352</td>
<td>10.15</td>
</tr>
<tr>
<td>O'Neill loam (light colored phase)</td>
<td>1</td>
<td>741</td>
<td>1.480</td>
<td>17.884</td>
<td>12.08</td>
</tr>
<tr>
<td>O'Neill loam</td>
<td>30</td>
<td>1.274</td>
<td>3.728</td>
<td>43.191</td>
<td>11.82</td>
</tr>
<tr>
<td>O'Neill silt loam</td>
<td>2</td>
<td>1.126</td>
<td>3.110</td>
<td>36.973</td>
<td>12.03</td>
</tr>
<tr>
<td>O'good very fine sand</td>
<td>1</td>
<td>1.220</td>
<td>1.340</td>
<td>10.670</td>
<td>7.96</td>
</tr>
<tr>
<td>Plainfield sand</td>
<td>1</td>
<td>431</td>
<td>2.60</td>
<td>5.177</td>
<td>9.91</td>
</tr>
<tr>
<td>Plainfield loamy fine sand</td>
<td>1</td>
<td>552</td>
<td>1.072</td>
<td>22.520</td>
<td>21.00</td>
</tr>
<tr>
<td>Plainfield sandy loam</td>
<td>3</td>
<td>828</td>
<td>1.400</td>
<td>16.835</td>
<td>12.15</td>
</tr>
<tr>
<td>Plainfield fine sandy loam</td>
<td>3</td>
<td>609</td>
<td>1.140</td>
<td>14.379</td>
<td>13.25</td>
</tr>
<tr>
<td>Plainfield loam</td>
<td>2</td>
<td>804</td>
<td>1.550</td>
<td>19.447</td>
<td>12.78</td>
</tr>
<tr>
<td>Ray silt loam</td>
<td>2</td>
<td>1.400</td>
<td>1.920</td>
<td>26.483</td>
<td>14.05</td>
</tr>
<tr>
<td>Sarpy sand</td>
<td>1</td>
<td>457</td>
<td>7.630</td>
<td>12.72</td>
<td></td>
</tr>
<tr>
<td>Sarpy fine sand</td>
<td>3</td>
<td>967</td>
<td>1.005</td>
<td>9.221</td>
<td>14.08</td>
</tr>
<tr>
<td>Sarpy very fine sand</td>
<td>1</td>
<td>840</td>
<td>440</td>
<td>10.300</td>
<td>25.75</td>
</tr>
<tr>
<td>Sarpy loamy sand</td>
<td>1</td>
<td>840</td>
<td>1.400</td>
<td>17.920</td>
<td>12.80</td>
</tr>
<tr>
<td>Sarpy sandy loam</td>
<td>1</td>
<td>1.090</td>
<td>1.290</td>
<td>17.915</td>
<td>13.88</td>
</tr>
<tr>
<td>Sarpy fine sandy loam</td>
<td>1</td>
<td>1.217</td>
<td>1.511</td>
<td>20.500</td>
<td>14.46</td>
</tr>
<tr>
<td>Sarpy very fine sandy loam</td>
<td>8</td>
<td>1.250</td>
<td>1.597</td>
<td>15.250</td>
<td>10.14</td>
</tr>
<tr>
<td>Sarpy loam</td>
<td>3</td>
<td>1.917</td>
<td>2.737</td>
<td>32.057</td>
<td>11.64</td>
</tr>
<tr>
<td>Sarpy silt loam</td>
<td>11</td>
<td>1.555</td>
<td>3.079</td>
<td>37.105</td>
<td>12.05</td>
</tr>
<tr>
<td>Sarpy silt loam (deep phase)</td>
<td>1</td>
<td>1.764</td>
<td>1.950</td>
<td>18.813</td>
<td>11.19</td>
</tr>
<tr>
<td>Sarpy silty clay loam</td>
<td>2</td>
<td>1.504</td>
<td>3.025</td>
<td>34.980</td>
<td>11.55</td>
</tr>
<tr>
<td>Sarpy silty clay loam (deep phase)</td>
<td>1</td>
<td>1.684</td>
<td>2.080</td>
<td>20.257</td>
<td>9.73</td>
</tr>
<tr>
<td>Sioux fine sandy loam</td>
<td>2</td>
<td>1.097</td>
<td>3.400</td>
<td>45.459</td>
<td>13.60</td>
</tr>
<tr>
<td>Sioux loam</td>
<td>9</td>
<td>1.301</td>
<td>3.026</td>
<td>47.223</td>
<td>11.76</td>
</tr>
<tr>
<td>Sioux silt loam</td>
<td>1</td>
<td>1.239</td>
<td>4.920</td>
<td>46.059</td>
<td>9.36</td>
</tr>
<tr>
<td>Sarpy fine sand</td>
<td>1</td>
<td>552</td>
<td>5.781</td>
<td>10.70</td>
<td></td>
</tr>
<tr>
<td>Wabash stony silt loam (colluvial)</td>
<td>1</td>
<td>1.347</td>
<td>4.440</td>
<td>53.212</td>
<td>11.98</td>
</tr>
<tr>
<td>Wabash fine sandy loam</td>
<td>8</td>
<td>1.329</td>
<td>2.474</td>
<td>29.875</td>
<td>12.29</td>
</tr>
<tr>
<td>Wabash very fine sandy loam</td>
<td>2</td>
<td>1.535</td>
<td>3.540</td>
<td>40.438</td>
<td>11.25</td>
</tr>
<tr>
<td>Wabash loam</td>
<td>38</td>
<td>1.523</td>
<td>4.808</td>
<td>54.394</td>
<td>11.64</td>
</tr>
<tr>
<td>Wabash silt loam</td>
<td>58</td>
<td>1.562</td>
<td>4.808</td>
<td>58.642</td>
<td>12.57</td>
</tr>
<tr>
<td>Wabash silt loam (colluvial phase)</td>
<td>18</td>
<td>1.422</td>
<td>4.010</td>
<td>48.395</td>
<td>11.99</td>
</tr>
<tr>
<td>Wabash silt loam (gray subsoil phase)</td>
<td>2</td>
<td>1.594</td>
<td>5.080</td>
<td>50.888</td>
<td>10.06</td>
</tr>
<tr>
<td>Wabash silt loam (heavy phase)</td>
<td>1</td>
<td>1.322</td>
<td>8.246</td>
<td>103.320</td>
<td>12.53</td>
</tr>
<tr>
<td>Wabash silty clay loam</td>
<td>44</td>
<td>1.770</td>
<td>5.747</td>
<td>67.880</td>
<td>12.46</td>
</tr>
<tr>
<td>Wabash clay</td>
<td>4</td>
<td>1.655</td>
<td>4.375</td>
<td>53.180</td>
<td>11.84</td>
</tr>
<tr>
<td>Wabash silty clay</td>
<td>7</td>
<td>1.821</td>
<td>4.298</td>
<td>51.758</td>
<td>12.22</td>
</tr>
<tr>
<td>Wabash clay</td>
<td>7</td>
<td>1.774</td>
<td>4.369</td>
<td>52.771</td>
<td>12.05</td>
</tr>
<tr>
<td>Waukesha sandy loam</td>
<td>2</td>
<td>970</td>
<td>2.568</td>
<td>31.827</td>
<td>12.38</td>
</tr>
<tr>
<td>Waukesha fine sandy loam</td>
<td>1</td>
<td>1.256</td>
<td>2.152</td>
<td>25.960</td>
<td>12.01</td>
</tr>
<tr>
<td>Waukesha loam</td>
<td>18</td>
<td>1.343</td>
<td>3.454</td>
<td>41.157</td>
<td>11.89</td>
</tr>
<tr>
<td>Waukesha silt loam</td>
<td>40</td>
<td>1.457</td>
<td>4.359</td>
<td>52.940</td>
<td>12.65</td>
</tr>
<tr>
<td>Meadow</td>
<td>1</td>
<td>1.640</td>
<td>3.600</td>
<td>47.547</td>
<td>13.20</td>
</tr>
<tr>
<td>Peat</td>
<td>3</td>
<td>1.805</td>
<td>37.112</td>
<td>538.803</td>
<td>14.34</td>
</tr>
<tr>
<td>Muck</td>
<td>8</td>
<td>1.844</td>
<td>25.775</td>
<td>342.184</td>
<td>13.21</td>
</tr>
<tr>
<td>Muck &amp; peat</td>
<td>1</td>
<td>2.504</td>
<td>27.100</td>
<td>412.444</td>
<td>15.21</td>
</tr>
<tr>
<td>Weighted average of all soils</td>
<td></td>
<td>1.451</td>
<td>4.134</td>
<td>49.478</td>
<td>12.18</td>
</tr>
</tbody>
</table>
### TABLE 18. ANALYSIS OF VARIANCE OF THE PHOSPHORUS, NITROGEN AND CARBON CONTENT OF THE TERRACE AND BOTTOMLAND SOILS OF IOWA.

Code: P and N +100; C +1,000.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Degrees of freedom</th>
<th>Phosphorus</th>
<th>Nitrogen</th>
<th>Carbon</th>
<th>C:N ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>566</td>
<td>18.4</td>
<td>422</td>
<td>642</td>
</tr>
<tr>
<td></td>
<td>Between soil types</td>
<td>41</td>
<td>74.6**</td>
<td>2,514**</td>
<td>3,923**</td>
</tr>
<tr>
<td></td>
<td>Within soil types</td>
<td>525</td>
<td>14.0</td>
<td>250</td>
<td>386</td>
</tr>
</tbody>
</table>

**Highly significant difference.

**NOTE:** This analysis has been restricted to those soils which have been sampled in three or more counties, and it does not include those terrace and bottomland soils for which only one or two analyses are available.

### TABLE 19. THE HIGH AND LOW MEAN PHOSPHORUS, NITROGEN AND CARBON CONTENT OF TEXTURAL GROUPS OF CERTAIN TERRACE AND BOTTOMLAND SOILS.

<table>
<thead>
<tr>
<th>Textural group</th>
<th>Soil type</th>
<th>No. of samples</th>
<th>Phosphorus</th>
<th>Nitrogen</th>
<th>Carbon</th>
<th>C:N ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Sandy loams</td>
<td>Mean</td>
<td></td>
<td>1,062</td>
<td>2,234</td>
<td>26,285</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Buckner</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cass</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>O’Neill</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Plainfield</td>
<td>3</td>
<td>828</td>
<td>1,400</td>
<td></td>
<td>16,838</td>
</tr>
<tr>
<td>Fine sandy loams</td>
<td>Mean</td>
<td></td>
<td>1,158</td>
<td>2,289</td>
<td>26,192</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Buckner</td>
<td>13</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cass</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Genesee</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>O’Neill</td>
<td>13</td>
<td></td>
<td></td>
<td></td>
<td>3,414</td>
</tr>
<tr>
<td></td>
<td>Plainfield</td>
<td>3</td>
<td>629</td>
<td>1,140</td>
<td></td>
<td>14,379</td>
</tr>
<tr>
<td></td>
<td>Sarpy</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td>1,329</td>
</tr>
<tr>
<td></td>
<td>Wabash</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td>1,329</td>
</tr>
<tr>
<td>Loams</td>
<td>Mean</td>
<td></td>
<td>1,430</td>
<td>4,124</td>
<td>48,251</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bremer</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Buckner</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cass</td>
<td>14</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Judson</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lamoure</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td>4,913</td>
</tr>
<tr>
<td></td>
<td>Millsdale</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>O’Neill</td>
<td>30</td>
<td>1,274</td>
<td>1,917</td>
<td>32,057</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sarpy</td>
<td>3</td>
<td>629</td>
<td>1,140</td>
<td></td>
<td>14,379</td>
</tr>
<tr>
<td></td>
<td>Sioux</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wabash</td>
<td>38</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Waukesha</td>
<td>18</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silt loams</td>
<td>Mean</td>
<td></td>
<td>1,498</td>
<td>4,205</td>
<td>52,384</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bremer</td>
<td>3</td>
<td>521</td>
<td>1,640</td>
<td>17,775</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bremer</td>
<td>33</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Buckner</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Calhoun</td>
<td>13</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cass</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chariton</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fargo</td>
<td>3</td>
<td>2,245</td>
<td>8,052</td>
<td>160,360</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Genesee</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Jackson</td>
<td>14</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Judson</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lamoure</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sarpy</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wabash</td>
<td>58</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Waukesha</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silty clay loams</td>
<td>Mean</td>
<td></td>
<td>1,704</td>
<td>5,876</td>
<td>67,744</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bremer</td>
<td>22</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Case</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Davenport</td>
<td>3</td>
<td>1,233</td>
<td>3,800</td>
<td>44,830</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fargo</td>
<td>11</td>
<td>1,233</td>
<td>3,800</td>
<td>44,830</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lamoure</td>
<td>22</td>
<td></td>
<td>8,418</td>
<td></td>
<td>91,090</td>
</tr>
<tr>
<td></td>
<td>Wabash</td>
<td>44</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
In the first place a study was made to determine whether or not the individual soil types within a textural group differed significantly in their content of phosphorus, nitrogen and carbon. The results of this study are presented in table 20.

In view of the fact that the soils of most of the textural groups differ among themselves in nitrogen and carbon content,
TABLE 22. TERRACE AND BOTTOMLAND LOAM SOILS RANKED IN ORDER OF DECREASING PHOSPHORUS, NITROGEN, AND CARBON CONTENT.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Phosphorus</th>
<th>Nitrogen</th>
<th>Carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>O’Neill</td>
<td>Sarpy</td>
<td>Sarpy</td>
</tr>
<tr>
<td>2</td>
<td>Sioux</td>
<td>Sioux</td>
<td>Buckner</td>
</tr>
<tr>
<td>3</td>
<td>Buckner</td>
<td>Buckner</td>
<td>Waukesha</td>
</tr>
<tr>
<td>4</td>
<td>Waukesha</td>
<td>Waukesha</td>
<td>O’Neill</td>
</tr>
<tr>
<td>5</td>
<td>Millsdale</td>
<td>Millsdale</td>
<td>Judson</td>
</tr>
<tr>
<td>6</td>
<td>Bremer</td>
<td>O’Neill</td>
<td>Millsdale</td>
</tr>
<tr>
<td>7</td>
<td>Wabash</td>
<td>Judson</td>
<td>Sioux</td>
</tr>
<tr>
<td>8</td>
<td>Lamoure</td>
<td>Bremer</td>
<td>Cass</td>
</tr>
<tr>
<td>9</td>
<td>Cass</td>
<td>Cass</td>
<td>Bremer</td>
</tr>
<tr>
<td>10</td>
<td>Judson</td>
<td>Wabash</td>
<td>Wabash</td>
</tr>
<tr>
<td>11</td>
<td>Sarpy</td>
<td>Lamoure</td>
<td>Lamoure</td>
</tr>
</tbody>
</table>

whereas most of them do not differ significantly in their phosphorus content, it is important to determine whether or not the soils of the various textural groups as a whole differ in their content of phosphorus, nitrogen or carbon. The analysis designed to answer this question is shown in table 21. It appears that the variance of the phosphorus, nitrogen and carbon content between the various textural groups is significantly larger than that within groups. Such a difference is not indicated for the carbon-nitrogen ratio, however. The mean phosphorus, nitrogen and carbon content for the various textural groups is shown by the graph in fig. 5.

[Graph: The mean phosphorus, nitrogen and carbon content of various textural groups of terrace and bottomland soils.]
These conclusions agree with those obtained in the analysis of the drift soils on a textural basis. They point out the close relationship of texture to content of phosphorus, nitrogen and carbon in soils. Furthermore, they lend support to the statement made by Russell and McRuer (16) that "texture is the outstanding factor determining nitrogen content in any soil type." In this study a great variety of soils was considered: soils that had widely different inherent characteristics, and soils that had developed widely different profile characteristics as a result of their environment, and yet they showed a marked relationship between texture and composition. It is believed that there would be a rather high degree of correlation between these two factors if it were possible to express the texture of the soils in numerical form. This, however, as was pointed out earlier, is not possible with the data available.

COMPARISON OF SOILS OF UNIFORM TEXTURE

In order to eliminate, insofar as possible, the influence of texture on composition of these soils, and yet obtain a relative idea of their content of phosphorus, nitrogen and carbon, all those soils of the loam class have been ranked in order of their decreasing content of these constituents and the ranking is shown in table 22. A similar ranking for the soils of silt loam texture is shown in table 23. Such a ranking would undoubtedly be of considerable aid in making a fertility rating of these soils.

COMPARISON OF UPLAND AND TERRACE AND BOTTOMLAND SOILS

In order to present a more generalized picture of the phosphorus, nitrogen and carbon content of the soils of the state as

<table>
<thead>
<tr>
<th>Rank</th>
<th>Phosphorus</th>
<th>Nitrogen</th>
<th>Carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bertrand</td>
<td>Bertrand</td>
<td>Bertrand</td>
</tr>
<tr>
<td>2</td>
<td>Jackson</td>
<td>Genesee</td>
<td>Genesee</td>
</tr>
<tr>
<td>3</td>
<td>Genesee</td>
<td>Jackson</td>
<td>Jackson</td>
</tr>
<tr>
<td>4</td>
<td>Chariton</td>
<td>Sarpy</td>
<td>Sarpy</td>
</tr>
<tr>
<td>5</td>
<td>Calhoun</td>
<td>Calhoun</td>
<td>Calhoun</td>
</tr>
<tr>
<td>6</td>
<td>Waukesha</td>
<td>Chariton</td>
<td>Chariton</td>
</tr>
<tr>
<td>7</td>
<td>Sarpy</td>
<td>Judson</td>
<td>Judson</td>
</tr>
<tr>
<td>8</td>
<td>Wabash</td>
<td>Buckner</td>
<td>Buckner</td>
</tr>
<tr>
<td>9</td>
<td>Judson</td>
<td>Waukesha</td>
<td>Waukesha</td>
</tr>
<tr>
<td>10</td>
<td>Cass</td>
<td>Cass</td>
<td>Cass</td>
</tr>
<tr>
<td>11</td>
<td>Bremer</td>
<td>Wabash</td>
<td>Bremer</td>
</tr>
<tr>
<td>12</td>
<td>Buckner</td>
<td>Bremer</td>
<td>Bremer</td>
</tr>
<tr>
<td>13</td>
<td>Lamoure</td>
<td>Lamoure</td>
<td>Lamoure</td>
</tr>
<tr>
<td>14</td>
<td>Fargo</td>
<td>Fargo</td>
<td>Fargo</td>
</tr>
</tbody>
</table>

TABLE 23. TERRACE AND BOTTOMLAND SILT LOAMS RANKED IN ORDER OF INCREASING PHOSPHORUS, NITROGEN, AND CARBON CONTENT.
TABLE 24. THE MEAN PHOSPHORUS, NITROGEN, AND CARBON CONTENT OF THE SOILS OF IOWA.  
(pounds per acre, 0 to 6 2/3 inches)

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Degrees of freedom</th>
<th>Mean square</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Phosphorus</td>
<td>Nitrogen</td>
</tr>
<tr>
<td>Total</td>
<td>1,180</td>
<td>34.3</td>
</tr>
<tr>
<td>Between geological</td>
<td>3</td>
<td>642.2**</td>
</tr>
<tr>
<td>groups</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Within geological</td>
<td>1,177</td>
<td>32.9</td>
</tr>
<tr>
<td>groups</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Highly significant.

TABLE 25. ANALYSIS OF VARIANCE OF THE PHOSPHORUS, NITROGEN AND CARBON CONTENT OF GEOLOGICAL GROUPS OF SOILS IN IOWA.  
Geological groups: Loess, Drift, Terrace, and Bottomland Soils.  
Code: P = N + 100; C = 1,000.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Degrees of freedom</th>
<th>Mean square</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Phosphorus</td>
<td>Nitrogen</td>
</tr>
<tr>
<td>Total</td>
<td>1,180</td>
<td>34.3</td>
</tr>
<tr>
<td>Between geological</td>
<td>3</td>
<td>642.2**</td>
</tr>
<tr>
<td>groups</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Within geological</td>
<td>1,177</td>
<td>32.9</td>
</tr>
<tr>
<td>groups</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Highly significant.

TABLE 26. THE t TEST OF THE MEAN DIFFERENCES BETWEEN THE PHOSPHORUS, NITROGEN, AND CARBON CONTENT OF GEOLOGICAL GROUPS OF SOILS IN IOWA.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Phosphorus</th>
<th>Nitrogen</th>
<th>Carbon</th>
<th>C:N ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loess + Drift</td>
<td>M1 = 1,291</td>
<td>3,508</td>
<td>42,303</td>
<td>12.06</td>
</tr>
<tr>
<td></td>
<td>M2 = 1,436</td>
<td>4,124</td>
<td>49,475</td>
<td>12.18</td>
</tr>
<tr>
<td>t</td>
<td>= 4.78**</td>
<td></td>
<td>4.72**</td>
<td></td>
</tr>
<tr>
<td>Terrace + Bottomland</td>
<td>M1 = 1,215</td>
<td>3,201</td>
<td>37,109</td>
<td>11.75</td>
</tr>
<tr>
<td></td>
<td>M2 = 1,384</td>
<td>3,720</td>
<td>45,742</td>
<td>12.34</td>
</tr>
<tr>
<td>t</td>
<td>= 2.52**</td>
<td></td>
<td>3.96**</td>
<td></td>
</tr>
<tr>
<td>Loess</td>
<td>M1 = 1,384</td>
<td>3,983</td>
<td>47,232</td>
<td>11.98</td>
</tr>
<tr>
<td></td>
<td>M2 = 1,537</td>
<td>4,327</td>
<td>52,345</td>
<td>12.44</td>
</tr>
<tr>
<td>t</td>
<td>= 3.80**</td>
<td></td>
<td>2.28*</td>
<td></td>
</tr>
</tbody>
</table>

*Significant difference.
**Highly significant difference.

a whole the means for the drift, loess, terrace and bottomland soils and for all the soils of the state as a whole are shown in table 24. Certain differences between groups may be observed in this table. The test for the significance of the differences is shown in table 25.

Although the means for the various groups were found to be different, it would be of interest to know which ones differ
from the others. Table 26 shows the results of testing the mean differences. The loess soils as a group contain significantly more phosphorus, and less nitrogen and carbon than the drift soils, but they are not significantly different in carbon-nitrogen ratio. The bottomland soils contain significantly larger amounts of phosphorus, nitrogen and carbon than the terrace soils, but the two groups do not differ in carbon-nitrogen ratio. When the terrace and bottomland soils as a group were compared with the drift and loess soils as a group, it was found that the terrace and bottomland soils contain significantly larger amounts of phosphorus, nitrogen and carbon. There is no significant difference in carbon-nitrogen ratio between the two groups.

**CARBON-NITROGEN RATIO**

Numerous investigations have shown a rather close relationship between the carbon and nitrogen content of soils, and the conclusion has been drawn that the ratio of carbon to nitrogen tends to approach 10:1. The explanation for this has been pointed out by Waksman (21) (22), Stewart (19), Sievers and Holtz (17) and others. The characteristics of the decomposition process have been investigated by Waksman (22) and his associates.

Brown and O'Neal (5) reported the C:N ratio of Carrington loam in Iowa to be about 12 or 13 to 1 in most instances but in some cases it was much wider. The ratio for Tama silt loam was as low as 10 in some cases but most of the samples examined had a ratio near 12 or 13. Stewart (19) found the C:N ratio of brown silt loam soils of Illinois to be 12.1. Alway and McDole (1) found it to be somewhat below 11.6 in cultivated chernozem soils of Nebraska, and later Rost and Alway (15) found the ratio in Minnesota drift forest soils to be 11.6 and in drift prairie soils to be 12.3 and 12.4.

Leighty and Shorey (10) have reported data from 176 samples of soil from 63 locations in 12 states which show that the C:N ratio is quite variable and, with a few exceptions, is widest in surface soil and becomes narrower at lower levels.

Sievers and Holtz (17) found a C:N ratio ranging from 12.5 to 14.0 in virgin Palouse silt loam and 9.4 to 12.0 in similar soils that have been cropped from 35 to 40 years. These investigators point out the fact that the C:N ratio in virgin soils rarely, if ever, reaches the narrowest ratio compatible with active decomposition of organic matter by microorganisms for there is a continuous return of plant residues having a wider ratio and also because soil conditions are rarely optimum for decomposition for any considerable period of time. In cultivated soils, however, where little effort is made to return crop
residues to the soil and where conditions are made favorable for the decomposition of organic matter, this ratio may become rapidly narrower and thus approach the theoretical minimum.

McLean (13) determined the C:N ratio for 50 British soils and 16 foreign soils. The ratio for the British soils varied from 6.5 to 13.5 and the average was $10.2 \pm 0.3$, whereas the ratio for the foreign soils varied from 2.0 to 23.0. It was observed that the ratios of soils, whether high or low in organic matter, from limited areas were approximately constant. It was also found that the ratios of arable soils do not differ appreciably from those of grassland soils, although the percentages of carbon and nitrogen were slightly higher in the latter.

McKibbin (12) found a mean C:N ratio of 21.3 for 25 upland podzols, 22.6 for 11 lowland podzols, 15.9 for 16 brown earths, 14.2 for 17 sandy clays and 15.2 for 17 heavy clays. Within each group there was considerable variability in the ratio between soils.

Hosking (7) found that the C:N ratio of Australian soils varied not only over wide areas, but also in very restricted ones, both in virgin and cultivated country. In the Australian black earths, a major grassland soil, the range for the ratios is very restricted, varying only from 13.5 to 18.3 in the surface soils, the modal frequency occurring at the mean 16.2. The ratio for the podzolized soils was somewhat more variable, the values ranging from 10 to 24.8 with a theoretical maximum frequency of 16.1. The mean ratio for the gray and brown zonal type of soils was 10.3, whereas, in the semi-desert gray soils the range covered by the ratios was from 6.3 to 9.8.

Remezov (14) computed the C:N ratio of 164 Russian soils representing 7 zonal types. As was pointed out by Hosking his figures are remarkably low throughout for all soil types and bear comparison with no other figures. It was also pointed out by Hosking that the wet combustion method used by Remezov did not give complete oxidation of the carbon in all cases, and his data therefore cannot be compared with those obtained by the complete combustion methods. Waksman and Hutchings (23) have also indicated that the discrepancies between their results and those of Remezov may be traced to the fact that the latter investigator subtracted the nitrogen found in the humus in the form of amides and amino acids from the total nitrogen and calculated the differences as protein, whereas other investigators have based their calculations upon the total organic nitrogen.

Waksman and Hutchings (23) found a progressive narrowing of the C:N ratio as one proceeds from the podzols, to chernozems, chestnut soils and to the serozems. The podzols studied were characterized by a rather wide ratio; the chernozems had
a ratio of about 10; and the serozems were characterized by a ratio of about 6. The work of these investigators in connection with the characteristics of the organic matter or humus associated with the C:N ratio for the different zonal soil types, has contributed much to our understanding of the carbon-nitrogen relationships in soils.

Lunt (11) has shown that the C:N ratio is higher for forest soils than for field soils.

Jenny (8) (9) concluded that the C:N ratio of the soil organic matter becomes narrower with increasing temperature. Under low temperature the nitrogen content of the soil approaches the nitrogen content of the vegetation and consequently the C:N ratio of the soil tends to become as wide as that of the undecomposed organic material. On the other hand, it was concluded that the C:N ratio does not vary with the humidity factors in the temperate region. Its average value is about 11.3 for the soils between Colorado and New Jersey along the 11°C isotherm (51 to 53°F.) and is nearly the same both in timber (10.9) and grassland soils (11.6); the same is true in the subtropical region in the states of Texas, Louisiana, and Mississippi where the annual temperature ranges from 64 to 68°F.

In analyzing the carbon and nitrogen data for the various soils of Iowa the carbon-nitrogen ratio was computed in each sample of soil. The means for the various types are shown in tables 1, 11 and 18.

The graph in fig. 6 shows the frequency distribution of the C:N ratios for all of the individual soil samples except for two that were too small for the graph, which were 4.1 and 5.1, respectively, and also for 15 that were too large, ranging from 23 to 62 each with a different ratio.

The frequency classes covered the C:N ratio values varying within 0.5 unit, and they were so arranged that the midpoint of the class would be either a half or a whole number. For ex-
ample one class included all items falling within the range 10.3 to and including 10.7 and the mid-point was 10.5; the next class ranged from 10.8 to 11.2 with the mid-point at 11.0. The mid-points of the frequency classes were used in plotting the graph in fig. 6.

It may be noted that the largest number of samples had a C:N ratio within the frequency class of 11.8 to 12.2 with 12 as the mid-point. The mean C:N ratio, however, was 12.15 or slightly higher than the modal frequency. This may be explained readily by the fact that there was an appreciable number of samples with a rather wide C:N ratio, which caused the mean to be slightly higher than the mode.

It is of interest that only a rather small percentage of the total number of samples had a ratio below 8 or above 15. Those samples having ratios beyond these values are indeed unusual and undoubtedly represent some peculiar soil condition.

In table 4 it was shown that there was a significant difference in C:N ratio in the surface and subsoil samples of the soils of drift origin. Reference to table 1 shows that the mean ratio for all drift soils is 12.34, and that in those cases where the soil type has been more widely sampled the mean ratio more nearly approaches the mean for the entire group. The variation of the ratio for the individual samples within a soil type is not shown in table 1 but this has been considered in the analysis of variance.

An analysis of the ratios for the loess soils, both surface and subsoil, shows that the differences between means is also significant.

The differences between the C:N ratio means of the terrace and the bottomland soils (table 18) are not quite large enough to be significant.

The analyses in table 7 show that the soil types within the coarser textured groups, i.e., sandy loams, fine sandy loams, and loams, differ significantly among themselves in C:N ratio, whereas the types in the finer textured groups, the silt loam, silty clay loam and clay loam soils, did not differ significantly in this respect. The data of table 8 indicate that there is no significant difference in the C:N ratio of the soils of textural groups considered as a whole.

In the case of the terrace and bottomland soils (table 20) the types within textural groups did not differ significantly among themselves in C:N ratio. Neither was there a significant difference between the means of the C:N ratios of the textural groups studied. This may be interpreted to mean that the terrace and bottomland soils as a whole may be expected to approach homogeneity in C:N ratio as nearly as do individual types. Or in other words, individual soil types
may be expected to be as heterogeneous with respect to C:N ratio as the terrace and bottomland soils as a whole. Furthermore it indicates that no definite relationship exists between the C:N ratio of these soils and their texture.

The data of table 14 show that there are significant differences between the C:N ratio means for soils in the light and also in the dark colored groups. In the light colored group the mean ratios are 12.05, 11.17, 9.25 and 12.07, respectively, for the Clinton, Fayette, Knox and Marion silt loams. In the dark colored group the mean ratios are 12.70, 11.22, 11.62 and 11.45 respectively for the Grundy, Marshall, Muscatine and Tama silt loams. Although the differences between these means are not large they are significant. It may be noted that there was appreciably less variability in C:N ratio within soil types in the loess group than in the drift or terrace and bottomland group, hence smaller mean differences are required to indicate real differences between types. When the light colored soils as a group are compared with the dark colored soils (table 15) the somewhat wider range of ratios serves to obscure the differences between groups. The results indicate that the C:N ratio mean of 11.78 for the dark soils is not significantly larger than that of 11.64 for the light soils.

In order to obtain a somewhat broader view of the relation between carbon and nitrogen in these soils, the quantities of nitrogen have been plotted against the quantities of carbon. The data for the drift soils, with a few exceptions, are shown by the scatter diagram in fig. 7. The regression equation for the data in this graph was computed to be

\[ C = 11.11N + 2.177 \]

and the straight line corresponding to this equation has been superimposed upon the scatter diagram. Furthermore the correlation coefficient between carbon and nitrogen was computed to be 0.95, a highly significant value.

The data points excluded from this graph and the accompanying correlation analysis are: First, those representing 11 samples of soils of the Webster, Clyde and Rogers series whose carbon and nitrogen values are so large that it was impracticable to represent them on the graph; second, those representing 6 samples of soil whose carbon-nitrogen ratios were over 30 and therefore obviously in error. By leaving out these 17 data the intercept value in the regression equation, 11.11, which is an average carbon-nitrogen ratio for all the data included in the analysis, is somewhat less than the average for all the drift soils given in table 24. It is probable that the lower carbon-nitrogen ratio, 11.11, more nearly approaches the average condition for the great majority of the drift soils.
A similar scatter diagram was drawn for the loess soils and it is shown in fig. 8. The equation for the line is

$$C = 11.05N + 2,246$$

and the correlation coefficient for the quantities of carbon and nitrogen is 0.93. In this case, as with the drift soils, a few sam-
Fig. 8. Scatter diagram and regression line showing the relationship of carbon to nitrogen in the loess soils of Iowa.

Examples of soil whose carbon-nitrogen ratio was obviously abnormal have been excluded from the analysis, and thus a lower average value was obtained than the one shown in Table 24.

These graphs show a very definite relationship between the carbon and nitrogen content of the loess and drift soils of Iowa. Furthermore this relationship seems to be fairly constant, irrespective of whether the quantities of carbon and nitrogen in the soil are low or high.

The regression line in these diagrams may be of considerable value in interpreting the results of carbon and nitrogen determinations on these types of soil in the future. The straight line serves as sort of a moving average for both carbon and nitrogen content. For example, if a soil is found to be rather low in nitrogen content, it should, under normal conditions, be suffi-
ciently low in carbon content to correspond with the equivalent point on the regression line. Obviously the determined values may not fall on the line in certain cases. Soils that may be represented by dots farther removed from the line immediately become of interest. One may inquire as to the accuracy of the chemical determinations, the validity or representativeness of the sample, or into the unusual characteristics of the soil. If the C:N ratio is appreciably lower than the average the explanation may be sought in the peculiar type of decomposition process resulting perhaps from a special type of bacterium or fungus; to the type of management to which the soil is being subjected; or perhaps this condition may be the result of certain temperature and moisture relationships such as those favoring the development of serozem soils. On the other hand, if the ratio is unusually high the explanation may be sought in the peculiar type of organic matter which may have been added to the soil rather recently, or again to the peculiar type or types of microorganisms responsible for the decomposition process. Other explanations may be offered to explain these unusual conditions, and undoubtedly each individual case will necessarily be treated by itself. The important thing in this connection is that a carbon-nitrogen relation that is far removed from that expressed by the regression line in these graphs may aid greatly in the recognition of unusual soil conditions.

**DISCUSSION**

**FACTORS AFFECTING THE PHOSPHORUS, NITROGEN AND CARBON CONTENT OF IOWA SOILS**

It is apparent that many forces have had a part in determining the phosphorus, nitrogen and carbon content of the soils of Iowa. Undoubtedly the content of the original rock and organic material from which the soils have been formed has had some influence on their present composition. An analysis of the data presented in this bulletin, however, seems to indicate that other factors have had a much greater influence in this connection.

Russell and McRuer (16) pointed out that the nitrogen content of Nebraska soils varies with the rainfall and topography, level types containing more nitrogen than rolling types under the same precipitation, probably because of the difference in the effectiveness of rainfall in such cases. Probably the most outstanding contributions on this subject have been made by Jenny (8) who has ingeniously studied the functional relationships of the nitrogen content of soils
and climatic factors. In the first place, he has shown that in the semi-arid, semi-humid and humid regions of the United States a correlation exists between the mean annual temperature and the average total nitrogen content of upland prairie and timber soils and of terrace and bottomland soils. The nitrogen content of soils was found to decrease exponentially with an increase in temperature. In general, for every 10°C decline in mean annual temperature, the average nitrogen content of the soil was found to increase two to three times. In the second place, Jenny (9) found the average nitrogen content of grassland soils to increase logarithmically with the humidity factors. It was also observed that the nitrogen-humidity factor relationship is a discontinuous one, consisting of two separate curves, one for grassland soils and one for timber soils, thus indicating an interaction between the effects of forest development itself and the humidity factors.

The temperature and humidity factors therefore have had a major role in determining the nitrogen and carbon content of the soils of Iowa. The effects undoubtedly have been direct and also indirect. They have been direct in that the total amount of nitrogen that may have been accumulated in Iowa soils has been definitely limited by the mean annual temperature and the humidity factors, which embrace the mean annual rainfall and the precipitation-evaporation ratio. Fortunately the combined effects of these factors have permitted rather large accumulations of nitrogen and carbon in Iowa soils, and undoubtedly they have played a major role in the development of our highly fertile soils.

On the other hand they have had a marked indirect effect on the nitrogen and carbon content of Iowa soils as a result of their interaction with the topographic, textural and vegetative conditions under which these soils have developed. A study of the data presented in this bulletin will show a rather definite relationship between the nitrogen, and carbon content, and also of the phosphorus content, of these soils and their topographic characteristics. For example, under the discussion of the drift soils it was shown that the difference between the mean composition of the Clarion and Webster silt loams, and between the Carrington and Clyde silt loams, was real and highly significant. This difference is not one of texture, as soils of the same texture have been compared. A knowledge of the important characteristics of these soils leads to the assumption that the primary force responsible for their differentiation is that of topography. Such a comparison may be made for many Iowa soils. The rolling upland soils in general have better under-drainage than the soils of level to flat topography. As a result plant nutrients have been leached from the more rolling lands
of higher topographic position and they have been allowed to accumulate in the lower and more nearly flat lands. Furthermore, the terrace and bottomland soils have received deposits from the richer surface horizon of the upland soils and in this way they have developed a significantly higher phosphorus, nitrogen and carbon content than the upland soils as was shown by the data previously presented. Thus it may be concluded that as an interacting force, along with the temperature and humidity factors, the topography of the land has played an important role in determining the present phosphorus, nitrogen and carbon content of the soils of Iowa.

Similarly the texture of the soils of Iowa has had considerable influence in differentiating them with respect to their content of phosphorus, nitrogen and carbon. This has been definitely shown by the data presented. Under given humidity and temperature factors there has undoubtedly been a larger loss of plant nutrients from the coarser textured soils, and particularly those of rolling to steep topography, than from the finer textured soils. As a result, the soils of finer texture that have developed under otherwise uniform conditions now contain large quantities of phosphorus, nitrogen and carbon.

The vegetative factor also has had considerable influence in differentiating the soils of Iowa. In the discussion of the results of the loess soils it was shown that the light colored soils contain significantly smaller amounts of these constituents than dark colored soils of similar texture. The light colored soils have developed in the main under forest conditions, whereas the dark colored soils have developed under grassland or prairie conditions. Although it is not supposed that the type of vegetation has been the sole differential factor in this case, it has undoubtedly played a major role along with topography and perhaps certain other less important factors. Similarly, other cases might be cited to illustrate the effects of the type of vegetation on the nutrient content of soils.

In general, it may be concluded therefore that the topographic characteristics of the land, the texture or fineness of the soil, and the type of vegetation under which the soil has developed, have all played important secondary roles in determining the phosphorus, nitrogen and carbon content of the soils of Iowa. In fact, owing to the comparatively uniform temperature and humidity factors within the boundaries of the state, and also to the great variability of the soils within the state especially in topography and texture, the temperature and humidity factors may well be removed from consideration and it may be concluded that the topography, texture and type of vegetation have been the predominant factors in the differentia-
tion of soils within the state in content of phosphorus, nitrogen and carbon. The latter conclusion would not be warranted, however, for soils occurring in an area having a wider range of mean annual temperature and humidity factors.

LITERATURE CITED


Genetic Aspects of the Danish System of Progeny-Testing Swine

By Jay L. Lush

AGRICULTURAL EXPERIMENT STATION
IOWA STATE COLLEGE OF AGRICULTURE AND MECHANIC ARTS

R. E. Buchanan, Director

ANIMAL BREEDING SUBSECTION
ANIMAL HUSBANDRY SECTION

AMES, IOWA
CONTENTS

Summary ................................................................. 108
Introduction ............................................................. 109
History of the swine breeding and testing system ............. 112
  Markets for Danish swine ............................................. 112
  Breeds used and breeding policies ................................ 114
  Breeding centers and their supervision ............................ 116
  Progeny testing stations ............................................. 119
  Publication and use of data from the testing stations ........ 120
  Procedure of testing .................................................. 124
  Feeding plan ............................................................ 127

Changes which have occurred in the swine population, 1907 to
1935 ............................................................................ 130
  Number and representativeness of material ....................... 130
  Trends in health .......................................................... 132
  Age and weight at slaughter ......................................... 133
  Trends in daily gain ..................................................... 134
  Trends in economy of gain ............................................ 136
  Changes in body length ................................................ 139
  Changes in thickness of back fat and in thickness of belly . 142
  Changes in dressing percent and in yield of export bacon . 143
  Changes in average classification of bacon sides ............... 145
  Changes in scores for various characteristics .................... 146
  Visible changes in the conformation of the swine ............. 151
  Summary of changes in average characteristics of the swine population ........................................ 156

Resemblances and differences between litter mates ............ 157
Resemblances between paternal half brothers and sisters .... 168
Correlation between maternal half-sib litters ..................... 172
Correlation between full brothers and sisters which were not
litter mates .................................................................... 176
Correlation between progeny test of sire and progeny test
of son ........................................................................... 178

Summary of evidence on heritability ................................. 182
Numerical evidence as to the selection practiced ................ 184
Correlation between six characteristics of the same litter .... 188

General discussion ....................................................... 192
References ..................................................................... 195
SUMMARY

1. The history of the Danish system of progeny testing swine is traced briefly.

2. Changes in the average characteristics of the Danish swine since this system began in 1907 are shown in graphs.

3. The variance of six of these characteristics is analyzed, largely by means of correlations between litter mates, between half-sibs and between progeny tests of sire and of son, to find the extent to which individual variance in each characteristic can be attributed to the additive effects of genes.

4. A little less than half the individual variance in body length, thickness of back fat and thickness of belly can be thus ascribed to additive gene effects. Differences in rate of gain, yield of export bacon and in economy of gain are less highly hereditary, yet there seems to be in them enough additive gene variance to permit selection still to make distinct changes in the population for at least a few more generations. (Summary in table 11.)

5. Although the actual basis of the selections which the Danish farmers practice is not completely demonstrated, the figures from these progeny tests must have played a considerable part.

6. The Danish plan of progeny testing has been developed in such close connection with the economic peculiarities of Danish cooperative organizations that its operating principles might need much revision before it could be used in other countries. The biological principles involved, however, are the same everywhere and any people wishing seriously to improve the real economic productivity of their livestock, especially in characteristics which cannot be seen or measured until the animals are slaughtered, will find useful suggestions in this Danish model.
Denmark has an international reputation for the practical emphasis in its animal breeding customs. Not only is it the land which originated the cow testing association and which ever since has had the highest percentage of its cow population under such tests, but it is also the land which devised the first successful plan for getting a reasonably complete measure of the practical usefulness of the offspring from individual breeding swine. This system of progeny-testing swine, which was devised in Denmark about the beginning of this century, has spread (with some modifications) to several other countries of northern and central Europe since 1920. It has also been introduced into Great Britain and the United States on an experimental scale.

The present system of swine testing in Denmark began in 1907 (although this system itself was planned from experience previously gained in some 10 years of scattered and preliminary testing and experimenting with methods) and since then has operated continuously, except for 3 years during the war when shortage of feed forced the suspension of all testing. There have been only slight modifications in procedure or in methods of reporting. The data published in the annual reports from these testing stations constitute what is probably the most nearly complete and objective account anywhere in the world of what has happened to a breed or species of farm animals when man has sought for many animal generations to change it so that it would suit his ideals better. For that reason these data contain much of interest to students of general genetics, as well as to people interested primarily in the breeding of swine.

These Danish swine progeny-testing stations were not planned as scientific experiment stations intended to discover general principles. Instead they were intended to assist the breeders in finding the boars and sows which produced the most valuable offspring, not in one respect alone but in all characteristics which the breeder or his customers might

---

1Projects Nos. 492 and 361 of the Iowa Agricultural Experiment Station.
2Largely on the initiative of Dean H. H. Kildee of the Iowa State College and Prof. E. F. Ferrin of the University of Minnesota.
consider important. The data therefore lack the control lots and the simplicity which would characterize a scientific laboratory experiment intended to test some genetic principle concerning the effectiveness of selection. However, because of the multiplicity of the characteristics measured, many of which were correlated with each other, and because of the changing emphasis upon this or that characteristic in the selections, this case probably corresponds more closely than do most laboratory experiments to the evolutionary changes which go on in nature, where fitness to survive depends upon a complex of many characteristics, some independent and some closely interrelated, varying among each other in their importance at any one time, and each characteristic varying in importance from time to time and from situation to situation. This very complexity of the present case and its similarity to problems of evolution give it a scientific interest which is not entirely cancelled by the slight changes in procedure, nor by the marked changes in the emphasis placed on different points in selection, nor by the absence of control lots which often makes it impossible to be certain whether a given sequence of procedure and subsequent event was a cause and effect relationship or only a coincidence.

Another unusual feature of these data, interesting from the genetic point of view, is that they consist entirely of progeny tests. The sows and boars which were to be used for breeding purposes could not themselves be fattened and killed. Hence data on their own ability to produce desirable meat economically could not be obtained. Their ability in that respect could be estimated only from the performance of their own offspring or from the performance of collateral relatives, themselves without offspring. This is shown graphically in fig. 1.

Doubtless the selections which the breeders actually made were also based partly on the external appearance of the breeding animals themselves. Some of the men in close touch with swine breeding assert that breeders generally paid little attention to the testing station figures until the last decade and that pre-war selections were based mostly on external appearance and on the sow's ability to farrow and wean large litters. (Cf. Jespersen, 1935, page 2.) In the case of some characteristics (for example, length of body) external appearance of the parent probably is correlated closely enough with the trait actually measured in the offspring that such selections would have considerable effect. However, some characteristics (for example, thickness of belly flesh or economy of gain) are doubtless so poorly cor-
related with external appearance that selection based on the external appearance of the breeding animals themselves would have little or no effect in changing these traits in the population.

Thus, while the data available for study consist entirely
of the performance of progeny or of collateral relatives, yet the selections actually practiced were based in part on unrecorded differences in the individual appearance of the breeding animals themselves. This doubtless affected some characteristics more than it did others.

A fellowship from the Division of Biology and Agriculture of the National Research Council made it possible for the writer to spend the last half of 1934 in Denmark studying the genetic aspects of this testing system and these records at first hand. A part of the computations could not be made in the time available in Denmark, but the necessary data were brought home and the computations finished as a part of the regular work of the Animal Breeding Subsection of the Iowa Agricultural Experiment Station. The present bulletin contains the findings which seem of most interest.

HISTORY OF THE SWINE BREEDING AND TESTING SYSTEM

An account of present Danish swine testing and breeding practices would scarcely be understandable without some reference to the history of swine production and swine markets in Denmark during the last three-quarters of a century. The official breeding and testing plans have always been operated with close attention to contemporary economic needs of the swine producers.

MARKETS FOR DANISH SWINE

From the middle of the last century until near 1895 swine-growing was an important industry in Denmark but the surplus swine not needed for Danish consumption were mostly exported alive to Germany. The first bacon factory planned especially to prepare bacon for direct export to the English market was built in 1879. The German market demanded a large and fat pig, the preferred weights being around 275 to 330 pounds. Germany prohibited the importation of living swine from Denmark for a short time in 1887 and finally made this prohibition permanent in 1895. During the 16 years from 1879 to 1895 there was a steady growth in the business of exporting bacon to England. Since 1895 the

It is a pleasure to express thanks for the counsel received from Dr. O. Winge of the Carlsberg Laboratory, especially in regard to the genetic aspects of the study, and the information and friendly help received from Prof. Johs. Jespersen and many other members of the experiment station of the Royal Veterinary and Agricultural College at Copenhagen. I wish especially to mention help received from Dr. Knud Rottensten, Mr. M. P. Østerlund Madsen and Dr. Hjalmar Clausen.

These historical comments are based largely on information in the book: “Svineavl og Svinehold” (Swine breeding and management) by Prof. Johs. Jespersen.
English market has been by far the most important outlet for Denmark’s surplus swine. Since then the Danish swine producers have constantly tried to produce the kind and quality of bacon which was most desired in the English market.

“Bacon” as used in the British and Danish markets is not as restricted a term as in America but, unless otherwise qualified, means the whole side of the pig with the head and feet off and the shoulder blade, backbone and most of the pelvic bone removed. About 17 percent of the cold dressed weight of the carcass is thus removed in the trimming and preparation for export. That which is exported is usually called bacon in England and “Eksportflæsk” in Denmark, but the word “bacon” is often heard in Denmark, too. The terms “bacon” or “bacon sides” will be used in this report but mean what is usually called a “Wiltshire side” in the technical language of the meat trade in the United States and Canada.

The first cooperative bacon factory was built in 1887 and 8 years later, when the swine industry turned its full attention to the English market, there were already 17 cooperative bacon factories. Between 80 and 90 percent of the swine killed for export now are killed in these cooperative factories. The extensiveness of this cooperation has helped make it possible for the bacon factories to unite in policies of paying for each individual pig a higher or lower price according to whether it conforms well or poorly to the demands of the market. By thus paying each farmer for his accomplishments in improving his own swine, these policies have been a powerful force in raising the average merit of Danish bacon and its reputation in the export markets where, especially during the last 10 years, it has met increasing competition from other lands. Probably these policies could not have been achieved so readily without the cooperative system since they cost each local factory some immediate money for which the increased returns were not at once apparent. Moreover the financial advantage to be had from enhancing the reputation of Danish bacon in the export markets could not be achieved very fully unless a large part of the Danish factories participated in the efforts and used similar standards of grading, curing and packaging. The Danish cooperative bacon factories have paid a large part of the cost of the swine testing system ever since its inception and have also helped pay the costs of other efforts for swine improvement.

According to Professor Jespersen, in 1931 over 99 percent of the bacon exported from Denmark was going to England, and England was getting 60 percent of its bacon imports from Denmark.
The primary purpose of the swine enterprise on most Danish farms is to utilize the skimmilk and other by-products of the dairy enterprise and a part of the crop of small grains. The principal grain fed to swine is barley, but considerable use is made of low grade wheat, corn, oats, rye and mill by-products. The small grains are mostly home-grown, but the corn and some of the mill by-products are imported. There is little use of pastures for swine.

**BREEDS USED AND BREEDING POLICIES**

Breeding stock was imported, especially from England but also from more distant lands, at least a century ago. The extensiveness of the importations may be inferred from the census of 1861 in which there were reported 1,924 boars of which 889 were of English origin and 1,035 were of the Danish Landrace. As long as the German market was the most important goal, the most widely used English breeds were the Berkshire and the Middle White, but a number of Large Whites (or Yorkshires, as they are more commonly known in Denmark and America) had been introduced into Denmark at least as long ago as 1880.

With the change to the bacon market there came more interest in the Yorkshire which was regarded as the outstanding breed in the closeness with which its bacon approached the ideal of the English market. At the same time the native Landrace was generally regarded as more hardy and prolific and better suited to the conditions and treatment usually provided on Danish farms. Many of the bacon factories took an active part in the importation of Yorkshire boars which were stationed out on favorable terms with farmers in the regions surrounding those factories.

Thus when the time came in 1895 for a unified striving to meet the demands of the bacon market, there was considerable practical experience already available for guidance, and the farmers were accustomed to having the bacon factories counsel with them and even lead them in such matters. In so far as the bacon factories were cooperative, support and leadership of swine-breeding policies by them was self-leadership of the farmers but guided by those of their employees whose duties naturally brought them in closest contact with actual market demands. In the years around 1895 to 1896 the merits of breeds and types, the question of market demands and proposed ways of breeding swine to meet those demands all received lively discussion at various meetings of farmers’ societies. It was a common opinion then
that the native swine breeding stock had generally been harmed by too much indiscriminate crossbreeding. The native swine race, which up to that time had been unorganized and without means of preserving pedigrees, was believed to be in imminent danger of completely disappearing under the flood of planless crossbreeding unless special measures for its preservation were at once undertaken. At the same time it was frankly recognized that bacon from the native swine did not meet the ideals of the English market nearly as well as that from the Yorkshires did. Perhaps there was also some belief in the intrinsic benefits of crossbreeding in the production of market animals. At any rate the policy officially adopted at that time was to concentrate on the production of two pure breeds of swine, the Yorkshire and the Danish Landrace, with as much crossbreeding as possible for the production of market pigs, by using Yorkshire boars on Landrace sows.

In organizing the pure breeding of the Landrace an effort was made to select the foundation stock from farms and in regions where there had been the least frequent use of boars from foreign breeds and those animals were selected which in outward details most resembled the Danish swine which the older farmers remembered from their youth. This whole movement toward the establishment of a pure Landrace may be considered as part of a reaction against too much uncontrolled and unsystematic crossbreeding. No one knows how much blood of the English races introduced long before 1895 went into the foundation stock for the Landrace. Probably there was at least a little Berkshire and Middle White blood and perhaps some Yorkshire in spite of the strenuous efforts to seek foundation animals most like the Danish swine of the time before the extensive importations began.

Many of the interested breeders, even in 1895 and 1896, regarded the Yorkshires and the crossbreeding as only a temporary measure for the immediate adaptation of the bacon to the English market and hoped that they could improve the bacon qualities of the Landrace until it by itself would suit both the purposes of the farmers and of the market well enough that there would be no more need for the Yorkshire and for the crossbreeding. The undisputed improvement in the bacon qualities of the Landrace is today (1935) causing many to ask whether the other breed and the crossbreeding are really advisable now. On the other hand, the better understanding of the principles of crossbreeding which has been gained by progress in the science of
genetics, together with the practical experiences of breeders of cross-fertilized plants like sugar beets and corn, are causing others to believe that there should be even more cross-breeding than hitherto but on a more systematic plan. Whatever may be the truth about that, not far from one-seventh of the recognized swine breeding centers are Yorkshire centers. This proportion has not varied much for many years.

**BREEDING CENTERS AND THEIR SUPERVISION**

The groundwork of the present system of state-recognized swine breeding centers (of which there are now about 250) was laid soon after 1896, largely under the leadership of Statskonsulent Peter Aug. Mørkeberg. These centers are privately owned and operated but are under a certain amount of supervision by a district committee (Avlscenterudvalg) representing the farmers’ organizations and the cooperative bacon factories in each of the nine districts of Denmark. This committee visits each breeding center at least twice a year, scores the sows and boars intended for breeding, inspects the identifying marks of the individual animals, sees that pedigree records and sales records are carefully kept, advises the owner about his breeding policy and about any general faults in his herd, quarantines the center against any further sales of breeding stock (until the case can be investigated in detail by a veterinarian) whenever they suspect the presence of contagious disease, and sees that the center is managed in an orderly and sanitary way “so that everyone who sees it will be impressed that here is a real breeding place where accidental circumstances do not govern but where the work is carried on according to a definite plan.” Each breeding center is also given a veterinary inspection each September and February and a tuberculin test in April of all animals over 3 months old. The owner must discard from the herd all animals found unworthy either by the scoring committee or in the veterinary examination. Each center is obligated to send to the progeny-testing stations each year enough test litters (of four pigs each) to average two pigs per scored sow in the herd. Some leniency is shown in enforcing this rule where the center-owner has a reasonable excuse for non-compliance in any one year. The scoring committee can specify certain sows from which test litters must be sent at the earliest possible opportunity.

---

9Page 12, Regler og vejledning vedrørende svineavlens ledelse. (Rules and guidance for the leadership of swine breeding.) 1934. Andelsslagerierernes Fueleskontor, Axelborg, Copenhagen.
Thus it will be seen that the committee has ample powers for as thorough supervision as it wishes. The details concerning the appointment and organization of these committees vary from time to time. The government extends them such legal authority as they need and pays a small sum (about 20 dollars per year in 1933-34) to each owner whose farm receives the designation of state approved swine breeding center. Denmark is divided into nine districts for the administration of this work. Until 1934 there were several committees in each district, often with interlocking membership, so that many farmers and breeders participated in the supervisory activities of these committees. In 1934 the plan was simplified to have one committee for each district, one member of that committee being appointed by the cooperative bacon factories, another by the Husmands’ (small holders) union, and the third by the cooperative union of farmers with medium-sized holdings (Landboforening). The rules for these committees and the policies governing all public activities for swine improvement are formulated by a central committee for the guidance of swine breeding (“Landsudvalget for Svineavlens Ledelse”) and approved by the minister of agriculture. There is no organization of the breeders which would correspond to the Breed Registry Societies in the United States. Registration and other activities intended to improve the breeding stock are sponsored by the cooperative bacon factories or by the Landboforening.

Each year the central organization of the cooperative bacon factories issues a report in which the following items are published for each state-recognized breeding center besides the name and address of the owner and of the breeding center committee which inspects that center:

1. Score in the summer at the beginning of the inspection year separately for:
   (a) Management and general appearance of the farm (Maximum is 50 points; some centers scored as low as 16 in 1933-34.)
   (b) Breeding animals’ conformation (Maximum is 36 points. One center scored as low as 9 in 1933-34.)
   (c) Breeding animals’ fertility (Maximum is 24 points. Some centers scored as low as 13 in 1933-34.)
   (d) Efficiency in the use of feed by the test pigs from this center (Maximum is 16 points. Some centers scored as low as 8 in 1933-34.)
   (e) Slaughter quality of the test pigs from this center (Maximum is 24 points. Some centers scored as low as 12 in 1933-34.)
2. Date when breeding herd was established  
   (Six of the 255 centers inspected in 1933-34 were established before 1900.)

3. Number of boars and of sows approved by the breeding center committee  
   (In 1933-34 there were 351 boars and 1,652 sows of the Landrace and 52 boars and 295 sows of the Yorkshire breed.)

4. Number and sex of young animals not yet formally inspected (kaarede)  
   (In 1933-34 there were 3,751 over 3 months old and 6,906 under 3 months among the Landrace.)

5. Number of pigs born and weaned in the preceding year and the corresponding percentage as an indication of vitality (Levedygtighed)  
   (In 1933-34 in the Landrace 35,866 pigs were born and 77.7 percent of these were weaned. The corresponding weaning percentage in the Yorkshire was 77.3 percent.)

6. Number of litters farrowed and hence the average number born per litter and weaned per litter  
   (In 1933-34 the average number per litter was 11.5 farrowed and 8.9 weaned in the Landrace and 11.6 farrowed and 9.0 weaned in the Yorkshire.)

7. Number of boars and of sows sold for breeding purposes  
   (In 1933-34 the total numbers sold for breeding purposes were 4,130 boars and 5,517 sows of the Landrace; 511 boars and 544 sows of the Yorkshire.)

This published list serves as a breeders' directory and, so far as concerns the items listed above, can serve as a basis for comparing the breeding centers with each other. It is of course probable that most purchasers make personal inspections and also consider other things besides those in this list when deciding where they will buy their breeding stock.

It was originally advocated that the centers should produce all the breeding stock and that farmers who did not have breeding centers should procure both their boars and their sows from the centers and should practice cross-breeding for the production of the pigs which went to the bacon factories. However, nothing so extreme was ever put into practice. Most farmers continue to raise their own sows for breeding, although they usually procure their boars from a recognized breeding center. The practice of cross-breeding never became as common as was originally intended. Professor Jespersen on the basis of the census figures for each breed and from his own acquaintance with the industry thinks it "unlikely that more than one-fifth or one-sixth, possibly less, of the sows which are used for the production of slaughter pigs have been bred to Yorkshire boars."

A national herdbook for recording the ancestry and characteristics of the Landrace swine did not appear until 1906.
Only a few of the lines in those foundation pedigrees can be traced farther back than 1895. Until very recently it was not absolutely necessary that both parents be registered or eligible to registry before the animal itself was eligible. That is, the herdbook permitted some registration of animals which would be called "grades" in America, if they were outstanding in individual merit or performance. Only scored (or selected — "kaarede," in Danish) animals from recognized breeding center herds, were eligible to registration and the breeding records of those centers were under the supervision of the local committee. Moreover boars were not eligible to registry until after some of their progeny had been scored and approved as suitable breeding animals for a breeding center herd. Also a boar must have had progeny tested at one of the progeny testing stations. A sow must have farrowed at least two litters of pigs and the average size of litters must have been at least 10 pigs at birth and at least 8 pigs at weaning time. The sow must also have had progeny tested at one of the testing stations. The rules for registry have been revised recently (1934) so that purity of breeding (i.e. registration or eligibility to registration of all ancestors in the last three generations) is necessary. Purity of breeding, however, is not enough by itself for registration and both sows and boars must still come up to various standards of individual performance by themselves or by their progeny.

The natural result of these rules is that animals are not entered in the herdbooks until they are mature. At any one moment the number of living registered animals is only a fraction of the total number of scored and approved animals alive and in use at the breeding centers. The local committee's supervision of each breeding center's records and markings makes it possible to regard the national herdbook mainly as a means of facilitating the interchange of breeding stock and information about breeding stock between regions which are too far apart for the breeders to know each other's stock and pedigrees. For purely local purposes, the breeding center records are regarded as sufficient.

PROGENY TESTING STATIONS

After the system of breeding centers had been set in operation with the necessary local committees and scoring of the outward appearance of the swine and of their progeny, it was felt that something more than judging external appearance was necessary if the breed was to be improved rapidly in its ability to produce a high class of bacon efficiently.
Some kind of an actual slaughter test was thought necessary for any very accurate judgment of the kind of meat an animal would produce, but this of course could not be done with animals which were themselves to be used for breeding.

In the period from about 1895 to 1907 a number of progeny tests of various kinds were conducted in a more or less unofficial way on various large estates to find some way of judging breeding swine by the performance of their offspring in the feeding pen and at the bacon factory. By 1907 enough practical experience had been gained in such tests that it was decided to start a system of official progeny testing stations, financed largely by the cooperative bacon factories and partly under their supervision but also supervised by the state agricultural experiment station.

The first such official progeny testing station was opened at Elsesminde near Odense on Funen in 1907. Within a year another station was opened on Zealand and one in Jutland. Late in 1917 all official testing had to be suspended because of war-caused shortages of feed and animals. Work was resumed on nearly the original plan during 1920 and 1921 but did not function smoothly until late in 1921. In 1926 two more stations, one on Zealand and one in Jutland, were established to take care of the increasing number of pigs offered for testing. These five are still (1935) functioning under a plan which has been changed but little since its inception in 1907.

Besides the five official stations, there are about 15 “local” stations which operate with almost the same methods but are not officially recognized for testing swine from the recognized breeding centers, although data from them may be valid for entering animals in the national herdbook and in awarding prizes for pedigree at the swine shows. The first of these local stations was opened in 1915 and the second in 1920. Most of the financial support for them comes from the local bacon factories. Some of the farmers who send litters to the local stations hope some time to establish approved breeding centers of their own, but many are without such intention and believe the information from these tests is worth getting for use in culling their breeding sows and in selecting boars to correct the more serious general defects of their herds.

**PUBLICATION AND USE OF DATA FROM THE TESTING STATIONS**

As soon as the last pig of a litter has been slaughtered, the results are reported by letter to the center owner and to the
animal husbandry konsulent in the district where that center is located. A printed list showing the results for all litters which finished the test in the preceding 3 months is sent quarterly to all owners of breeding centers and to all animal husbandry konsulents and all other agricultural officials who might be interested. Soon after the end of the testing year (August 31), all information about litters which have completed the test during that year is assembled in a single report which also includes a description of the testing system, various tables showing trends noted during the years, new procedures adopted, any changes in emphasis on certain points, tables showing which centers have averaged highest in various respects, comparisons between gilts and barrows, etc. These annual reports are published in the regular series of reports from the research laboratory of the Royal Veterinary and Agricultural College in Copenhagen. In the early reports the man in charge of each particular testing station wrote the report for his station independently of the reports from the other stations, although the reports for a single year were all printed together. Since 1925 the preparation of this annual report as well as the immediate supervision of the whole testing system has been the duty of one man. These annual reports, together with some unpublished figures for individual pigs, were the material used in this study.

No satisfactory way was found for determining objectively how much the breeders and farmers use these figures. The active interest shown in them by many people, the eagerness with which they are awaited, the publicity given at swine shows and the operation of so many "local" stations, all make it probable that these figures are given much weight in selecting breeding stock, both by general farmers and by the owners of the breeding centers. Naturally the figures for as many as three or four litters all sired by one boar, cannot often be available before that boar is 18 to 20 months old, and he will have been used rather extensively by that time. Hence it seems a reasonable conjecture that these figures are used most in determining whether or not the untested sons of a tested boar shall themselves be used and tested. That is, they may be very influential in deciding which boars shall become the paternal grandsires of a large portion of the breed, but other reasons will largely decide which particular sons of those paternal grandsires are the actual sires of the breed, since most pigs, purebred as well as market, are sired by boars too young to have been tested.

As long ago as 1923 there was a demand from the cooperative bacon factories that this already voluminous material be
summarized in some convenient form, perhaps by families, so that the breeder or farmer who wished to compare one animal or pedigree with others might do so without an enormous amount of study and assembling of figures. This led to a separate series of studies financed by the cooperative bacon factories on the progeny of boars of the Danish Landrace. A preliminary report on this was published in the consolidated volume (volumes 1 to 15) of the herdbook for boars of the Danish Landrace in 1929. Beginning in 1931 there has been published each year a report ("Beretning om Afkomsundersøgelser over Orner af Dansk Landrace" af Johs. Jespersen og M. P. Østerlund Madsen udgivet af de samvirkende Danske Andelssvineslagterier) about the progeny of various boars. With these studies has come an organized effort to keep in the Research Laboratory office complete and up-to-date lists of the performance of all tested progeny of all individual boars and sows and to publish such information in a usable form.

Figures 2 and 3 taken from the third of these reports about the progeny tests of boars show the best way yet found to present the most important data graphically. Each little square represents the slaughter characteristic of one barrow or gilt sired by the boar concerned. The heavy perpendicular line is drawn at about the average performance of all pigs tested and the scale for each of the six characteristics shown is arranged with the more desirable values on the right, so that one can see at a glance whether the majority of the offspring lie to the right (are better than average) or to the left (are poorer than average) for each trait and whether they are closely bunched together (i.e. are uniform) or are strung far apart showing much variability, and can see this progeny test separately, for each of the six characteristics. It is rare that a boar's progeny are far above average in all six traits.

The characteristics shown are: Body length (Laengde), thickness of back fat (Ryg), thickness of belly (Bug), score for firmness of flesh (Fasthed), score for distribution of fat along the back (Fordeling) and score for proportion of lean meat (Kødfylde). Accompanying each chart in the report is some discussion of circumstances which may help in interpreting these charts correctly, such as whether the dams of these progeny were of varied breeding or closely related and by a boar which had sired offspring distinctly above or below average. Figure 2 shows the case for the boar, "Mester Sejrups" whose progeny are distinctly above average in length, a little above in thickness of back fat, a little below in belly and in firmness and in meatiness and about average
Fig. 2. Graphic presentation of the progeny test of "Mester Sejrup" for six important characteristics.
in distribution of fat. Not many boars get such an extensive progeny test — 58 offspring fattened and slaughtered.

Figure 3 shows the progeny test of the boar, "Stendys Elkenøre" who is about average or a little below on all characteristics but shows an exceptionally wide range in the thickness of back fat. Forty of his progeny are shown.

PROCEDURE OF TESTING

From the litter to be tested, four pigs are sent to the testing station when about 7 or 8 weeks old and are fed there under standard procedure until each reaches a live weight of about 90 kilograms (200 pounds), when it is slaughtered at a nearby bacon factory and the meat is weighed, measured and scored. When the testing plan first started, some attempt was made to have the local committee select the litters and pigs which were to be tested. That was later modified to give the center-owner freedom of choice in this. Now the breeding center committee makes a list of sows which are to be tested. When the testing stations are full, only litters from those lists are accepted. When there is plenty of room at the stations, other litters not on this list may be accepted from center-owners. The four pigs from each litter should, so far as possible, consist of two males and two females. Over most of the period, only about half of the litters received at the testing stations have conformed exactly to this rule. From some of these one pig had to be discarded because of unthriftiness. The result was that only about one-third to two-fifths of the litters which finished the test in the past consisted of exactly two gilts and two barrows.

Naturally, in spite of all precautions, a few pigs die during the test period and others become so sick or seriously unthrifty that it seems unfair to include them as evidence about the breeding worth of their parents. The rule on this point has been to discard from the experiment any pig which for three consecutive weighings, i.e. in a continuous period of 4 weeks, makes no gain at all. Those in charge are permitted some discretion in administering this rule. If only one pig of a litter dies or is discarded because it is unthrifty, the litter is continued and the results are figured as the average of the other three, but if two or more from the same litter die or are unthrifty, the litter is discarded entirely.

Formerly the pigs were started on the experimental feeding period soon after their arrival at the testing station, the intention being to have them all started near the age of 8 weeks. In actual practice, however, the average age was
Fig. 3. The progeny test of "Stendys Eikenre" as it was in 1934.
nearly always higher than this, and the centers varied in the age at which their pigs were sent. Beginning Jan. 1, 1929, this policy was changed so that the pigs are now started on the experimental feed when the litter reaches an average weight of 20 kilograms. The assistant in charge at each station has authority to send back to the center-owner any lot of pigs which he thinks is not worth putting on test when they arrive, but this right is not often exercised except in case of pigs which are both under-sized and sickly or where the male pigs have been castrated very recently and appear not to be recovering properly. At present the average weight of the lot must be less than 20, but no pig may weigh less than 13 kilograms upon arrival.

The pigs are weighed individually every 14 days until they near the slaughter weight when they are weighed every 7 days. The standard weight for slaughter is 90 kilograms. Practical expediency dictates that slaughtering shall not be oftener than once a week at each station. Hence it sometimes happens that a pig is slaughtered weighing as little as 87 or as much as 96 kilograms. Also there have occasionally been unavoidable circumstances (such as strikes at the bacon factories in 1920 and 1921) which prevented slaughtering at the proper date. Figure 4 shows that the variations in the average weight at slaughter have not been large. Because slaughter is on the basis of the weight of the individual pig and not on the basis of the average weight of the litter, the ages of litter mates at slaughter may sometimes be as much as 7 or 8 weeks apart.

![Figure 4. Average weight and age of Landrace pigs at slaughter. These averages are based on all the Landrace pigs in table 1.](image)
The housing of the pigs and the construction of the barns are described in considerable detail in some of the annual reports. The pigs are kept indoors at all times, with considerable attention to the ventilation of the stalls which have concrete floors. Each stall has a slightly raised portion with straw bedding for sleeping quarters, a back portion which is also a runway for cleaning purposes, and a front portion with the feed trough where it can be reached from the central aisle. The younger pigs are sometimes kept in smaller stalls until larger stalls are made available by the slaughter of the litters which have been in them. Except for this, the litter is kept in the same stall during the whole experiment, being taken out only for the regular weighings. After a litter has been removed from a stall, that stall is cleaned and disinfected before another litter is placed in it.

FEEDING PLAN

The feeding plan is described in detail in each report. The ration consists of ground grain mixed with skimmilk and some water. Before it is mixed with the grain, the skimmilk stands 24 hours for souring, or else it is obtained from the creamery already mildly soured. The skimmilk is always pasteurized before being soured. The ground grain and skimmilk for 24 hours feeding are mixed for each lot in the morning and the first feeding from this mixture is at noon. The ration is hand-fed three times daily at a rate based on the live weight of the pigs at the last weighing. Deviations from this rate of feeding are made when the pigs do not eat all the feed within a very short time after it is given to them. The skimmilk constitutes a larger portion of the ration for small pigs than for larger ones, but there have been only slight deviations from the rule that, in terms of feed units, the skimmilk constitutes about 20 percent of the total feed eaten during the experimental period, and the grain constitutes 80 percent (a kilogram of dry grain or 6 kilograms of skimmilk equals one “feed unit” in all these calculations). A 20-kilogram pig receives 1.5 kilograms of skimmilk daily, and this amount is increased as the weight increases until the pig weighs 50 kilograms and receives 3 kilograms per day of skimmilk. Thereafter there is no further increase in the daily ration of skimmilk. Water is added whenever necessary to give the feed the desired consistency. The feeding plan is thus a limited feeding one and is planned to utilize much skimmilk.

Since 1923 the grain mixture has consisted of the follow-
ing by weight: 1/2 ground barley, 1/4 ground wheat and 1/4 ground corn. Wheat was not used before 1923. Prior to 1923 the most characteristic grain ration consisted of equal parts of corn and barley. However the stations were not always uniform in their feeding policy. Thus some rye was fed at Bregentved until as late as 1914 and it occasionally (fourth report) constituted fully half by weight of the concentrates fed. The “svinefoder” prepared by the bacon factory at Odense constituted one-third of the concentrates fed at Elsesminde until 1913 (Reports 1 to 5). Whey was sometimes used in the early years to replace much of the skim-milk. Buttermilk sometimes was used instead of skimmilk for the very small pigs. Under the stress of the war-caused shortages, there was fed less barley and more maize and considerable amounts of cocoanut cake (up to one-fourth of the concentrate ration at Bregentved during much of 1917). Up to 1910 the stations made some use of green or succulent feeds such as alfalfa and root crops but this was then discontinued because the seasonal nature of these feeds was thought to make the results from pigs fed at different seasons of the year not fairly comparable.

Beginning in 1928 it has been the uniform practice at all stations to feed common cod-liver oil at the rate of from 5 to 10 grams daily to each pig in those lots which have not yet reached an average weight of 25 to 30 kilograms. The only mention of cod-liver oil prior to this is that it was occasionally given in the winter months as medicine to pigs apparently suffering from lameness (Stivsyge).

Also in 1928 was begun the steady use of a mineral mixture consisting of equal parts of salt and limestone. This is fed at the rate of about 10 grams daily per pig, a little less for the small ones and a little more for the large ones. In the earlier reports there is irregular but frequent mention of the use of a little bonemeal at several of the stations. The large amounts of “svinefoder” fed at Elsesminde in the first 5 years may have contained a noteworthy amount of minerals.

The very small pigs have usually received ground barley instead of the grain mixture. Since 1929 an average weight of 20 kilograms has been the dividing line between large and small pigs, but before 1929 that was sometimes as much as 25 or 30 kilograms. In the eleventh to thirteenth reports it is stated that the very small pigs received their grain dry instead of soaked in skimmilk as was always the case with the older pigs.

In estimating from the reports themselves the changes which have been made in the feeding plans, the fact should
be kept in mind that in the first 13 reports (up to Aug. 31, 1924), the report for each station was written by the man in charge of that station. There was some freedom for each man to go into detail concerning points which interested him especially. The fourteenth report (1924-25) and all subsequent reports up to and including the twenty-second were written by Mr. N. Beck who had been in charge of the station at Elsesminde from its very beginning and who was in charge of all the stations from 1925 until his death early in 1934. Beginning with the fifteenth report, the results are presented primarily by subjects rather than by stations. This editorial change gives the impression of increased uniformity of procedure, whereas it is possible that the procedure might still have seemed somewhat diverse if the account for each station had continued to be written by the man in immediate charge of that station. One is therefore at somewhat of a loss to estimate from the reports themselves how much of the apparent increase in uniformity of procedure since about 1924 to 1926 is real and how much of it is editorial. The fact that one man gave his full time to the supervision of all stations since 1925, whereas previously they were under the supervision of a committee or committees which met only from time to time, must surely have made some increase in the uniformity of procedure. Those who have been actively in charge of the progeny investigations are convinced that the data since about 1926 are much more

<table>
<thead>
<tr>
<th>Year</th>
<th>1907</th>
<th>1910</th>
<th>1914</th>
<th>1917</th>
<th>1920</th>
<th>1923</th>
<th>1925</th>
<th>1926</th>
<th>1934</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grain ration</td>
<td>1/2 barley, 1/4 wheat, and 1/4 maize</td>
<td>Uniform use of cod liver oil and mineral mixture</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Over Lajstrup</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Over Borrevaag</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Over Bregentved</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Over Hjøn</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Over Marsikfjær</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Over Skaruplund</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diet of experiment. Some variations in concentrates and in proportion of milk. Some green feed used.</td>
<td>Most typical grain ration: 1/2 barley, and 1/4 maize, dry used at some stations and hay at others. Some use of whey and butter milk. Less barley, more maize, some coconut milk used at some stations and enough at one. Some use of whey and butter milk.</td>
<td>Less barley, more maize, some coconut milk used at some stations and enough at one. Some use of whey and butter milk.</td>
<td>Less barley, more maize, some coconut milk used at some stations and enough at one. Some use of whey and butter milk.</td>
<td>Less barley, more maize, some coconut milk used at some stations and enough at one. Some use of whey and butter milk.</td>
<td>Less barley, more maize, some coconut milk used at some stations and enough at one. Some use of whey and butter milk.</td>
<td>Less barley, more maize, some coconut milk used at some stations and enough at one. Some use of whey and butter milk.</td>
<td>Less barley, more maize, some coconut milk used at some stations and enough at one. Some use of whey and butter milk.</td>
<td>Less barley, more maize, some coconut milk used at some stations and enough at one. Some use of whey and butter milk.</td>
<td></td>
</tr>
<tr>
<td>Uniform use of cod liver oil and mineral mixture</td>
<td>Uniform use of cod liver oil and mineral mixture</td>
<td>Uniform use of cod liver oil and mineral mixture</td>
<td>Uniform use of cod liver oil and mineral mixture</td>
<td>Uniform use of cod liver oil and mineral mixture</td>
<td>Uniform use of cod liver oil and mineral mixture</td>
<td>Uniform use of cod liver oil and mineral mixture</td>
<td>Uniform use of cod liver oil and mineral mixture</td>
<td>Uniform use of cod liver oil and mineral mixture</td>
<td></td>
</tr>
<tr>
<td>United reports and supervision by one full-time man</td>
<td>United reports and supervision by one full-time man</td>
<td>United reports and supervision by one full-time man</td>
<td>United reports and supervision by one full-time man</td>
<td>United reports and supervision by one full-time man</td>
<td>United reports and supervision by one full-time man</td>
<td>United reports and supervision by one full-time man</td>
<td>United reports and supervision by one full-time man</td>
<td>United reports and supervision by one full-time man</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 5. Diagram showing history of ration changes and the location of the official testing stations. Vertical shifts in the lines in the diagram of location history indicate changes of the official testing station from one farm to another.
comparable with each other than before, both as concerns data from different stations and data taken at the same station but at different times.

The history of the major changes in the feeding policy, as gleaned from the reports, may be seen at a glance in the schematic diagram, fig. 5. There is, of course, room for dispute as to which features of the feeding policy were really important enough to have been mentioned here. For example, the steady use of minerals and of cod-liver oil for the young pigs seems theoretically important, but the percentage rejected for death or unthriftiness, the average daily gain, and the average economy of gain do not show any sudden favorable change coinciding with that addition to the ration. The changes shown in fig. 5 were selected largely on the basis of what current knowledge and theory of nutrition indicate might have affected the results.

**CHANGES WHICH HAVE OCCURRED IN THE SWINE POPULATION, 1907 TO 1935**

In this section will be presented an account of the changes which have occurred in the averages of the characteristics weighed, measured or scored on the pigs at these progeny testing stations. In cases where a distinct change undoubtedly has occurred in these averages, the question of most interest is: What caused this change and what determined the effectiveness of the various agencies which had some part in producing it? Naturally it is not possible to get a complete and indisputable answer to all parts of this question. However some possible answers will be made more probable and others less probable by a description of the changes which have occurred, together with the accompanying circumstances. In a later section detailed studies of the resemblances and unlikenesses between animals related by descent in various ways will throw additional light on this.

**NUMBER AND REPRESENTATIVENESS OF MATERIAL**

Table 1 shows the number of litters tested at these stations. Except for the crossbreds, these numbers show only minor changes during the pre-war period, a steady increase when testing was first resumed after the war, and a sharp increase in 1926 when the two new stations were opened. The regular stations have sometimes had to refuse litters on account of lack of space. If this could be taken into account and if the numbers of pigs tested at the local stations could
TABLE 1. NUMBER OF LITTERS TESTED EACH YEAR

<table>
<thead>
<tr>
<th>Year</th>
<th>Stations</th>
<th>Total for all stations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Høng</td>
<td>Haraldskjaer (or</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Skæruplund)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(or Rodstenseje)</td>
</tr>
<tr>
<td>1907-08*</td>
<td>182</td>
<td>55</td>
</tr>
<tr>
<td>09-10*</td>
<td>34</td>
<td>59</td>
</tr>
<tr>
<td>10-11</td>
<td>77</td>
<td>43</td>
</tr>
<tr>
<td>11-12</td>
<td>89</td>
<td>60</td>
</tr>
<tr>
<td>12-13</td>
<td>92</td>
<td>53</td>
</tr>
<tr>
<td>13-14</td>
<td>81</td>
<td>56</td>
</tr>
<tr>
<td>14-15</td>
<td>79</td>
<td>57</td>
</tr>
<tr>
<td>15-16</td>
<td>91</td>
<td>64</td>
</tr>
<tr>
<td>16-17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20-21</td>
<td>62</td>
<td>31</td>
</tr>
<tr>
<td>21-22</td>
<td>90</td>
<td>64</td>
</tr>
<tr>
<td>22-23</td>
<td>87</td>
<td>98</td>
</tr>
<tr>
<td>23-24</td>
<td>104</td>
<td>104</td>
</tr>
<tr>
<td>24-25</td>
<td>105</td>
<td>71</td>
</tr>
<tr>
<td>25-26</td>
<td>151</td>
<td>124</td>
</tr>
<tr>
<td>26-27</td>
<td>66</td>
<td>174</td>
</tr>
<tr>
<td>27-28</td>
<td>111</td>
<td>198</td>
</tr>
<tr>
<td>28-29</td>
<td>116</td>
<td>174</td>
</tr>
<tr>
<td>29-30</td>
<td>108</td>
<td>176</td>
</tr>
<tr>
<td>30-31</td>
<td>130</td>
<td>211</td>
</tr>
<tr>
<td>31-32</td>
<td>129</td>
<td>236</td>
</tr>
<tr>
<td>32-33</td>
<td>128</td>
<td>233</td>
</tr>
<tr>
<td>33-34</td>
<td>139</td>
<td>220</td>
</tr>
<tr>
<td>34-35</td>
<td>128</td>
<td>218</td>
</tr>
</tbody>
</table>

*The dates for the beginning and ending of these first two reports were not quite the same at all three of the stations.

have been included, the figures would show a larger increase in the progeny-testing of swine in recent years. On account of the varying and often small numbers of crossbred pigs tested in different years, the averages for the crossbreds are shown as disconnected circles or dots on most of these graphs.

The data themselves provide little basis for any judgment concerning the representativeness of the test pigs. The local committee on its semi-annual inspections of each breeding center requests that certain sows be tested and such litters are given preference if lack of space at the testing station makes it impossible to accept all the litters offered. Otherwise the choice of test pigs is left to the center-owner, subject to the sex-requirements and to the rule that the total number of test pigs from each center should average two pigs per year per scored sow. There would naturally be some desire to select better-than-average pigs for the testing. This would be at least partly offset by a desire to save the very best pigs for breeding purposes or for sale to customers who must be satisfied if they are to be kept as steady customers. Perhaps the most important limiting factor on selection is that the pigs must be sent in for testing at an age of about
Fig. 6. Percentage of accepted pigs which did not finish the test either because of death or because they were removed for sickness severe enough that they made no gains during a 4-week period.

6 to 8 weeks. It is doubtful whether such selection as can be made at this age could make the tested samples very unrepresentative of the herds from which they came.

Many of the crossbred litters tested were deliberately produced for studying crossbreeding. In all but 3 years the number of crossbreds has been so small that one cannot have much confidence in the results being very typical of crossbreeding in general.

TRENDS IN HEALTH

Figure 6 shows the percentage of accepted pigs which because of death or unthriftness were discarded before they reached the slaughter weight. The crossbreds are shown only for the 3 years when more than 30 crossbred litters were tested. There has been fairly steady improvement in both breeds or in the conditions of management or in both. The breed difference is especially interesting because it is so highly consistent and shows no certain indication of changing, although the means of both breeds have rather steadily changed. The breed difference is statistically significant in nearly all but the last one of the recent years considered singly (the standard deviation of the difference is not very far from 0.9 percent) and is overwhelmingly significant in view of the fact that it is so consistent year after year. Is the downward trend a genetic improvement in both breeds
rendering them healthier and more resistant to adverse environmental circumstances? Or is it only improvement in environmental circumstances? If the latter, why is it so regular year after year?

Figure 7 shows the percentage of those which were found to have tubercular lesions when they were slaughtered. Most of these had only slight lesions in the neck glands. There is no clear evidence of a breed difference unless it be a breed difference in trends since 1926. All Danish bacon factories maintain rigid inspection for tuberculosis, and no part of any pig which is found affected, no matter how slightly, is allowed to go to the English market. The experimental pigs were inspected as rigidly as the others. In addition the annual reports stress the findings about tuberculosis as being of help in locating the most highly infected herds and thus perhaps helping in the eradication of tuberculosis.

**AGE AND WEIGHT AT SLAUGHTER**

Figure 4 shows that there has been no distinct trend in weight at slaughter although the weights have usually been a little nearer the desired goal since 1926. In age at slaughter there was a distinct trend downward for 7 years following the war but practically no trend for the most recent 6 years.
The pre-war fluctuations were irregular and the two extremely high ages both occurred in the 2 years when the average weight at slaughter was also unusually high. The post-war trend showed so nearly the same progress each year and lasted so long that it can hardly have been accidental. But, whatever the reason for this change, genetic or otherwise, why did the trend so suddenly cease after 1929 and why was there no distinct pre-war trend?

TRENDS IN DAILY GAIN

Figure 8 shows for both breeds and for the crossbreds the trends in rates of gain. The only pronounced change occurred in the 7 years beginning in 1922. The parallelism between the two breeds is very striking but might be expected either on the hypothesis that feeding and management were steadily improving and were the causes of this increase, or on the hypothesis that the change was a genetic one caused by selection which immediately after the war was focused mainly on rates and economy of gain but in recent years has been turned much more to improving the market desirability of the pigs. In either case it is hard to see why the change should have been so regular and rapid for so long a time and should then have ceased so abruptly. The reports since about
1926 to 1928 have certainly stressed features of market type such as body length, thickness of belly and back fat, and score for bacon type and for firmness of flesh far more than they did formerly. Of course this has meant relatively less emphasis on selecting for economy and rate of gain, but it seems improbable that all the breeders would suddenly follow this advice. Also the reports in the pre-war years certainly stressed rate and economy of gain very much, and yet there is no indisputable evidence of a pre-war trend. Perhaps the changes from 1910 to 1914 can be interpreted as such a trend abruptly halted by the war-time conditions, but one cannot be certain that this trend over such a short period is other than accidental. The undisputed fact remains that the rate of gain at the testing stations for the last 6 years has been about 16 to 18 percent higher than it averaged before 1923.

There is no material difference between the breeds in rate of gain. The crossbreds on the whole seem to gain a little faster, but in the 3 years when they were numerous enough for their averages to be very dependable (1928-1931), the crossbreds averaged about the same as the purebreds. There may have been less selection among the crossbreds, since many of them were bred especially for these tests and every qualified litter would be used.

Fig. 9. Changes in the average feed requirement per unit of gain.
TRENDS IN ECONOMY OF GAIN

Figure 9 shows the annual averages of feed units required per unit of gain. The average ration since 1923 has been 2 parts barley, 1 part corn, 1 part wheat and 6 parts of skim-milk. Hence the figures shown in figs. 9 and 11 may be considered as pounds of this ration per pound of gain in live weight, except that the actual weight of the skimmilk is first divided by six before it is added in with the other feeds to compute the "feed units" eaten.

The annual reports until about 1926 or 1928 stressed economy of gain more than any other one feature. The Yorkshires seem to have shown a steady improvement, interrupted only by the war period, until about 6 years ago. The Landrace showed no distinct trend before the war but a sharp improvement for 7 successive years after 1922 — an improvement which has almost ceased for the last 6 years. The crossbreds seem generally to have been more efficient than the purebreds but the differences were small and irregular. Naturally these curves are closely related to those in figs. 4 and 8, since a more rapid gain means less time on feed and less feed used for maintenance. An attempt was made to answer the question of whether the real improvement in the practical economy of gain was entirely a consequence of the more rapid gains or whether there was also some increase in physiological efficiency in addition to this. The following figures were computed, using from the reports the averages for the most dependable pre-war years, the 3 post-war years before the improvement began, and the first 5 years after it ceased. The results are as follows:

<table>
<thead>
<tr>
<th>Period used</th>
<th>Average age at slaughter (days)</th>
<th>Total feed units used per unit of gain</th>
<th>Feed units per unit of gain, after deducting feed used for maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1911-14</td>
<td>194.3</td>
<td>3.75</td>
<td>2.26</td>
</tr>
<tr>
<td>1920-23</td>
<td>196.0</td>
<td>3.63</td>
<td>2.10</td>
</tr>
<tr>
<td>1928-29</td>
<td>178.2</td>
<td>3.36</td>
<td>2.07</td>
</tr>
</tbody>
</table>

The figures in the last column indicate some increase in physiological efficiency. This increase, however, is slight, particularly in the last interval.

Figure 10 shows the regression of economy of gain upon age at slaughter (computed by Prof. Johs. Jespersen and M. P. Østerlund Madsen from data on more than 3,000 litters fed at the official testing stations during the time from 1922 to 1928). While this shows that a distinct regression ex-

\*With the help of Dr. Knud Rottensten.
Number Of Litters  
Average Feed Units Per Unit Gain  

<table>
<thead>
<tr>
<th>Days Old At Slaughter (About 200 Pounds Live Weight)</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
</tr>
<tr>
<td>3.27</td>
</tr>
<tr>
<td>3.78</td>
</tr>
</tbody>
</table>

Fig. 10. Average feed requirement per unit of gain for pigs slaughtered at various ages.

isted, it seems not to tell anything critical as to the causes of that. There is a distinct time trend in the data since they come from a period of years when the average age at slaughter and the average feed required per unit of gain were falling. This regression line may reflect both the saving in maintenance feed and some gains in physiological efficiency. That is, under this system of feeding where the amount fed was according to a fixed schedule determined by the weight of the pig at the beginning of the weighing period, the most efficient pigs (in the genuine physiological sense of that word) would gain the most per unit of feed and would therefore come to their slaughter weight at an earlier age than the others. This of itself would give rise to additional savings in maintenance feed. Another point which may have some bearing on the question of improvements in physiological efficiency is the composition of the pig at slaughter. Chemical analyses of pig carcasses were not made. However consider-
able efforts have been made to breed longer pigs with thinner back fat and more lean flesh. There has also been striving for thicker bellies. Some of these goals have been partly realized, but the data do not make possible a quantitative estimate of how the proportions of fat, lean, bone, water, etc., in the pig at slaughter time have changed. There has been no material change in dressing percentage. The changes in carcass measurements have been most pronounced in the last 6 or 8 years at the time when the efficiency in use of feed has almost ceased to change.

If the changes in apparent efficiency in the use of feed were primarily caused by improvement in sanitation, ventilation, or other matters of management at the testing stations, it is difficult to see how progress could have been so steady.
as it was from 1922 to 1929. To throw some light on this, fig. 11 was prepared to show separately for each of the three oldest stations how the efficiency in the use of feed varied from year to year for each breed. The close parallelism of the year-to-year changes in both breeds at the same station is eloquent testimony of the importance of local variations in health or management, yet there is at all three stations this general downward trend which, if its origin were to be explained in environmental improvement, would seem to require steady improvement in many small features of the management at each station for some 7 or 8 years and then a rather abrupt cessation of such improvement. It seems to the writer easier to believe that much of the general improvement was due to genetic changes in the swine population brought about by selecting breeding stock from the descendants of those animals which had made the best showing in rate and economy of gain. The increased emphasis on carcass qualities which began about 1925 to 1927 might have been enough to bring almost to a stop, 2 or 3 years later, further improvements in economy of gain. Nevertheless the data do not preclude belief that steady environmental improvement may have had much importance.

This topic can be summarized by saying that there was a large gain in the practical efficiency of using feed (a decrease of about 8 percent in the amount of feed required for a pound of gain, occurring in the 7 years between 1922 and 1929) but that most of that improvement may have come from the more rapid rate of gain which saves considerable of the feed which would have been needed for maintenance if the rates of gain had not been changed. The figures also indicate some improvement in physiological efficiency, more especially in the early years, but the differences are small and other possibilities are too uncontrolled to warrant extreme confidence in the reality of this. That these improvements in efficiency were largely due to breeding is indicated by two things: (1) The absence of recorded changes in feeding or management which might reasonably be supposed to have produced the improvements, and (2) the correlations between relatives which show (especially for rate of gain) that there was considerable hereditary variability available for selection.

CHANGES IN BODY LENGTH

Figure 12 shows the yearly averages of body length. During the pre-war period this was measured from the hip socket to the front edge of the side, that is, to the cut by which the
head was removed from the body. Since this edge was somewhat variable and dependent on the cutting, it was decided to change this when testing was resumed after the war. Since the war the measurement has been from the hip socket to the middle of the body of the atlas bone in the neck. Prior to this time length was measured on the chilled carcasses, while they were still hanging from the rail. Since then measurements have been made while the chilled carcasses were lying on the cutting table. This last change alone caused the measurements to be about 1.5 cm. shorter. One of the stations for the first year or two after the war through misunderstanding continued to use the old methods. Hence the pre-war results are not comparable with the post-war ones, and the first 2 years of post-war results are a mixture of both methods in varying amounts and are not directly comparable with either the preceding or the following measurements.

There seems to have been no definite trend prior to about 1925 or 1926 but a distinct increase since then. The increase has been larger in the Landrace than in the Yorkshire. There is no distinct difference in breed means, and the crossbreds are scattered irregularly around the means of the two pure breeds. The desirability of more length has been heavily

---

**Fig. 12.** Changes in body length. (Pre-war and post-war measurements are not comparable with each other, and the first two post-war years are not entirely comparable with the later years.)
stressed in the reports for the last 6 to 8 years, and the verbal testimony of those familiar with the swine breeding, as well as the data, all fit the hypothesis that this change is a genetic one produced mainly by selecting the descendants of those boars and sows whose progeny were unusually long and were at least reasonably desirable in other respects. Probably body length can be estimated more accurately from the appearance of the breeding animals themselves than can any of the other characteristics discussed here. Selection for body length may have been based as largely on the appearance of the breeding animals as on their progeny tests.

Table 6 in the twenty-third annual report shows that 1,492 ordinary farm swine measured at nine different bacon factories averaged 3.7 cm. shorter than the 2,644 contemporary Landrace from the official testing stations and 2.5 cm. shorter than the 541 Yorkshires from the testing stations. This is what would be expected if the changes in length are really genetic changes with selection in the breeding center herds causing that change while the general population of commercial swine shows an average lag of something like one to three generations.

An interesting feature about body length is that it is one of those characteristics (perhaps not so rare as might be inferred from many discussions of applied genetics) for which the most highly preferred measurement is neither the extremely large nor the extremely small but an intermediate. The ideal length at present in Denmark is considered to be 92 or at most 92.5 centimeters. The general average of the Landrace has almost reached that ideal. Already there are occasional litters which average 95 or more centimeters in length. What progress can be expected after the breed comes to the point where the average length is just what is wished but a considerable percentage are too long and an equal percentage are too short? That question is already being discussed, as well as the question of whether animals whose progeny are too long can be used profitably for mating to animals whose progeny are too short. The theoretical genetic basis for such cases as this was clarified by Wright in 1921 and 1935, but especial interest will attach to the actual developments in the present case because it seems to offer an unusually good illustration of these principles, and may even provide some semi-experimental testing of the theoretical expectations.

---

The analysis of variance and the correlations between relatives with respect to deviations from an optimum. Jour. of Genetics, 90:249-256. 1935.
Fig. 13 shows the averages for both of these measurements. The back fat measurement is an average of three measurements, one from over the shoulder, one from over the front of the loin, and one (itself an average of three) from over the front edge of the pelvis. The belly measurement is made with a dagger thrust through the belly flesh in the teat row. An average of three such measurements is used, one a hand's breadth back of the sternum, one a hand's breadth in front of the ham, and one mid-way between those two. The teats themselves are avoided, of course, in making these measurements. These measurements therefore are objective, but are subject to considerable measuring error, especially because these thicknesses vary from spot to spot, even on the same pig. Two pigs may have the same average thickness of back fat (or of belly) and yet one may be an average of three widely different measurements while the other is an average of three measurements very nearly the same. The uniformity of this thickness is scored separately (see figs. 16 and 17) but does not appear in fig. 13.

Little emphasis was given to these two measurements in the early reports except to stress that pigs must not be too
fat and that the fat should be well distributed. Beginning about 1925 to 1927, however, a strong and increasing emphasis, second only to the emphasis laid on body length, is laid on these two measurements. In some reports thickness of back fat seems to receive even more emphasis than length of body, since it has more to do with the market classification of the carcass. In recent years every effort has been made to get the back fat thinner and the bellies thicker. Figure 13 shows that these efforts have been highly successful in the case of back fat in both breeds and fairly so for thickness of belly in the Landrace. Back fat is like body length in that the ideal is not the extreme but an intermediate which is already being exceeded in individual cases and even by whole litters now and then. Carcasses with too thin back fat often are too soft to suit the market demand. Hence as the back fat becomes thinner, more emphasis in selection is naturally being laid on firmness of flesh (fig. 16). If the present rate of progress continues, it may not be more than 2 or 3 years before the average thickness of back fat is optimum for the degree of firmness now prevailing. When that point is reached some pigs will have fat too thick, and an equal number of others will have fat too thin. If the flesh can be made firmer by other means, then the ideal thickness of back fat may itself be changed to a somewhat thinner dimension than is ideal at present. That is, the ideal at present is not merely a dimension but is a combination of just enough fat to make the flesh firm. Thickness of belly is increasing but not as rapidly as thickness of back fat is decreasing. There seems to be no immediate likelihood that thickness of belly will reach its optimum within 5 or 6 years at least. Both of these traits show a definite sex difference, that being particularly important in the case of belly thickness. Barrows have thicker backs and thinner bellies than gilts.

There was a distinct breed difference in the early years, but the improvement in the Landrace has been so much more rapid than in the Yorkshire that the breed averages have been almost identical for the last 4 years. The crossbred averages seem to be scattered almost at random about the parental averages.

CHANGES IN DRESSING PERCENT AND IN YIELD OF EXPORT BACON

"Dressing percent" is the percentage which the cold dressed meat is of the live weight of the pig at slaughter. After the carcass has chilled for 24 hours or more, it is
trimmed for export by removing the head, feet, some of the neck, the backbone, shoulder blades, part of the pelvic bones, part of the sternum and various small parts which are trimmed off to make the carcass neat and smooth. The remaining meat is known as export bacon ("Wiltshire sides" in the United States and Canada). Its weight at this stage, divided by the live weight, is the "yield of export bacon" studied here. After this trimming it goes immediately into a brine solution where it remains 4 days. When removed from the brine it is allowed to drain for 3 or 4 days and then is shipped to England without further trimming.

Figure 14 shows the annual averages for these two characteristics. The distinct breed differences which persist from the beginning until the present with no clear indication of diminishing or increasing and with no overlapping of the breed averages, seem clear evidence that the variations are partly hereditary. The crossbred averages are in nearly all cases conspicuously intermediate. It is difficult to see why there were no distinct general trends in these percentages. Most of the men familiar with the testing work stated that no emphasis had been laid on these percentages and breeders had not been urged to pay attention to them in their selections. However in the annual reports
for recent years the figures for yield of export bacon are printed in bold-face type as if to call special attention to them. The figures for dressing percent are given only indirectly as the percentage of loss during slaughtering. The recent reports include special tables calling attention to those litters which have yielded 61 percent or more of export bacon.

CHANGES IN AVERAGE CLASSIFICATION OF BACON SIDES

Danish farmers are paid at the cooperative bacon factories for their pigs according to weight and classification of the carcass. The classification is based almost entirely on thickness of back fat. The price posted at the bacon factory is for cold dressed carcasses weighing 58-64 kilograms (128

---

Fig. 15. Changes in proportions of the slaughter pigs which produced first, second and third class bacon sides. "Class" is determined almost entirely by the thickness of the back fat.
to 141 pounds), and from this price there are deducted certain penalties for the amount of overweight or underweight on each pig which is outside these weight limits. These weight limits correspond to a live weight of about 180-195 pounds. There have been occasional changes in these weight limits. The farmer is paid the day he delivers a pig nearly all of what it is thought to be worth, and at the end of the year he receives the balance in the form of his cooperative dividend. After the pig is killed the meat is graded as first, second, or third class, according to the thickness of the back fat. A small deduction is made from the base price if the pig proves to be second class and twice as large a deduction is made if it proves to be third class. This classification is thus of considerable economic importance and is emphasized in these reports. There is little room for personal opinion in deciding whether a pig falls inside or outside of a given class. First class pigs have the thinnest fat and third class pigs the thickest. The Elsesminde station began reporting this classification in 1923-24 and the other stations followed 2 years later. Figure 15 shows the breed averages, but the first 2 years contain data only from Elsesminde. Data for the crossbreds are shown only for those years when more than 90 crossbred animals were tested.

There is in fig. 15 a distinct increase in proportion of first class bacon sides and a sharp decrease in the proportion of third class sides. The percentage of second class sides remains about the same or perhaps decreases a little. The crossbreds seem to be about intermediate between the paternal breeds, although they fall below in one year and somewhat above in another of the 3 years concerned. There is a distinct superiority of the Yorkshire until the last 3 or 4 years when this has disappeared.

CHANGES IN SCORES FOR VARIOUS CHARACTERISTICS

Since the beginning of these experiments a system of scoring has been used for various traits which could not readily be measured. The scores run from 0 to 15, the latter figure being for perfect development of the characteristic. Scores were given to the nearest half point. The averages were published in each annual report to the nearest tenth of a point. Naturally this, like any other system of scoring, cannot be entirely free from subjective error. Constant efforts are made to keep personal opinion from having any influence, and much of the scoring is done by two or three men rather than by one alone. The man in general charge of all swine
testing work nearly always takes the lead in this scoring. Other men who help usually include the managers of the local plant or of nearby bacon factories when they happen to be present. Figures 16 and 17 show the changes which have taken place in average scores. The precautions taken to standardize this scoring are probably adequate to make contemporary breed or lot averages fairly comparable, but it is not so certain that the standards could be kept so unchanging over a long period of years that these averages would be dependable evidence about time trends. The superiority of the Yorkshire over the Landrace in most traits, especially in the early years, is evident. The Landrace has improved so much in recent years that this difference has been practically eliminated or reversed in all but the scores for firmness of flesh. The crossbreds, in general, have been intermediate, but there has been considerable scattering of their averages.

“Bacon type” (fig. 16) is a general expression for the closeness with which the conformation and characteristics of the whole side conform to the bacon ideal. This was not recorded until the thirteenth report and then only for Bre­gentved. The following year this item was also scored at Elsesminde and since 1925 has been observed at all stations.

The scores for bacon type and for fullness of lean meat have been emphasized more than any other scores in the annual reports. Next to these in the annual reports and ahead of them in the reports for progeny testing have been emphasized the score for firmness of flesh and for evenness of the covering of fat. Next to this have come the scores for belly, for ham, and for fineness. The scores for firmness of flesh (fig. 16) are receiving increasing attention as success of the breeders in making the back fat thinner and the carcass longer has led to more trouble with the meat being too soft unless special care is taken to select breeding stock for firmness.

The average scores for evenness of fat along the back (fig. 16) for the first four and the last five reports concern only the uniformity of the thickness of fat along the back, but for the intervening reports some attention is given to thickness itself. The score of the shoulder includes something about the general conformation of the whole front part of the carcass.
Fig. 16. Changes in average scores for meatiness (Kædfylde), bacon type, firmness of flesh and uniform thickness of back fat.
Fig. 17. Changes in average scores for bellies, hams, shoulders and for fineness of head, bone and skin.
Fig. 18. Prominent foundation boars and sows of the Danish Landrace breed.
VISIBLE CHANGES IN THE CONFORMATION OF THE SWINE

Figure 18 shows four of the six boars and four of the six sows pictured in Volume 1 of the herdbook for Landrace swine. That volume was prepared after most of these animals were dead. Their average birth date was in 1897. Perhaps some of them were dead before anyone seriously suspected they would contribute enough to the foundation of the breed that photographs of them would be wanted to illustrate the herdbook. These animals were selected for entry into the herdbook because their descendants were widely used in founding the Landrace breed and not primarily because of their own conformation or appearance. In using them to show the change in appearance of the breed it is perhaps fairer to compare them with the average of all modern Landrace swine raised than to compare them with modern animals selected for show purposes.

Figure 19 shows some Landrace boars farrowed in 1933 and 1934. The upper one and lower ones were purchased at 8 and 5 months of age. Doubtless they were considered of better conformation than the average of the breed at that time. The middle one was regarded at weaning time as the best individual among six sons of the upper one. The pictures, however, were taken long afterward. Hence these animals selected partly for their appearance had time to retrogress before these pictures were taken. Therefore it seems fair to regard these pictures as somewhat above the breed average in appearance but not quite equal to pictures of first prize winners taken on show day at one of the larger Danish district fairs. This is also true of the pictures in figs. 20 and 21. Figure 20 shows one Landrace sow at two ages and a single view of another sow. Figure 21 shows a third sow at two ages and a single view of a fourth.

The methods of their selection make it probable that the pictures in fig. 19 to 21 are a little farther above the average of the modern breed in general appearance than the pictures in fig. 18 were above the average of the foundation animals. Yet after making what seems reasonable allowance the pictures show that there have been distinct changes in the appearance of the breed. The modern pigs are longer, less coarse, trimmer in their middles, have more nearly square hams, and lighter and neater heads, necks and shoulders than the foundation animals. By American standards the modern Landrace would be called small-boned and weak in their legs, although that is not considered important in Denmark where most of the pigs are kept inside and their feed
Fig. 19. Modern types of Danish Landrace boars. Upper: a 13-month old boar. Middle: a 17-month old son of the upper boar. Lower: a third boar 2½ years old.
Fig. 20. Modern Landrace sows. Upper: sow 22 months old shortly before weaning her second litter. Middle: same sow at 32 months while her fourth litter was quite young. Lower: another sow at 32 months.
is brought to them. Also many of them are low in the back or even swaybacked according to current American standards. No attention is paid to swirls in Denmark, and about 8 to 12 percent of the Landrace pigs at the large district fairs have one or two swirls. (So far as is known, swirls have no undesirable effect on the dressed meat or on the health of the pig. Hence the widespread American and British selection against them seems to be based only on aesthetic reasons.) Some Landrace have very sparse hair and others have abundant hair, but this is regarded as of no consequence, since the climate is equable and nearly all pigs are kept in carefully constructed and ventilated barns.

Perhaps some of the changes in external appearance during the 40 years the breed has had a somewhat organized existence would have occurred anyhow if the only selection practiced had been that based on the testing station data concerning rapid and economical gains and desirable carcass qualities. But during all this time selection on the basis of external appearance was also being encouraged and made effective, largely through the extensive use of local and district shows. There seems no way now of discovering how much of the change in outward appearance came about directly as a result of selection for outward appearance and how much of it came from selections based primarily on the data from the testing stations. To some extent—perhaps to a large extent—the two bases of selection would lead in the same direction.

Some of the men who have been in contact with the swine breeding for many years hold the opinion that selection was mainly on external appearance with some attention to rate and economy of gain (and of course to fertility) until the early or middle twenties and that until then the other testing station data were a basis for selection only indirectly as a means of guiding their standards for the kind of external appearance which should be sought. There seems to be no objective way of testing the correctness of that view. Somewhat against it speak the facts that the testing station system was made so comprehensive from the very beginning and that even the early reports emphasize the progeny performance of those sows and dams which were most extensively tested. Even the early reports contain scores and measures for many different carcass qualities. Surely many people thought those things important or they wouldn't have been observed, tabulated and published. Yet it remains possible that the breeders who did the actual selecting paid little attention to those figures.
Fig. 21. Modern Landrace sows. Upper: a two year old about a month after having weaned her second litter. Middle: the same sow at 33 months old. Lower: another sow at 18 months old, shortly before farrowing.
Not all of the selections for external appearance seem to have been directed toward economic goals. Thus the selection for large and drooping ears seems difficult to explain on any other logical grounds than that these may have been valued as one of the few sharp distinctions between the Landrace and the (more or less) competing Yorkshire. They therefore would have had economic value only in the sense that a “trade mark” on a manufactured article does.

SUMMARY OF CHANGES IN AVERAGE CHARACTERISTICS OF THE SWINE POPULATION

Some characteristics have changed markedly, and some have changed little if at all in the quarter of a century during which this testing has been in operation. In some cases there has been little or no breed difference. In other cases there has been a distinct breed difference which has persisted with little or no change throughout the entire period. In still other cases there have been distinct breed differences in the early years which have disappeared or have been reversed in the late years as the one breed changed more rapidly than the other. On the whole the crossbreds have been intermediate to the parent races with an occasional trait where they averaged nearer to the higher parent or even above the higher parent.

Mere description and measurement of these changes give little insight into their causes. Changes in the breed averages may have been the result of changes in the methods of management, feeding, average sanitation, etc., which may all be roughly classified as environmental changes. On the other hand changes may have been brought about in the average genetic composition of the population of swine from which the test pigs came, so that certain genes that were once relatively rare are now abundant and vice versa. There is also the possibility of some interaction between these changes of such a nature that the genetic changes have made more abundant certain genotypes which respond more readily (or less readily) to certain changes in environment.

To throw light on this question and to measure the magnitude of the variables involved, it is necessary to make some kind of a study of the resemblances and differences between individuals related by descent in various ways. The most important facts of this kind which one would like to know are: The correlations between litter mates, the correlations between paternal and maternal half brothers and sisters, the correlation between parent and offspring and some informa-
tion on the system of mating used; that is, the closeness of
the correlation between sire and dam and whether that was
brought about primarily through mating like pedigrees (that
is through inbreeding) or primarily through mating indi-
viduals thought to be alike in their somatic expression of
the particular characteristic being studied. The following
sections give the answers to those questions, so far as ans-
swers were found in this study.

RESEMBLANCES AND DIFFERENCES BETWEEN
LITTER MATES

The reasons for studying the degree to which litter mates
resemble each other are two-fold. First, such studies may
tell something about the extent to which individual differ-
ences are hereditary and how much they are determined by
each environmental influence which can be measured directly
or isolated by indirect methods. Second, such studies will
go far toward answering the pragmatic question of how
dependable are results based on one, two, three, four, or n
pigs as an estimate of what would be true of the entire litter,
or (which is a different thing) as a basis for estimating the
real breeding value of one or both parents.

Five characteristics which could be measured objectively
were studied. They were: Length of body, thickness of back
fat, thickness of belly, daily gain, and yield of export bacon.
Data concerning economy of gain were not available for indi-
vidual pigs, since the four litter mates were fed together
and there is no way of determining how much feed each pig
ate. However economy of gain was included in the studies
which dealt with litter averages.

Individual data on the other five characteristics were
studied in the following way. From the twenty-second an-
nual report all litters were selected in which two gilts and two
barrows all finished the test. There were 287 such litters,
distributed among stations as follows:

- Bregentved  - 53 litters
- Elsesminde   - 30   ”
- Haraldskjaer -94   ”
- Hønå   - 38   ”
- Over Løjstrup-72   ”

Table 2 shows the individual data concerning thickness of
back fat from the Hønå Station. Tables 2 and 3 illustrate
the method of analyzing the data. When the data from all
five stations were put together, differences between station
averages could also be studied.
Table 2. Individual data concerning thickness of back fat at Hông.

<table>
<thead>
<tr>
<th>Thickness (cm)</th>
<th>Individual data</th>
<th>Distribution of pairs of like-sexed litter mates</th>
<th>Distribution of litters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Frequency Males</td>
<td>Frequency Total for pair (cm)</td>
<td>Frequency Total for litter (cm)</td>
</tr>
<tr>
<td>2.7</td>
<td>1</td>
<td>5.7</td>
<td>12.3</td>
</tr>
<tr>
<td>2.8</td>
<td>1</td>
<td>6.3</td>
<td>13.0</td>
</tr>
<tr>
<td>2.9</td>
<td>1</td>
<td>6.4</td>
<td>13.5</td>
</tr>
<tr>
<td>3.0</td>
<td>1</td>
<td>6.5</td>
<td>13.6</td>
</tr>
<tr>
<td>3.1</td>
<td>1</td>
<td>6.6</td>
<td>13.7</td>
</tr>
<tr>
<td>3.2</td>
<td>3</td>
<td>6.7</td>
<td>13.8</td>
</tr>
<tr>
<td>3.3</td>
<td>2</td>
<td>6.8</td>
<td>13.9</td>
</tr>
<tr>
<td>3.4</td>
<td>7</td>
<td>6.9</td>
<td>14.0</td>
</tr>
<tr>
<td>3.5</td>
<td>2</td>
<td>7.0</td>
<td>14.1</td>
</tr>
<tr>
<td>3.6</td>
<td>15</td>
<td>7.1</td>
<td>14.2</td>
</tr>
<tr>
<td>3.7</td>
<td>9</td>
<td>7.2</td>
<td>14.3</td>
</tr>
<tr>
<td>3.8</td>
<td>3</td>
<td>7.3</td>
<td>14.4</td>
</tr>
<tr>
<td>3.9</td>
<td>8</td>
<td>7.4</td>
<td>14.5</td>
</tr>
<tr>
<td>4.0</td>
<td>8</td>
<td>7.5</td>
<td>14.6</td>
</tr>
<tr>
<td>4.1</td>
<td>5</td>
<td>7.6</td>
<td>14.7</td>
</tr>
<tr>
<td>4.2</td>
<td>1</td>
<td>7.7</td>
<td>14.8</td>
</tr>
<tr>
<td>4.3</td>
<td>1</td>
<td>7.8</td>
<td>14.9</td>
</tr>
<tr>
<td>4.4</td>
<td>1</td>
<td>7.9</td>
<td>15.0</td>
</tr>
<tr>
<td>4.5</td>
<td>1</td>
<td>8.0</td>
<td>15.2</td>
</tr>
<tr>
<td>4.6</td>
<td>1</td>
<td>8.1</td>
<td>15.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8.2</td>
<td>15.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8.3</td>
<td>16.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8.6</td>
<td>16.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Number</th>
<th>76</th>
<th>76</th>
<th>38</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total thickness</td>
<td>279.2</td>
<td>267.0</td>
<td>546.2</td>
</tr>
<tr>
<td>Mean thickness</td>
<td>3.67</td>
<td>3.51</td>
<td></td>
</tr>
</tbody>
</table>

Sum of squares = 1978.08

Table 4 shows for all five characteristics a summary of what was found from the kind of analysis illustrated in table 3. In this analysis, it seems impossible to eliminate sampling errors, which may be considerable in a sample of data no larger than these. The negative results obtained for sex and litter interaction and for sex and station interaction in the case of two characteristics were not statistically significant and are interpreted as sampling errors. Many of the positive figures of small size are not statistically significant and may have been only sampling errors, although they are presented here at their face value. Dismissing the insignificant negative results as non-existent increases slightly the apparent importance of other sources of variance in the same characteristic, but this cannot have been a large effect, and no other way was found to treat it. The test of significance was the Z-test given by Fisher for differences between mean squares such as are shown in the upper part of table 3.

As seen in table 4, sex has an important influence on thickness of belly and is fairly important for thickness of back fat.
TABLE 3. ANALYSIS OF VARIANCE OF DATA IN TABLE 2. (ORIGINAL DATA EXPRESSED IN MILLIMETERS.)

<table>
<thead>
<tr>
<th>Variance due to</th>
<th>D/f</th>
<th>Sum of squared deviations</th>
<th>Mean square</th>
</tr>
</thead>
<tbody>
<tr>
<td>All causes</td>
<td>151</td>
<td>1535.34</td>
<td>10.17</td>
</tr>
<tr>
<td>Sex in general</td>
<td>1</td>
<td>97.92</td>
<td>97.92</td>
</tr>
<tr>
<td>Remainder</td>
<td>150</td>
<td>1437.42</td>
<td>9.58</td>
</tr>
<tr>
<td>Causes common to litter mates</td>
<td>37</td>
<td>653.84</td>
<td>17.67</td>
</tr>
<tr>
<td>Remainder</td>
<td>113</td>
<td>783.58</td>
<td>6.93</td>
</tr>
<tr>
<td>Sex interaction with litter differences</td>
<td>37</td>
<td>279.58</td>
<td>7.56</td>
</tr>
<tr>
<td>Between litter mates of the same sex</td>
<td>76</td>
<td>504.00</td>
<td>6.63</td>
</tr>
<tr>
<td>Within litters, including sex</td>
<td>114</td>
<td>881.50</td>
<td>7.73</td>
</tr>
</tbody>
</table>

Theoretical variance in an infinite population of pairs, the two members of each pair being of opposite sex and from different litters, extending the analysis indicated by R. A. Fisher in his discussion of "A" and "B" in section 40 of "Statistical Methods for Research Workers."

<table>
<thead>
<tr>
<th>Cause or kind of variance</th>
<th>Portions of variance</th>
<th>In actual units</th>
<th>As a percentage of the total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual variance</td>
<td>6.63</td>
<td>60.7</td>
<td></td>
</tr>
<tr>
<td>Sex and litter interaction</td>
<td>.46</td>
<td>4.2</td>
<td></td>
</tr>
<tr>
<td>General sex difference</td>
<td>1.20</td>
<td>10.9</td>
<td></td>
</tr>
<tr>
<td>Causes affecting all litter mates alike</td>
<td>2.64</td>
<td>24.2</td>
<td></td>
</tr>
</tbody>
</table>

Correlation between litter mates:
(a) not allowing for sex = \( \frac{10.17 - 7.73}{10.17} = .24 \)
(b) in data corrected for the general sex difference = \( \frac{9.58 - 6.93}{9.58} = .28 \)

TABLE 4. PERCENTAGES OF THEORETICAL VARIANCE FROM EACH SOURCE. (COMBINED DATA FROM ALL FIVE STATIONS.)

<table>
<thead>
<tr>
<th>Sources of variance</th>
<th>Body length</th>
<th>Thickness of back fat</th>
<th>Thickness of belly</th>
<th>Daily gain</th>
<th>Percentage of export bacon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual variance</td>
<td>62.2*</td>
<td>56.0</td>
<td>45.7</td>
<td>62.2*</td>
<td>82.6*</td>
</tr>
<tr>
<td>General sex difference</td>
<td>4.5*</td>
<td>19.2*</td>
<td>28.1*</td>
<td>.2*</td>
<td>.9*</td>
</tr>
<tr>
<td>Sex and litter interaction</td>
<td>negative*</td>
<td>1.7*</td>
<td>3.3*</td>
<td>1.4*</td>
<td>negative*</td>
</tr>
<tr>
<td>Sex and station interaction</td>
<td>negative*</td>
<td>1.2*</td>
<td>.5*</td>
<td>.5*</td>
<td>negative*</td>
</tr>
<tr>
<td>Differences between stations</td>
<td>2.2*</td>
<td>.5*</td>
<td>8.6*</td>
<td>11.6*</td>
<td>1.0*</td>
</tr>
<tr>
<td>Things common to litter mates</td>
<td>31.2*</td>
<td>21.4*</td>
<td>13.8*</td>
<td>24.1*</td>
<td>15.5*</td>
</tr>
</tbody>
</table>

\*Not significant. Probability of a chance difference this large or larger is greater than .05
\| Of doubtful significance. P is between .01 and .05
\‡Statistically significant. P is less than .01

Sex has a statistically significant influence on body length and on yield of export bacon, but this is small compared with other causes of variance. There was no significant sex difference in daily gain. Probably there was no genuine interaction between either sex and litter or sex and station differences, although the latter appeared to be statistically sig-
significant in the case of thickness of back fat, and both of them are possibly significant in some other characteristics.

There was an important difference between the stations in daily gain and in thickness of belly. The other three characteristics showed station differences which may perhaps be significant in the statistical sense but are certainly too small to be important. Such a significant difference between station averages may arise from differences in management or differences in the general characteristics of the swine population in different parts of Denmark. Each breeding center normally sends its test pigs always to the same testing station, with a few exceptions in cases when there are no empty pens left at some testing stations and there is space available at others. Hence regional differences in the kind of breeding stock might cause differences in the averages at the various testing stations. For example, the average thicknesses of belly for the swine from the two stations on Zealand were 3.15 and 3.17 cm, while the same characteristic for the two Jutland stations averaged 3.29 and 3.27 cm. It is possible either that conditions of feeding and management at the two Zealand stations were so different from those at the two Jutland stations that they caused this difference or that the genetic characteristics of the general population of swine in the Jutland breeding centers were different from the swine in the breeding centers which send their pigs to the Zealand stations. The data do not decide between these two hypotheses.

The figures in table 4 picture the relative importance of various groups of causes which produce the individual variations in these five characteristics. For all five characteristics, things which apply only to the individual pigs are the most important single group of causes. This group of causes would include about half of the hereditary causes of difference, plus the environment which varied from pig to pig, plus the effect of whatever random error there may have been in measuring or recording these things.

The sex difference and the station difference are important for only two of the five characteristics, although they have some slight effect on body length also.

The things common to litter mates within stations would include about half of the hereditary differences. Also the effects of that environment which is common to all litter mates would be here. If one were to assume that the differences in the environment from litter to litter at the same station were not important enough to affect these measured characteristics of the pigs, and if one could also assume
that there was neither extreme assortative mating nor an excess of extreme inbreeding over extreme outbreeding in producing these pigs, then one could obtain a crude maximum estimate of the extent to which each characteristic is hereditary (in the narrowest sense of that word) by doubling the bottom row of figures given in table 4. Since such assumptions are undoubtedly too extreme, all that is thus accomplished is to find upper limits for the answer to the question of how hereditary the variations in each of these traits really were in this population. Such maximum estimates vary from 62 percent in the case of body length to 28 percent in belly thickness.

In any interpretation which might be made of these figures, it should be kept in mind that they are percentages of the variance found in data not corrected for sex and not corrected for station differences. Such corrections if made would remove from table 4 variance ascribable to sex and station. The variance common to litter mates would then be recomputed as a percentage of the variance remaining in the sex-and-station-corrected data. For example, in the case of belly thickness in such corrected data, a maximum estimate of the importance of heredity would be to double the percentage which 13.8 is of $13.8 + 45.7$. This gives a maximum estimate of 46 percent of the variance in belly thickness in sex-and-station-corrected data as possibly due to hereditary differences between the pigs. This is to be contrasted with 28 percent of the variance in the uncorrected data.

The figures in table 4 concern variance in the records of individual pigs. In most practical uses made of swine progeny-testing data, litter averages are used. If those were all four-pig litters evenly balanced for sex, the sex variance would disappear and the variance coming from sources pecu-

---

*This includes all those gene effects which can be expressed by any scheme of assuming that each gene, when substituted for its allele in combinations, adds to or subtracts from the characteristic it affects a constant amount, regardless of what other genes are already present in that combination. For more precise definition and discussion of this definition, see Fisher's "The genetical theory of natural selection" (1930), pages 30-34, where it is discussed under the term, "genetic variance", or Wright's (1933) definition (Journal of Genetics 30:245) of variance due to "additive gene effects". This narrow definition excludes some variance ordinarily called "hereditary" in the broader sense such as deviations from this scheme which result from dominances, and from complex non-additive interactions (epistasy) between each gene and others, and from the fact that certain genotypes may be more liable than others to environmental variations. In this bulletin the computations of the portion of the variance which comes from additive gene effects were made as if the non-additive gene interactions contributed nothing to the correlations between relatives. Since Wright has shown (1933) that the correlation between relatives on account of these non-additive interactions cannot be less than the square of the correlations on an additive scale, the figures given in this bulletin for the additive portion of the variance due to heredity include an uncertain portion of the variance from non-additive effects of gene combinations along with the whole of the purely additive combination effects."
liar to each individual pig would be divided by four. Table 4 would thus be changed to the following if it concerned variance in litter averages instead of variance in individual pigs.

<table>
<thead>
<tr>
<th>Source of variance</th>
<th>Body length</th>
<th>Thickness of back fat</th>
<th>Thickness of belly</th>
<th>Daily gain</th>
<th>Percentage of export bacon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Things peculiar to individual pigs</td>
<td>31.8</td>
<td>39.0</td>
<td>33.7</td>
<td>30.4</td>
<td>55.5</td>
</tr>
<tr>
<td>Station differences</td>
<td>4.5</td>
<td>1.4</td>
<td>25.4</td>
<td>22.6</td>
<td>2.7</td>
</tr>
<tr>
<td>Things peculiar to each litter</td>
<td>63.7</td>
<td>59.6</td>
<td>40.8</td>
<td>47.0</td>
<td>41.8</td>
</tr>
</tbody>
</table>

In the data actually reported the litters are not always perfectly balanced for sex. Hence there remains some variance from sex differences, which may be considerable in the two thicknesses and noticeable in body length. Also in actual practice there are litters where one pig dies or is discarded for unthriftiness and the litter average is based on only the three pigs which finish. The variance among the averages of such litters would certainly include some sex differences and the variance due to things peculiar to individual pigs would be one-third instead of one-quarter as large as that variance among individual pigs.

Table 5 shows the actual correlations between litter mates and the correlations to be expected (so far as this sample is truly representative) if all data were corrected for the sex difference and for the station differences. Whether it is legitimate thus to correct for the station differences depends upon whether the reasons for the station differences are genetic or environmental—a point upon which these data are non-committal—and upon the use which is to be made of the corrected data.

The size of the correlation between litter mates provides
an answer to the practical question of what is gained by testing four litter mates instead of three or two or some other number. In the Danish, Swedish and Dutch testing stations four are started on test and if more than one dies or is discarded, the whole litter is removed from the test, as it is generally believed that the results from testing one or two pigs are not reliable enough for use as indicators of what other pigs from that mating would do. In Germany, however, extensive use is made of a similar progeny-testing system in which only two pigs from each litter are tested and the lot is discarded if either pig fails to finish. Figure 22 shows, after the manner of Wright’s path coefficients, how the average performance of a test sample of n pigs chosen at random is correlated with the average performance of all (t) pigs in the litter. The correlation between the average of n and the average of t approaches \[ \frac{nr_{oo}}{1 + (n-1)r_{oo}} \]
as \( t \) becomes indefinitely large. When \( t \) is indefinitely large, \( A_t \) may be considered the "true" average for that litter if all sampling error due to individual variations could be eliminated. The correlation between litter mates is the only observed biological fact which enters this formula. Figure 23 shows for several values of \( r_{oo} \) how the correlation between the sample and an indefinitely large number of litter mates varies with \( n \). The correlation rises with \( n \), sharply at first but at an ever-decreasing rate.

The formula and graphs describe the case when the test pigs are chosen at random. If the test pigs are selected with intent to get a representative sample, the correlations should be higher where \( n \) is small but would not rise at so rapid a rate with \( n \). If the samples from some herds are intentionally selected to do better than is really typical of the litter but are not so selected in other herds, the correlations should be lower than those pictured but would rise more rapidly with increasing \( n \) (since the possibilities of such selection become limited sharply as \( n \) rises). The effects of selection in distorting the picture shown in fig. 23 are probably small, since the pigs must be selected before they average 44 pounds in weight, the sex requirements set some limits on selection, the breeder will often wish to save for breeding purposes some of those he thinks are the very best, and finally these traits (except perhaps for body length) can not be estimated very closely on the live pigs, even at the end of the feeding period. From the standpoint of accuracy, fig. 23 shows that
a larger sample is always to be desired but, since the testing costs for pigs after the first one in each litter must rise almost in proportion to their number, the maximum return of useful information per unit of expense must be passed while \( n \) is still fairly small. Besides depending on the size of \( r_{oo} \), the exact size of \( n \) which will be most practical may vary from country to country or from time to time according to costs and according to how ready the breeders are to make full use of the information. From the slope of the curves in fig. 23 and from practical considerations of litter size, etc., it seems unlikely that the optimum size of test litter would ever be less than two or more than five.

If we ask how \( n \) affects the correlation between the average of \( n \) test pigs and the genotype or real breeding value of either or both parents, the correlation between litter mates (\( r_{oo} \)) must be broken up into at least two main parts, that due to common parentage and that due to common environment, before an answer can be had. That is shown in fig. 24 where \( r_{oo} = e^2 + 2a^2 b^2 g^2 h^2 (1 + m) \). However, the correlation between sire's genotype and test sample of course does not contain any term for the effect of common environment on litter mates. In the definition of terms used in fig. 24, the "sire's genotype" is the sum of the average effects of all genes the sire possesses. It is not likely that all genes actually do combine additively. The portion of the gene combination effects which can be expressed additively by a least squares scheme is represented by \( g^2 \). The portion of the actual individual variance which is due to differences in the gene combination of various pigs is represented by \( h^2 \). Therefore \( gh^2 \) is the portion of the actual individual variance which is hereditary in the narrow sense, i.e. which can be expressed by an additive scheme for evaluating average effects of genes. Such of the non-additive gene combination effects as contribute anything to the correlation between litter mates (for example about one-fourth of the dominance deviations from an additive scheme) in fig. 24 are included under \( e^2 \) which is thus to be considered as including all the causes for litter mates resembling each other except the fact that they are from the same parents, each of which has a certain genotypic or breeding value. The path coefficient from genotype of parent to genotype of offspring is \( ab \) (8) and is never much larger or smaller than .5 unless the parents and offspring differ widely in their degree of inbreeding. This \( ab \) is only a mathematical expression for the extent to which the laws of Mendelian segregation and recombination permit the genotype of the parent to determine the genotype of the offspring.
Diagram of Relation Between Sires Breeding Value and The Performance of One Test Litter of His Progeny

![Diagram of biometric relations between performance of a test litter and breeding value of sire and dam.](image)

Probably the simplest way to show how variations in $n$ affect the usefulness of the litter average as an indicator of the breeding value of the parents is fig. 25 which shows, for two values of $r_{oo}$ and several values of $e^2$, how the correlation between the litter average and the average genotype of the two parents increases with $n$. The formula for this correlation is

$$ r_{oo} = \frac{abgh (1+m)}{2} $$

The correlation between genotype of sire and genotype of dam, which may arise either from mating related individuals (i.e. from inbreeding) or from assortative mating based on the animals' own performance or appearance, or on that of their relatives, is represented by $m$, which need not be separately evaluated here if values are assigned to $r_{oo}$ and $e^2$.

Similar information about the general correlation between the litter average and the genotype of one parent can be had by multiplying each point in fig. 25 by the term $\sqrt{\frac{1+m}{2}}$. An exact evaluation of $m$ is not available but the inbreeding
currently practiced is almost negligible, and it seems unlikely that \( m \) from assortative mating in this population could go as high as \( .2 \).

The upper lines in fig. 25 are identical with the corresponding lines in fig. 23, but the other lines in fig. 25 show that the benefits to be gained by testing more litter mates are especially small when any considerable part of the correlation between litter mates is due to the common environment under which they were kept.

The correlations between the progeny tests of two relatives will be the product of two such terms as those pictured in fig. 25 times whatever correlation exists between the genotypes of the two relatives concerned. Such correlations will therefore vary with \( n \) as the square of the correlation pictured in fig. 25. That is, they will be much lower than those shown, especially at the start, and will show less curvature than the graphs in fig. 25.

Since most practical applications will involve the correlation between the progeny tests of two relatives rather than the correlation between one animal's real breeding value and its own progeny test, fig. 25 exaggerates the practical usefulness of the test litter average when \( n \) is very small somewhat more than it does when \( n \) is large. That is, there is relatively more to be gained in most practical applications by having \( n \) large than is apparent from fig. 25.

The wide differences between the curves in fig. 25 emphasize the importance of knowing something more definite

---

**Fig. 25.** Graphs showing how the performance of the test sample improves in accuracy as an indicator of the average genotype of the parents when the number of pigs in the test sample increases from 1 to 8.
about \( e^{2/r_{oo}} \). One possible approach to that is through a study of the resemblance between half-brother litters, although this introduces other complications which prevent a definite answer.

**RESEMBLANCES BETWEEN PATERNAL HALF BROTHERS AND SISTERS**

The resemblance between paternal half-sib litters was studied to get some light on how much of the variation was really hereditary and also to find how the reliability of the progeny test of a boar depended on the number of litters tested.

The data consisted of the first litters by the sires of the boars which sired the 287 litters which were studied in the section on correlation between litter mates. Thus the litters studied in this section were paternal half-sibs to the sires of the litters studied in the preceding section. In a few cases, due to overlapping of generations, some of the 287 litters were included both in the preceding section and in this one. There were 64 sires which had five or more litters each, 9 which had four litters each and 10 which had three litters each. The litters studied for each sire where possible were the first five in which exactly two gilts and two barrows finished the test. For sires which had less than five such litters, other litters in which four pigs finished the test but were not evenly distributed for sex were used as far as necessary to get five litters for each sire. In a very few cases there were not enough of these and some litters containing only three pigs were included. Litters not evenly balanced for sex were corrected for the average sex difference in body length, thickness of back fat and belly thickness found in the preceding section. There were 386 litters studied, but because most of them were included in groups of five by the same sire, the total amount of evidence they furnish on the magnitude of the correlation between paternal half-sib litters is about the same as if there had been 122 pairs of litters, each by a different sire. The sampling errors are therefore high.

Figure 26 shows a path coefficient diagram of the basis for the correlation between paternal half-brother litters. Besides the symbols used previously, \( c \) indicates the average correlation existing between the genotypes of the different mates of the same boar. Many of these would be half-sisters. Some would be even more closely related but many would be less so. No exact study of this was made, but from the swine
breeding customs concerned it is unlikely that the average value of c would be higher than .2 or lower than .1. Besides this value of c arising from blood relationship between the sows, something additional from assortative mating might be included if the ideals of different breeders were highly divergent. On account of the unified goals for swine breeding and marketing in Denmark, it seems unlikely that assortative mating can have made an important contribution to c.

The environment pictured in fig. 26 is that which is common to the different paternal half-sib litters and doubtless would be less than that common to litter mates. Environment common to litters which are paternal half-sibs would arise from the fact that such litters would nearly all be produced at the same breeding centers, and any peculiarities of ration, management or sanitation prevailing at that center would tend to affect all of these litters alike. Also the different paternal half-sib litters would generally be produced within a comparatively short time, and many of them would actually be contemporary at the testing stations. Any tem-
porary conditions of weather, sanitation, contagion or peculiarities of ration would to a considerable extent apply alike to paternal half-sib litters. No way was found for measuring directly the importance of the effects of this common environment, although the figures in table 4 indicate that differences between testing stations are not important unless it be in daily gain or in belly thickness.

As will be seen from fig. 26 the portion of the individual variance due to additive gene effects \((h^2g^2)\) is equal to 
\[
(r_{AA} - e_t^2) (1 + 3r_{oo})^{\frac{1}{4}a^2b^2(1+c+2m)}
\]
so long as there are no sudden changes from outbreeding to intense inbreeding, or the reverse. Hence this portion of the individual variance is approximately 
\[
\frac{(r_{AA} - e_t^2)}{1+c+2m}
\]
The value of \(c\) will probably not be far from .15 to .20 (for example if two of the five dams were full sisters, two others were half sisters to each other and to the first two and if the fifth were unrelated to the other four, \(c\) from blood relationship would be .175) and \(m\) will almost certainly be less, owing to the general practice of avoiding close breeding as much as possible. If these values are approximately correct this fraction which multiplies \(r_{AA} - e_t^2\) will range from a little over 1 to almost 2.

Table 6 shows the correlations actually found between paternal half-sib litters. In the second column is the percentage of the individual variance which is genetic in the narrow sense of the word, assuming that \(c\), \(m\), and common environment are all zero which is too extreme an assumption and gives maximum values for the importance of additive gene effects in these data. In the last column environment is still supposed to be zero, but \(c\) and \(m\) are assigned what is probably a higher combined value than they actually would

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Correlation found*</th>
<th>Portion of individual variance due to additive gene effects, (h^2g^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rate of gain</td>
<td>.24</td>
<td>(r_{AA} - e_t^2)</td>
</tr>
<tr>
<td>Economy of gain</td>
<td>.29</td>
<td>(r_{AA} - e_t^2)</td>
</tr>
<tr>
<td>Yield of export bacon</td>
<td>.27</td>
<td>(r_{AA} - e_t^2)</td>
</tr>
<tr>
<td>Thickness of back fat</td>
<td>.44</td>
<td>(r_{AA} - e_t^2)</td>
</tr>
<tr>
<td>Thickness of belly</td>
<td>.40</td>
<td>(r_{AA} - e_t^2)</td>
</tr>
<tr>
<td>Body length</td>
<td>.39</td>
<td>(r_{AA} - e_t^2)</td>
</tr>
</tbody>
</table>

*Standard errors are about .08.
**Still to be multiplied by \(1+3r_{oo}\)
have. The actual value found for the correlation between litter mates in the preceding section was used. These last two columns in table 6 give what are probably maximum and minimum values, so far as c and m are concerned, but are almost certain to be too large in view of the assumption in them that environmental effects contribute nothing to paternal half-sib correlations. They should be multiplied by that fraction of the paternal half-sib litter correlation which is not due to common environment in order to reach an unbiased estimate of the extent to which each characteristic is hereditary. Unfortunately no way was found to get a direct measure of the importance of common environment. In this connection it is well to call attention to the fact that common environment may well play a larger role for some of these six characteristics than for others. For instance, it is easier to conceive of such common environmental effects having an important influence on rate of gain or on thickness of back fat than to imagine such an effect on body length.

These estimates of the extent to which these characteristics are hereditary are based on a different set of data from similar estimates which were presented in table 4. Both are unsatisfactory in their lack of a direct measurement of the effect of common environment, and both are subject to considerable sampling error, but they do not disagree very widely, and the fact that they rest on different sets of data makes the general picture which they show somewhat more plausible.

As regards the practical question of what accuracy is gained by testing more and more litters from the same sire, it need only be pointed out that the correlation between the average of q litters already tested and the average of an indefinitely large number of litters which might be tested under the same general conditions, varies with q, in just the same way that the similar problem for number of pigs tested in each litter was pictured in the graph in fig. 23.

This tells little about the reliability of the progeny average as an indicator of the sire's genotype since that correlation can not be observed directly. That part of the directly observed correlation between paternal half-sib litters which is not due to common environment is a very little more \((\frac{1+2m+c}{1+2m+m^2})\) times as much) than the square of the correlation between sire and the litter average. That is not very enlightening, however, so long as there is no direct measure of the part played by common environment in the correlation between paternal half-sib litters. The correlation between a sire's
real breeding value and the average of the tests of q of his litters will rise with q less sharply, the more \( r_{AA} \) is composed of the effects of common environment and the larger c is. This will correspond somewhat to the picture which is shown in fig. 25, but does not simplify quite as much as that does.

**CORRELATION BETWEEN MATERNAL HALF-SIB LITTERS**

Partly for its own interest and partly to verify the findings from the correlation between paternal half-sib litters, the correlation between maternal half-sib litters was computed for these same six characteristics. Since there is no index of dams of tested litters in the printed annual reports, it would be difficult to find the maternal half-sib litters from the printed reports alone. Recourse was had to the sow progeny files kept by Mr. M. P. Østerlund Madsen. They were kindly placed at the author's disposal for this purpose. In these files a card is kept for the dam of each tested litter, and when a second litter from the same dam completes the test, the essential items from both litters are recorded on the back of the same card. Thus by glancing through these card files it was easy to find all cases of sows from which two or more litters had been tested since the card files were begun some 4 or 5 years ago.

Three hundred such sows were found which had a total of 337 independent pairs of half-sib litters. The extra 37 pairs come from cases where a sow had three or more litters tested. If all three were half-sib to each other, the first was paired with the second and the first was paired with the third for computing these correlations. If, however, the first two were full-sibs to each other, then the first was paired with the third and the second was paired with the third. In one case a sow had four tested litters, all of them half-sibs to each other. In this case the first was paired with the second and the third with the fourth in computing these correlations. For 17 of the pairs, the average daily gain made by the later litter of the pair was not yet recorded in the office files and time was not available to secure those figures from the original books at the testing station. Hence information on daily gain among pairs of maternal half-sib litters is based on only 320 pairs instead of 337 pairs.

The findings are shown in table 7 which is comparable with table 6. The biometric relations underlying maternal half-sib correlations are as pictured in fig. 26, except that sire and dam should be interchanged in that figure so that
TABLE 7. CORRELATION BETWEEN MATERNAL HALF-SIB LITTERS.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Correlation found*</th>
<th>Portion of individual variance due to additive gene effects, h^2g^2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>If c, m and c₁ each = zero</td>
</tr>
<tr>
<td>Rate of gain</td>
<td>.28</td>
<td>.46</td>
</tr>
<tr>
<td>Economy of gain</td>
<td>.12</td>
<td>.12**</td>
</tr>
<tr>
<td>Yield of export bacon</td>
<td>.21</td>
<td>.32</td>
</tr>
<tr>
<td>Thickness of back fat</td>
<td>.34</td>
<td>.55</td>
</tr>
<tr>
<td>Thickness of belly</td>
<td>.28</td>
<td>.44</td>
</tr>
<tr>
<td>Body length</td>
<td>.41</td>
<td>.81</td>
</tr>
</tbody>
</table>

*Standard errors are about .05.
**Still to be multiplied by 1+3r₀p₀.

it would indicate several litters from the same dam but by different sires. Also general breeding practices are such that the different sires mated to the same sow are much less likely to be closely related to each other than are different sows mated to the same boar. That is, c in fig. 26 might reasonably be expected to be of the magnitude of .15 to .20 for paternal half-sib litters but probably would be very little above zero for maternal half-sib litters.

Comparison of tables 6 and 7 shows a good agreement, the biggest discrepancy being in the case of economy of gain, a difference which is almost twice its standard error. An arithmetic average of the six correlations shown in table 7 shows them to be .07 lower than the six correlations in table 6. One reason for this is the fact already discussed that c would naturally be smaller in table 7 than in table 6. Another difference between the two data is that more of the paternal half-sibs would have been tested contemporaneously with each other. Therefore any uncontrolled variation in the environment such as weather, epidemic sickness or temporary change in feeding would naturally have made somewhat larger environmental contributions to the correlations in table 6 than to those in table 7. Another difference between the causes underlying these correlations is that the nursing ability of the sow would have tended to make maternal half-sib litters alike, whereas this would not have been operating to make paternal half-sib litters alike. Thus of these three apparent reasons for differences between tables 6 and 7 (other than sampling errors which of course are rather large in samples of data no larger than this), two would operate to make the correlations in table 6 larger and one would operate to make the correlations in table 7 larger. Whether the two (the larger c and the contemporaneous exposure to environmental fluctuations, especially during the testing per-
iod) are larger than the opposing one (pre-natal environment and nursing ability of the dam) we can only guess, but this might be a cause of the slight decrease from table 6 to table 7.

The last two columns in table 7 are computed in exactly the same way as the corresponding columns in table 6. The same qualifications apply to the middle column of table 7 as to the corresponding column of table 6. The last column of table 7 is a more extreme assumption in the minimum direction than is the corresponding column in table 6 because c has a smaller value. Neither table throws much light on how much of the variance in economy of gain is due to additive gene effects.

No extreme degree of confidence in the figures in the last columns of tables 6 and 7 is justified so long as they involve the assumption that common environment contributes nothing to the half-sib litter correlations. The figures in table 7 include little if any effect of temporary environmental influences at the testing stations, but neither set of figures is free from environmental conditions which might prevail at some of the breeding centers but not at others, and those figures in table 7 may contain something from pre-natal environment and from peculiarities in the nursing ability of each dam. It does not a priori seem likely that such environmental influences could have had a noticeable effect on body length, and it is questionable whether they could have influenced the other three characteristics which do not directly involve gain. They might logically be expected to have had some influence on gain.

The general conclusion from these two tables seems to be that body length is the most hereditary of these six traits with thickness of back fat a close second. Thickness of belly and rate of gain seem to come third and fourth, but some doubt is cast on this because of the distinct station-to-station difference shown in table 4 for these traits. Nothing very definite can be said about economy of gain in the absence of information about the correlation between individual litter mates for that characteristic.

In computing the correlation between maternal half-sib litters it was noted that the variance of the population of earlier litters was for all six characteristics about 30 percent greater than the variance of the population of later litters from the same sow. The probability of this large a difference resulting from chance alone in such a large body of data is about .04 for any one of the six characteristics by itself. It seems impossible that this difference in all six of the characteristics could have been a sampling accident. Diligent
search was made for a plausible explanation of this, either in the changing age of the dam or in whatever conditions govern the choice of sows which are to have a second litter tested, but no certain explanation was found. Two were suggested. The first is that many sows among those which get tested a second time do so only because their first test litters did poorly and yet the sow's owner feels sure (for reasons which do not appear in the official data) that the sow is good enough to keep and will do better if tested again. There might also be a few cases where a sow which did unusually well in her first test litter is therefore tested again in the hope of getting from her a phenomenal record which will have much advertising value (as is sometimes done in official testing of dairy cows in the United States). Either or both of these tendencies would lead to a lower-than-normal proportion of intermediate litters among the first test litters, while the regression naturally to be expected on account of this selection of extremes would make the group of second test litters more uniform. The second plausible suggestion was that there is a curvilinear effect of age of the dam, especially important between first litters and later ones, and that the population of first test litters consisted of a mixture of many which really were the first litters produced by those dams and many others which were second or later litters produced (although the first litters tested), while the population of later test litters studied here could not have contained any genuinely first litters. Either explanation would lead one to expect the second litters to show more desirable averages than the first ones, but that would also be expected merely from the time trend in most of the characteristics whether that trend be from improving environment or because of improved breeding whereby it would happen more often than not that the later sire was genetically superior to the earlier one. The averages actually do show this improvement in all six characteristics, the actual figures being: An increase of .0088 pounds in daily gain, a decrease of 0.016 units of feed required per unit of gain, an increase of 0.16 percent in yield of export bacon, a decrease of 0.14 cm. in thickness of back fat, an increase of 0.048 cm. in thickness of belly, and an increase of 0.31 cm. in body length.

The population of litters used in computing the correlation between paternal half-sibs was also studied from this point of view. The dams of this group probably had an age distribution typical of dams in general. In four characteristics this group agreed more closely with the group of early litters, but in the other two it more nearly agreed with the
TABLE 8. STANDARD DEVIATIONS OF TEST LITTER AVERAGES IN THREE POPULATIONS.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Sows with two or more litters tested</th>
<th>Litters on which table 6 is based</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Earlier litter tested 336 d/f*</td>
<td>Later litter tested of pair 336 d/f*</td>
</tr>
<tr>
<td>Gain (pounds per day)</td>
<td>.117</td>
<td>.104</td>
</tr>
<tr>
<td>Economy of gain (feed per unit of gain)</td>
<td>.210</td>
<td>.182</td>
</tr>
<tr>
<td>Yield of export bacon (per cent)</td>
<td>1.15</td>
<td>1.02</td>
</tr>
<tr>
<td>Thickness of back fat (centimeters)</td>
<td>.314</td>
<td>.274</td>
</tr>
<tr>
<td>Thickness of belly (centimeters)</td>
<td>.139</td>
<td>.120</td>
</tr>
<tr>
<td>Body length (centimeters)</td>
<td>2.01</td>
<td>1.80</td>
</tr>
</tbody>
</table>

*Degrees of freedom. Seventeen less than this were available for estimating the standard deviation of gain in the groups out of sows with two or more litters.

group of later litters. The standard deviations of the litter averages are shown in table 8 for all three groups of data, both as evidence showing this larger variability of earlier litters, and to show in actual units of measurement what may be considered the normal amount of variation among litter averages from this kind of progeny performance testing of swine.

CORRELATION BETWEEN FULL BROTHERS AND SISTERS WHICH WERE NOT LITTER MATES

In the sow progeny cards 43 cases were found of sows which had two test litters sired by the same boar. In five of these, two lots of four pigs had been taken from the very same litter and fed out as separate test lots. That leaves 38 cases of full-sib test litters which were not litter mates. Although the sampling errors are necessarily high for such a small population, the correlations were studied to get some idea of the importance of temporary environmental circumstances which would affect litter mates alike but would not be expected to affect full brothers and sisters from later litters. If such circumstances are of no importance, then full-sibs born at different times would resemble each other in their performance just as much as litter mates do, and the expected correlation between the average results of two full-sib test lots would be \( \frac{4r_{ss}}{1+3r_{ss}} \) where \( r_{ss} \) is the correlation between litter mates.

Table 9 shows the correlations computed from this population of 38 pairs of full-sib litters and the correlations expected on the hypothesis that full-sibs from different litters
are just as apt to be like each other as full-sibs from the same litter. The correlations between litter mates used in computing this expected correlation were the ones in the upper row of table 5. The observed correlations for the first three characteristics are very low, indicating that a considerable amount of the correlation between litter mates found for two of those was due to contemporary environmental influences. However the large sampling errors involved here and the fact that the expected correlations are based on litter mate correlations derived from a different group of data (although there is no reason to think that the group is any less representative) make it unnecessary to place high confidence in the discrepancy between observation and expectation. Observed and expected correlations for the last three characteristics agree even more closely than might have been expected from the size of the sampling errors involved.

**TABLE 9. CORRELATIONS BETWEEN GROUPS OF FULL-SIBS WHICH WERE NOT LITTER MATES.**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Observed correlation</th>
<th>Expected correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rate of gain</td>
<td>-.00</td>
<td>.67</td>
</tr>
<tr>
<td>Economy of gain</td>
<td>-.02</td>
<td>?</td>
</tr>
<tr>
<td>Yield of export bacon</td>
<td>.09</td>
<td>.43</td>
</tr>
<tr>
<td>Thickness of back fat</td>
<td>.44</td>
<td>.50</td>
</tr>
<tr>
<td>Thickness of belly</td>
<td>.53</td>
<td>.48</td>
</tr>
<tr>
<td>Body length</td>
<td>.63</td>
<td>.66</td>
</tr>
</tbody>
</table>

*Standard errors are about .17 for the very low correlations, about .13 for correlations around .50.

This short study of the full-sib litters therefore is an indication that variations in the two thicknesses and in body length are more highly hereditary than the other three characteristics and makes it probable that temporary fluctuations in environment have considerable influence upon rate of gain, economy of gain, and yield of export bacon. The large sampling errors, however, make it necessary to regard this interpretation as very tentative.

There is some question as to whether first and second litters are equally typical of the parents in those cases where two full-sib litters are tested. The breeder has considerable freedom to choose which sows shall have litters tested, and it is possible that a large percentage of those cases where full-sib litters are tested are cases where the breeder feels reasonably sure that the first litter was not truly typical and that the second should make a better record. If that were very generally the case and if the breeder was to any extent right in his opinion in such cases, then the correlation
between full-sib litters could not be as high as if those litters were truly random samples, equally typical of the general population of test litters. Some indication that something of this kind was happening comes from the fact that in four of the six characteristics the second litters had more desirable averages than the first litters. However the averages for rate of gain were identical, and for export bacon the average yield for the second litters was a little less than for the first litters.

**CORRELATION BETWEEN PROGENY TEST OF SIRE AND PROGENY TEST OF SON**

Since neither parent can have its own fattening ability or the quality of its own meat measured directly, there is no possibility of observing a direct parent-offspring correlation as can be done for example, in dairy cattle where the correlation between production of daughter and dam can be studied. The only parent-offspring correlations possible in the present data are correlations between progeny test of offspring and progeny test of parent, or between actual performance of offspring and progeny test of parent. The latter was not studied further, because in most such cases the progeny test of the parent included the offspring that would be correlated with the parent or, if the performance of the particular offspring being studied were excluded from the progeny test of the parent, still those other offspring which made up the parent's progeny test would usually have been born at the same breeding center and often would have been fed and tested contemporaneously with the offspring being used for this measurement. Whatever might have been gained by a study of that kind seems to have been achieved in a more readily interpretable manner by studying the correlation between half-sib litters, both paternal and maternal.

The correlation between progeny tests of parent and of offspring involves only small probability of influence by common environment where the parent and offspring used are sire and son, since it is not often that the son is used in the same herd where his sire was used. On the other hand, the correlation of the progeny tests of parent and of offspring are correlations of averages of the performance of groups of individuals (half aunts and uncles compared with nieces and nephews) who are separated from each other genetically by three Mendelian segregations and recombinations. The biometric basis for this correlation is shown in fig. 27.
The sire-son correlation was computed on part of the 287 litters already used for computing the correlation between litter mates. Each of these litters was regarded as a progeny test of a son. From the pedigree of that son his sire was identified, and from the boar progeny records on file at Copenhagen a search was made for all test litters by that sire. Some of the litters used in computing the litter mate correlation were by boars whose sires had less than five litters tested. When these were discarded, there remained 236 litters by 159 different boars which, in turn, were by 64 different sires, each of which had at least five litters tested. Where more than five litters were available for the sire, the first five which finished with exactly two barrows and two gilts were used. If there were not five of those, then all of those were used and enough which consisted of three of one sex and one of the other were used to make up five test litters for each sire. The data therefore correspond to those pictured in fig. 27 for the case: \( q = 1 \) and \( p = 5 \). On the as-
assumption that there is no particular tendency for the sire's litters and the son's litters to have been tested under the same peculiar environment and that there is no particular tendency for sire and son to be mated to the same peculiar kind of sows (that is, that the term: "Dam₁. Dam₂" equals zero), the formula for the observed correlation reduces to:
\[
g^2 h^2 \frac{(1+3m+c)}{2(1+3r_{oo})} \sqrt{\frac{5}{1+4r_{ss}}}.
\]
The second of these assumptions seems reasonable, but the first may not be absolutely true, since swine breeding in Denmark is somewhat localized so that the sire's and the son's offspring have some tendency to be tested at the same official testing station. To remove this regional effect (which may be either genetic or environmental), each correlation was computed both as a gross correlation for the single population of 236 litters, and then that gross correlation was separated, according to the station at which the son's litters were tested, into a correlation between station means and a correlation between progeny test of sire and of son within station.

Table 10 shows the correlations observed and the values computed (from those and from the correlations already found between litter mates and between paternal half-sib litters) for the portion of individual variance which can be attributed to additive gene effects. The standard errors for the observed gross correlations and the "within-station" correlations are about .06. The most surprising thing about table 10 is the presence of negative correlations for the first three characteristics. Since none of these exceeds its standard error by more than a small amount it could, of course, be dismissed as statistically insignificant and does not actually demand an explanation. Nevertheless if these things are hereditary, one would have expected at least a slight positive correlation between sire and son. That is, the observed correlations are not significantly different from zero, but they are significantly different from the positive values to be expected if very much of the individual variations in these characteristics were due to additive gene effects.

There is the possibility concerning the intra-station correlations, especially the one concerning rate of gain, that the differences between station averages are largely environmental but that the breeders, supposing these to be largely hereditary, have gone to considerable trouble to secure sons

---

\[n]Computed as though each of the 236 pairs concerned a different sire and a different son. Since there actually were only 64 different sires and 159 different sons, the standard errors are really a little larger than this, but no way was found to allow exactly for this bias.
TABLE 10. CORRELATIONS BETWEEN PROGENY AVERAGES OF SIRE AND OF SON.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Observed correlation</th>
<th>Portion of individual variance due to additive gene effects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gross 234 d/f</td>
<td>Between station means 3 d/f</td>
</tr>
<tr>
<td>Rate of gain</td>
<td>.06</td>
<td>.78</td>
</tr>
<tr>
<td>Economic gain</td>
<td>-.09</td>
<td>-.24</td>
</tr>
<tr>
<td>Yield of export bacon</td>
<td>.02</td>
<td>.55</td>
</tr>
<tr>
<td>Thickness of backfat</td>
<td>.18</td>
<td>.31</td>
</tr>
<tr>
<td>Thickness of belly</td>
<td>.32</td>
<td>.91</td>
</tr>
<tr>
<td>Body length</td>
<td>.13</td>
<td>.43</td>
</tr>
</tbody>
</table>

*Computed from the observed gross correlations, i.e. on the assumption that differences between station averages are entirely genetic.
**Computed from the correlation within stations, i.e. on the assumption that differences between station averages are entirely due to environmental peculiarities at each station.
†Still to be multiplied by 1 + 3r_{pp}.

of high testing sires. Most of those high testing sires would naturally have been tested at stations where the environmental circumstances were good and the desire to get sons of high testing sires would naturally be most acute in the district where the average performance was low. Hence the sons of those high testing sires would tend more to go to the districts where the station averages were low than to have been scattered at random all over Denmark. Such a condition might have led to a negative intra-station correlation as computed here, but it seems to the writer that the circumstances and breeding practices involved could not have been powerful enough to have had much effect of that kind.

The larger correlations for the last three characteristics indicate them to be more largely hereditary. The last two columns of table 10 present the case for what are probably the maximum values of m and c in these data. The two columns just before them present the case on supposition that mating is practically at random. The truth doubtless lies between these two extreme assumptions. The probable errors of the figures in these last four columns are undoubtedly high, not only because they rest on observed correlations which have fairly high sampling errors but also because the three different correlations involved — that between progeny tests of sire and son, that between litter mates and that between paternal half-sib litters — do not rest on exactly the same sample of data in each case, although there is much overlapping.
SUMMARY OF EVIDENCE ON HERITABILITY

The first three columns of numbers in table 11 show values assembled from tables 6, 7 and 10 for the portion of the individual variance which can be ascribed to additive gene effects. The first column shows the maximum and the second column the minimum values found in any of those tables. The third column shows the average of all values obtained, giving equal weight to each of the three tables and averaging with equal weight the values obtained by using the maximum and minimum values of \( m \) and \( c \) shown in each table. These figures in the third column seem the best estimate possible at present. In these figures in the third column the bias, if any, comes from the assumption that common environment contributed nothing to these correlations. This is probably too extreme an assumption for tables 6 and 7 although probably not far from the truth for table 10. This

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Values of ( h^2y^2 )</th>
<th>Double the littermate correlation corrected for sex and station</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maximum</td>
<td>Minimum</td>
</tr>
<tr>
<td>Rate of gain</td>
<td>.46</td>
<td>-.19</td>
</tr>
<tr>
<td>Economy of gain</td>
<td>.29°</td>
<td>-.11°</td>
</tr>
<tr>
<td>Yield of export bacon</td>
<td>.40</td>
<td>.00</td>
</tr>
<tr>
<td>Thickness of back fat</td>
<td>.80</td>
<td>.29</td>
</tr>
<tr>
<td>Thickness of belly</td>
<td>.72</td>
<td>.22</td>
</tr>
<tr>
<td>Body length</td>
<td>.81</td>
<td>.22</td>
</tr>
</tbody>
</table>

*Still to be multiplied by \( 1 + 3r_{uy} \).

bias might reasonably be expected to be of some importance for rate of gain and for thickness of belly since those two characteristics showed distinct station-to-station differences. The last column in table 11 shows a similar estimate based on the correlation between litter mates, corrected for sex differences and station differences. This is the case where the effect of common environment seems most certain to open the door to considerable error. The figures in this last column also may have a slight bias in the direction of largeness because of dominance deviations from the additive scheme of gene action. Those could have been important enough among full-sibs that they might perhaps have contributed around .04 to .08 to the figures in the last column of table 11. Dominance deviations would scarcely have contributed anything to the figures in the other columns, even though complete dominance were the rule—which is not at
all certain. It will be noted that all figures in the last column, except the one for thickness of belly, are higher than the corresponding averages based on the correlations of tables 6, 7 and 10. The exceptional case of thickness of belly may be explained from the fact that the figures in the last column were computed after correction for station differences and those were considerable in this characteristic.

This leaves a general picture of about half the variance in body length and thickness of back fat being due to additive gene effects, while the figure for thickness of belly is probably a little less, and that for yield of export bacon and rate of gain is around one-fifth; variance in economy of gain is much less. Considerable doubt applies to that conclusion about economy of gain in view of the impossibility of computing a litter mate correlation on this characteristic.

In interpreting these figures it should be remembered that they describe a condition prevailing in this population at this time and that they apply to variance in the performance of individual pigs. The portion of the variance which is due to additive gene effects in this population may be more or less than it was in the population of swine at the breeding centers 10 years ago or than it will be in the population 10 years from now. This portion will change if selection tends to exhaust it in changing the population averages or if more extreme inbreeding is practiced or if the population becomes submitted to a wider (or narrower) range of environments so that the environmental portion is greater (or less). In most practical applications the test litter averages are used instead of the figures for individual pigs. In litter averages the individual and uncontrolled variations which are not the same for litter mates will tend to cancel each other so that the proportion of the variance in litter averages which is due to additive gene effects will be larger than these figures.

For the immediate future the evidence is that there is still abundant additive genetic variance to permit rapid changes in the population in the last three characteristics, if selection for those characteristics in a given direction is constantly practiced. There is also room for noticeable and economically important improvement in rate of gain and in yield of export bacon, although less of what is reached for in each selection will be attained in those two characteristics than in the case of body length and the two thicknesses. The possibility of further rapid improvement in economy of gain is less certain, although there still seems to be possibilities for some slow improvement in this if those animals selected for breeding stock are the ones whose closest relatives have made the
best showing in this respect. The percentage actually gained of what is sought in selecting for economy of gain will be smaller than for the other five characteristics and there will be a bigger proportion of disappointments but there should be some progress for a while at least.

This method of analysis cannot be used to estimate the ultimate limits which various characteristics may reach. As the mean of the population changes, the portion of additive variance remaining subject to selection may also change, but the change in the proportion of variance is generally much slower than the change in the mean itself. Therefore these figures can be used for estimating how much success may be had in selection for the next few generations but become subject to increasing errors when the prediction is extended more than a few generations into the future, because one will not know how rapidly the genetic variance will change as the breed changes. For example, the standard deviation in average body length for test litters is about two centimeters. The portion of this which can be expressed as due to additive gene effects could be produced by \( n \) pairs of equal, non-dominant, cumulative genes each having a frequency of about .5 in the population, or by nearly three times as many of the same kind of genes, each having a frequency a little above .9. Progress (in centimeters) in changing the population mean would be equally great for the next generation in either case but in the former case could continue for many generations without much slackening, while in the latter case the rate of progress would quickly fall off. More important is the possibility that certain epistatic effects of gene interactions could be used to change the breed means distinctly if more use were made of moderate inbreeding within many strains alternating with rare outcrosses.

**NUMERICAL EVIDENCE AS TO THE SELECTION PRACTICED**

The preceding sections have described the changes which have occurred in the means and have analyzed the individual variance to show what portion was due to additive gene effects and might therefore respond to selection. No evidence was included as to how intensively the breeders actually did practice selection for any of these characteristics. Many things might determine a breeder’s actual use of one boar or sow instead of others which he might have used. It is difficult to measure the intensity of the selection actually taking
place in any population. Nevertheless this is important in interpreting the reasons for past changes and in estimating future possibilities.

Two small bits of actual evidence bearing on this question are presented here. They may indicate some useful leads for future study, although they are too scanty to furnish a complete answer themselves.

The first evidence comes from comparing the means of the progeny of sires and the means of the progeny of sons in the data used for computing the correlation between sire's progeny and son's progeny. The group of sons may be considered as unselected for their progeny performance, since all boars which sired litters in which two gilts and two barrows finished the test in the twenty-second report were included, provided their sires had as many as five litters tested by the fall of 1934. Now if breeders actually were paying much attention to the results of these progeny tests in choosing which young boars they would try next, then the sires of this group of sons should have been a selected group of sires and should first of all, have averaged more than their contemporaries who were tested at the same time but whose progeny tests were not so good that breeders thought it worth while to use their sons. In the second place if these sires were selected because they had an unusually good progeny test in the desired direction, then (since the outcome of those progeny tests is not entirely determined by the genotype of the sire but depends also on the genotype of the dam and on many environmental and accidental circumstances) the sons should have shown some regression toward the mean of the race. This might have been offset if the sons chosen for trial were from dams distinctly superior to the average of the sires' mates and if the sons' mates were chosen by selection almost as intense as that practiced on the sons themselves. This is in accord with the principle from "diallel crossing" whereby if two sires are mated to the same group of females, the difference in the real breeding value (genotype in the additive sense) of those sires is twice as great as the difference in their progeny averages. However, the additive genetic portion of the variance in litter averages would need to be at least $\frac{1}{2}$ if this off-setting of the expected regression were to be perfect. At first thought it seems unlikely that such selections could have been so successful as to overcome all the regression arising from the fact that only a portion of the variance in progeny tests can be attributed to additive gene effects. That is, one would expect the entire population of sons to average below their selected sires but
above the mean of the entire group from which those sires were originally selected. Table 12 presents the actual comparison of sire's means and son's means. The expectation is fulfilled in the case of daily gains and economy of gain although both differences are statistically quite insignificant. For the remaining four traits the son's means lie farther in the desired direction than the sire's means did. The statistical significance of the two differences in thickness seems beyond dispute. This comparison conveys therefore the impression either that selection of the dams of sons and mates of sons was intense enough and successful enough to more than offset the expected regression, or that the breed means were being changed by some other method than by retaining for breeding purposes the offspring of the most favorably proved sires. The fact that the sons exceed their sires most in two of the three most highly hereditary traits (table 11) and that one of the two characteristics in which they show the expected regression (economy of gain) seems to be least highly hereditary among the six studied, points toward the former interpretation.

**TABLE 12. WEIGHTED MEANS OF PROGENIES OF SIRE AND PROGENIES OF SONS**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Sire's mean</th>
<th>Son's mean</th>
<th>Difference*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily gain, lbs.</td>
<td>1.442</td>
<td>1.434</td>
<td>+.008 ± .008</td>
</tr>
<tr>
<td>Units of feed per unit of gain</td>
<td>3.322</td>
<td>3.326</td>
<td>-.004 ± .014</td>
</tr>
<tr>
<td>Yield of export bacon, percent</td>
<td>60.17</td>
<td>60.28</td>
<td>-.11 ± .07</td>
</tr>
<tr>
<td>Thickness of back fat, cm.</td>
<td>3.744</td>
<td>3.619</td>
<td>+.125 ± .019</td>
</tr>
<tr>
<td>Thickness of belly, cm.</td>
<td>3.190</td>
<td>3.246</td>
<td>-.056 ± .010</td>
</tr>
<tr>
<td>Body length, cm.</td>
<td>91.08</td>
<td>91.28</td>
<td>-.20 ± .14</td>
</tr>
</tbody>
</table>

*The figures after the plus or minus signs are standard errors computed as for a population of 236 pairs of sire and son. Since the 236 pairs were not entirely independent, the standard errors printed are somewhat smaller than they really should be.

The other evidence bearing on the intensity of selection is somewhat more direct. It is a comparison of these sire averages with the averages of their generation, including those contemporaries whose sons were not saved for breeding. A study of the ages of these sires shows them to have been contemporary with about two-thirds of the sires whose offspring constitute the twentieth annual report (1930-31) and about one-third of those whose offspring constitute the nineteenth annual report (1920-30). Therefore the sire averages are shown in table 13 for comparison with averages of all
TABLE 13. AVERAGE PROGENY TEST OF THOSE BOARS WHOSE SONS WERE LATER USED FOR SIRES, COMPARED WITH THE AVERAGE PROGENY TEST OF ALL THEIR CONTEMPORARIES.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Sires whose sons were used for breeding</th>
<th>Average of all in 19th and 20th reports</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily gain, lbs.</td>
<td>1.442</td>
<td>1.415</td>
</tr>
<tr>
<td>Units of feed per unit of gain</td>
<td>3.32</td>
<td>3.37</td>
</tr>
<tr>
<td>Yield of export bacon, percent</td>
<td>60.17</td>
<td>59.77</td>
</tr>
<tr>
<td>Thickness of back fat, cm.</td>
<td>3.74</td>
<td>3.83</td>
</tr>
<tr>
<td>Thickness of belly, cm.</td>
<td>3.19</td>
<td>3.17</td>
</tr>
<tr>
<td>Body length, cm.</td>
<td>91.08</td>
<td>89.73</td>
</tr>
</tbody>
</table>

The Landrace litters reported in the nineteenth and twentieth annual reports, giving twice as much weight to the latter. The difference is in the desired direction for all six characteristics, although it is small for thickness of belly. This comparison indicates that there was especially strong selection for length of body. That agrees well with the testimony of the men concerned with swine breeding. Table 13 therefore indicates that those boars whose sons were subsequently to be tried out as sires had progeny tests which were above average in desirability. This does not by itself tell whether this selection was primarily on these figures, deliberately choosing the sons of those boars whose progeny averages were highest (that is, a selection primarily directed toward and based on the published figures from the progeny testing) or whether the primary basis of selection was something else. For example, something in the external appearance of the animal or in the performance of other relatives, or some other characteristic correlated with this one might have been the primary basis of selection. In that case the differences shown in the table would have been a secondary result of selection based primarily on something else. This possibility is regarded as unlikely, in general, especially on account of the earnest attention and study which various men concerned with swine breeding were observed to give to the progeny testing work and the eagerness with which those results were received. Yet it is likely in this as in any other case where selection is practiced simultaneously for many traits, that a part of the selection for or against each trait was indirect and due to its association with other traits.
CORRELATION BETWEEN SIX CHARACTERISTICS OF THE SAME LITTER

It is perfectly possible and indeed almost inevitable that some of these characteristics are physiologically correlated with each other as the result of their being in part the result of the same body function and perhaps in part the result of manifold effects of the same genes. For example, it is a priori likely that two things which depend so much on general fatness as thickness of back fat and thickness of belly would be physiologically so closely related to each other that changes in one would tend to be accompanied by changes in the other. It is also likely that a distinct change in body length or in thickness of fat would have had some tendency to affect yield of export bacon or perhaps economy of gain, especially since average weight at slaughter was kept almost constant.

This question was early the subject of investigation by Jespersen and Østerlund Madsen. Table 14 shows the correlations they found between thickness of back fat, thickness of belly, body length and dressing percent. Since they did not compute the correlations involving yield of export bacon, those for dressing percent are quoted here as almost certain to show a similar picture. Their report also contains several correlations between these measurements and the scores for various characteristics.

The same authors using litter averages find a correlation of +.099 ± .024 between thickness of back fat and the quan-

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Thickness of back fat</th>
<th>Thickness of belly</th>
<th>Dressing percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body length</td>
<td>-.197</td>
<td>+.070</td>
<td>-.011</td>
</tr>
<tr>
<td></td>
<td>-.145</td>
<td>+.053</td>
<td>-.019</td>
</tr>
<tr>
<td>Thickness of back fat</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>+.180</td>
<td>+.382</td>
<td></td>
</tr>
<tr>
<td></td>
<td>+.218</td>
<td>+.308</td>
<td></td>
</tr>
<tr>
<td>Thickness of belly</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>+.383</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>+.336</td>
<td></td>
</tr>
</tbody>
</table>

*The standard errors range from .014 to .017.
**The upper figure in each square is the correlation for 3577 barrows. The lower figure is the similar correlation for 3382 sows.

13Jespersen, Johs. and M. P. Østerlund Madsen. 1931. Beretning om Afkomsundersøgelse over Orner af Dansk Landrace (Progeny investigations concerning Danish Landrace boars). (Especially pages XIV to XXIII.)
tity of feed required to produce a kilogram of gain. Lauridsen\textsuperscript{12} studied the litter averages in the twenty-second report using regressions, but not computing the correlation, and found no relation between body length and economy of gain and also no hint that long swine gain more rapidly or more slowly than short swine.

Two precautions should be observed in interpreting the correlations in table 14. The data come from a period (about 1926 to the end of 1929) when there was a marked time trend in several of these averages. During this time the average body length was increasing rapidly, the thickness of back fat was decreasing and the thickness of belly was slowly increasing. These time trends of themselves would have brought about a distinct negative correlation between body length and thickness of back fat, a positive correlation between body length and thickness of belly and a negative correlation between thickness of belly and thickness of back fat. Since there was no certain trend in dressing percent, the correlation concerning it would not have been thus affected. It is therefore probably legitimate to infer that in a population without time trends in these characteristics, the correlation between body length and thickness of back fat would not have been as strongly negative as it is here nor would the correlation between thickness of belly and body length have been as strongly positive while that between thickness of back fat and thickness of belly would probably have been even larger than the one shown here. Another qualification is that the material on which these correlations were computed consisted of swine which were killed at a nearly constant weight. A pig which is unusually long when it reaches that weight must generally have been smaller in some of its other dimensions. Thus there was automatically produced in the data some negative correlation between the dimensions of constituent parts not closely related to each other physiologically. No way to discount the effects of these two features of the data was found, but their bias should be remembered in any attempt to interpret from these correlations the physiological relations between growth of various parts of the pig.

We have computed from the data used in the earlier part of this study the correlation between all six of the characteristics studied here, using litter averages rather than the performance of individual pigs. Altogether the data include

\textsuperscript{12}Lauriden, K. P. 1934. Om Forholdet mellem Kroplaengde og Trivelighed samt Voksenevne hos Slarterisvin. (About the relation between body length and economy of gain and rate of gain in bacon swine.) Naesgaards Bogen, pp. 77-83.
1,285 litters, there being 236 litters in the twenty-second report used in computing the correlation between progeny test of son and sire, 392 involved in the progeny tests of those sires (mostly coming from the years 1929-1933), and 657 litters used in computing the correlation between maternal half-sib litters. There were some duplications among these, since the same litters would sometimes have been in two of these groups and very rarely could have been in all three. These duplications should not have contributed any bias to the resulting correlation, but probably the standard errors should have been computed on a slightly smaller number of litters—perhaps on less than 1,200. The observed correlations are shown in table 15.

Only five of them seem large enough to be worth special mention. The large negative correlation between daily gain and units of feed per unit of gain is quite to be expected for at least two reasons. The first is that this is a correlation between a fraction and its denominator and is therefore certain to be strongly negative unless numerator and denominator are almost perfectly correlated. The second is that the more rapidly gaining pigs were on feed a shorter time and therefore would have used less feed for maintenance. Perhaps there are still other reasons. This correlation can be used to estimate how much information about economy of gain is lost when the feed consumption is unknown but weight for age is known, as is often the case in selecting breeding stock in the United States.

The strong negative correlation between body length and thickness of back fat may be either time trend or the effect already mentioned of slaughter at a constant weight whereby the pig longer than average must usually be smaller than average in some other dimensions. Possibly there is also some other physiological relation involved.

The strong positive correlation between thickness of belly and yield of export bacon is natural since the bellies are trimmed but slightly and nearly all the extra thickness here would contribute directly to an increase in percentage of export bacon. That is, these two measurements are to some extent different measurements of the same thing. Also variations in general fatness above or below the average would tend to increase or decrease yield of export bacon and thickness of belly somewhat together. The somewhat small but significant positive correlation between thickness of back fat and yield of export bacon is doubtless to be explained in the same way.

The small but significant correlation between daily gain
TABLE 15. CORRELATIONS BETWEEN VARIOUS CHARACTERISTICS OF THE SAME LITTER*.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Units of feed per unit of gain</th>
<th>Yield of export bacon</th>
<th>Thickness of back fat</th>
<th>Thickness of belly</th>
<th>Body length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily gain</td>
<td>-.69</td>
<td>-.15</td>
<td>+.07</td>
<td>+.08</td>
<td>-.06</td>
</tr>
<tr>
<td></td>
<td>-.76</td>
<td>-.29</td>
<td>+.05</td>
<td>+.16</td>
<td>-.12</td>
</tr>
<tr>
<td></td>
<td>-.69</td>
<td>+.14</td>
<td>+.07</td>
<td>-+.09</td>
<td>+.01</td>
</tr>
<tr>
<td>Units of feed per unit of gain</td>
<td>+.01</td>
<td>-+.09</td>
<td>+.06</td>
<td>+.06</td>
<td>+.10</td>
</tr>
<tr>
<td></td>
<td>-.17</td>
<td>-+.06</td>
<td>+.03</td>
<td>+.08</td>
<td>+.10</td>
</tr>
<tr>
<td></td>
<td>+.04</td>
<td>+.09</td>
<td>-+.08</td>
<td>+.10</td>
<td>+.10</td>
</tr>
<tr>
<td>Yield of export bacon</td>
<td>+.18</td>
<td>+.33</td>
<td>-+.10</td>
<td>-+.39</td>
<td>-+.03</td>
</tr>
<tr>
<td></td>
<td>+.27</td>
<td>+.31</td>
<td>-+.21</td>
<td>-+.09</td>
<td>-+.09</td>
</tr>
<tr>
<td></td>
<td>+.14</td>
<td>+.31</td>
<td>+.04</td>
<td>+.38</td>
<td>+.06</td>
</tr>
<tr>
<td>Thickness of back fat</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thickness of belly</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*The upper correlations in each square are on the entire population of 1,285 litters including some duplications and something from the time trends. The standard errors are a little less than .03.

The middle correlations are from the population of 238 litters all from the twenty-second report and contain no duplications and no effects of a time trend. Their standard errors are .06 for very small correlations and a little less for higher correlations.

The lower correlations are for the 392 litters used in computing the correlation between paternal half-sib litters. This group may contain considerable time trend but does not include duplications. The standard errors are about .04.

and yield of export bacon may be due to the relation of them both to general fatness.

These correlations differ somewhat from those found by Jespersen and Østerlund Madsen, the main difference being in the higher correlation they found between thickness of back fat and thickness of belly. A priori their finding seems more logical than this one of practically no correlation. Also they find a smaller negative correlation between body length and thickness of back fat, and their correlation between dressing percent and thickness of back fat is larger than this one between yield of export bacon and thickness of back fat. The reason for these differences is not clear. Their correlations were on individuals, whereas these are on litter averages. Many of these data come from a later date than theirs. Perhaps by this time some herds had progressed in several respects much farther along the general time trends than others, so that the herds with the
longest pigs also tended to be thinner than average in back fat and to have thicker-than-average bellies?

The general conclusion from studying the correlations between these characteristics is that they are not absolutely independent of each other but are so nearly so (with the exception of gain and feed per unit of gain) that for breeding selections and changes only a little error is introduced by considering them as truly independent of each other. The only cases where there seems to be more than a small trace of antagonism between the desired goals involve thickness of back fat concerning which it appears (from table 14) that making the back fat thin would also tend to make the bellies thin and the dressing percent low and (from table 15) would tend to lower the yield of export bacon. The other correlations are either substantially zero or actually helpful, as those concerning back fat and length, or belly thickness and yield.

GENERAL DISCUSSION

It is obvious that many of the characteristics of the Danish Landrace have changed markedly since this system of testing began. Very few of them have had entirely parallel changes. Most of them have changed markedly at certain times but have continued practically without change during other periods. In some cases what was once a distinct breed difference has now disappeared because one breed changed more than another. In other cases a distinct breed difference has persisted through the entire period. In still other cases there appears never to have been a genuine breed difference.

The reasons for the changes which occurred are less clear. Collateral evidence not in the data themselves make it certain that the emphasis placed on this or that characteristic in selection has changed markedly from time to time. Probably the greatest change of this kind was from the emphasis on economy of gain during the early years to the emphasis on the quality of meat. This increased very much in importance somewhere around 1924-1926 when the world's supply of pork had so far recovered from the war depletion that it was flooding the market and therefore quality of product, in enabling the producer to retain his market, became more important than economy of production. Another less prominent illustration is the increasing emphasis being laid on firmness of flesh now that the back fat has become thinner and the pigs longer.
Many of the characteristics of this swine population responded to the changing emphasis on selection so quickly that there is a strong presumption that selection caused the observed changes through changing the average genotype of the population by making certain genes more abundant and others scarcer. But at the same time knowledge of nutrition has increased and feeding and management have improved at the breeding centers. Changes of this kind at the testing stations have been very slight, and there have been practically none in the ration since about 1923. Nevertheless there have been improvements in the ventilation and management of the stalls, and these may have contributed something to the changes.

Preliminary studies (by Dr. Knud Rottensten) on the amount of inbreeding in the Danish Landrace indicates that this has been only about the same amount as in the average pure breeds in the United States (i.e. not very far from a loss of about one-half of one percent of the existing heterozygosis per generation). Inbreeding by itself can hardly have been important in causing the whole population to drift far in any one direction except perhaps as it may have tended slightly to group the population into families and thus may have given selection a more favorable opportunity to be effective than if there had been no inbreeding.

The study of the variance in six measured characteristics leads to the conclusion that there was plenty of variance for selection to have produced all the changes in body length, thickness of back fat and thickness of belly. For example the standard deviation of litter averages for body length was about 2 centimeters. If only those young boars and sows whose sibs were above average in body length were tried out for breeding, the tests of that whole group would have averaged about 1.6 centimeter above the mean of all those tested at that time (assuming some approach to a normal distribution). If only half of the variance in litter averages is additively genetic (which seems an understatement since individual performance shows nearly that much and the basis of the actual selection is the test litter average) then the mean body length should increase about .8 centimeter per swine generation. (Actually the increase in the Landrace has been about 1.9 centimeters in the last 8 years, which is something like .6 centimeter per swine generation, but this cannot be considered as confirming the above calculations since it is not known whether the selection actually practiced was more or less strict than that used in this example.) There probably was enough variance also
to have permitted selection to have produced the observed changes in gain, economy of gain and whatever slight changes there may have been in yield of export bacon.

The part of this investigation least well answered is the question of what basis the breeders actually used in making their selections. Heavy emphasis in all Danish publications on the subject has been laid on the results of these progeny tests, and it seems that those boars whose sons actually get tried out as sires at the breeding centers have had progeny tests averaging higher than those of their contemporaries. Nevertheless classifications of swine on their external type not only at the shows but also at the semi-annual inspections of the breeding farm by the official committee have played a part—perhaps a large part. There is also under the Danish breeding systems inevitably heavy emphasis on the general reputation of the breeder and of his herd. The name of each breeding center appears in the registry name of all its sows and many of its boars. It seems certain that the general average reputation of a herd has been an important consideration in the selections actually practiced.

Whatever may have been the exact means by which the changes in this swine population have been accomplished, those changes have served the Danish farmers well by improving their swine, more especially at first in rate of gain and economy of gain but more in later years by changing the characteristics of the carcass to suit the demands of the market in which Danish bacon could best be sold. It is probably true that most of the progeny tests have been used more in evaluating pedigrees (i.e., in choosing which young boars and gilts would be used next) than in actually prolonging the use of well proven sires or dams. Because feeding ability and quality of meat could be determined only by progeny testing, the progeny test has been more nearly indispensable here than in most characteristics which livestock breeders desire.

The expenses of this system of progeny testing were largely met by the farmers themselves, acting through their cooperative bacon factories. In countries which do not already have a large percentage of their swine being slaughtered in cooperative factories, the matter of financing such progeny testing might prove more difficult.
REFERENCES


(7). Lauridsen, K. P. Om Forholdet mellem Kroplaengde og Trivelighed samt Vokseevne hos Slagterisvin. (About the relation between body length and economy of gain and rate of gain in bacon swine.) Naesgaards Bogen pp. 77-83. 1934.


(9). Wright, Sewall. The analysis of variance and the correlations between relatives with respect to deviations from an optimum. Jour. of Genetics 30:243-256. 1935.


(11). Annual reports of the swine testing results are numbered in the general series of reports from the research laboratory of the Royal Veterinary and Agricultural College at Copenhagen under the special title "Beretning om sammenlignende Forsøg med Svin fra statsanerkendte Avlscentre" (Report about the comparisons between swine from the state-recognized breeding centers.) (Some of the early reports are now out of print.)
The order of these reports and their number in the general series are as follows:

<table>
<thead>
<tr>
<th>Order of report</th>
<th>Number in general series</th>
</tr>
</thead>
<tbody>
<tr>
<td>24th</td>
<td>169</td>
</tr>
<tr>
<td>23rd</td>
<td>164</td>
</tr>
<tr>
<td>22nd</td>
<td>157</td>
</tr>
<tr>
<td>21st</td>
<td>150</td>
</tr>
<tr>
<td>20th</td>
<td>145</td>
</tr>
<tr>
<td>19th</td>
<td>139</td>
</tr>
<tr>
<td>18th</td>
<td>133</td>
</tr>
<tr>
<td>17th</td>
<td>130</td>
</tr>
<tr>
<td>16th</td>
<td>127</td>
</tr>
<tr>
<td>15th</td>
<td>124</td>
</tr>
<tr>
<td>14th</td>
<td>122</td>
</tr>
<tr>
<td>13th</td>
<td>117</td>
</tr>
<tr>
<td>12th</td>
<td>114</td>
</tr>
<tr>
<td>11th</td>
<td>110</td>
</tr>
<tr>
<td>10th</td>
<td>109</td>
</tr>
<tr>
<td>9th</td>
<td>98</td>
</tr>
<tr>
<td>8th</td>
<td>93</td>
</tr>
<tr>
<td>7th</td>
<td>90</td>
</tr>
<tr>
<td>6th</td>
<td>87</td>
</tr>
<tr>
<td>5th</td>
<td>85</td>
</tr>
<tr>
<td>4th</td>
<td>80</td>
</tr>
<tr>
<td>3rd</td>
<td>79</td>
</tr>
<tr>
<td>2nd</td>
<td>75</td>
</tr>
<tr>
<td>1st</td>
<td>67</td>
</tr>
</tbody>
</table>
The Oxidation of Acetylmethylcarbinol to Diacetyl in Butter Cultures

By M. B. Michaelian and B. W. Hammer

AGRICULTURAL EXPERIMENT STATION
IOWA STATE COLLEGE OF AGRICULTURE
AND MECHANIC ARTS

R. E. Buchanan, Director

DAIRY INDUSTRY SECTION

AMES, IOWA
CONCLUSIONS

1. The addition of purified acetylmethylcarbinol to sterile skim milk, adjusted to an acidity and a temperature satisfactory for the rapid production of the carbinol when the citric acid-fermenting streptococci are present, did not result in the formation of appreciable amounts of diacetyl in 48 to 72 hours. The results were the same when carbon dioxide, hydrogen, nitrogen, or oxygen was bubbled through the milk as when no gas was used.

2. The production of diacetyl in acidified skim milk cultures of the citric acid-fermenting streptococci was definitely influenced by bubbling various gases through the freshly acidified cultures. Oxygen regularly gave a higher yield of diacetyl than the control through which no gas was bubbled, while carbon dioxide, hydrogen or nitrogen gave lower yields. With all of the gases there was commonly a greater production of diacetyl, as well as acetylmethylcarbinol plus diacetyl, when the cultures were acidified with a mixture of citric and sulfuric acids than when acidified with sulfuric acid alone.

3. Various gases had the same general effect on the production of diacetyl in butter cultures as in pure cultures of the citric acid-fermenting streptococci, but the actual quantities of diacetyl formed appeared to be smaller with the butter cultures than with the pure cultures. When oxygen was bubbled through butter cultures prepared with various amounts of added citric acid, the yields of both diacetyl and acetylmethylcarbinol plus diacetyl were roughly proportional to the amount of citric acid added.

4. When acetylmethylcarbinol was added to milk and the milk inoculated with S. lactis, analyses after incubation showed no evidence of an oxidation of the carbinol to diacetyl.

5. The data obtained indicate that the oxidation of acetylmethylcarbinol to diacetyl in a butter culture is due to the activity of the citric acid-fermenting streptococci rather than to a direct chemical oxidation.
The Oxidation of Acetymethylcarbinol to Diacetyl in Butter Cultures

BY M. B. MICHAELIAN AND B. W. HAMMER

Diacetyl, acetymethylcarbinol, and 2,3-butylene glycol constitute a series of compounds that is of special importance in butter cultures and, presumably, in butter manufactured with the use of culture. A satisfactory butter culture commonly contains relatively large quantities of acetymethylcarbinol that are formed through the activity of the citric acid-fermenting streptococi normally present in the culture (2). Small portions of this acetymethylcarbinol appear to be oxidized to diacetyl which is important from the standpoint of the aroma of the culture. Some of the acetymethylcarbinol is also reduced to 2,3-butylene glycol through the action of the citric acid-fermenting streptococi (1). The reduction is much slower in a butter culture than in a pure culture of one of the streptococi to which acetymethylcarbinol has been added, and this relatively slow reduction is probably due to the inhibitory effect of the acid in the butter culture on these streptococi.

From the standpoint of the aroma of a butter culture, the oxidation of acetymethylcarbinol to diacetyl is especially important since diacetyl, in the proper concentration, has an odor suggestive of fine butter, while highly purified acetymethylcarbinol is odorless. Accordingly, an attempt was made to determine whether this oxidation is a direct chemical action or whether it is brought about through the activity of the citric acid-fermenting streptococi. The general procedure followed was to study the effect of carbon dioxide, hydrogen, nitrogen, and oxygen on the production of diacetyl (a) in acidified sterile milk to which acetymethylcarbinol had been added, (b) in acidified cultures of the citric acid-fermenting streptococi, and (c) in butter cultures.

METHODS

Diacetyl was determined as nickel dimethylglyoximate (3), using either a 200 or 400-gm. sample for analysis; carbon dioxide or nitrogen was bubbled through the system for some time before the distillation was begun, in order to remove oxygen which might produce diacetyl from acetymethylcarbinol during the process. Acetymethylcarbinol was also determined as nickel dimethylglyoximate by oxidizing the carbinol in a 200-gm. sample to diacetyl with ferric chloride and distilling it as diacetyl (3).

1 Project 127 of the Iowa Agricultural Experiment Station.
The pH determinations were made electrometrically, using quinhydrone.

When gas was to be bubbled through milk, water, or a culture, the material was placed in a bottle fitted with a stopper carrying two glass tubes. One of the tubes, which was used as the inlet tube, led nearly to the bottom of the bottle while the other, or outlet tube, terminated a very short distance below the stopper. Gas from a cylinder was bubbled through the material rather rapidly for about 10 minutes; although the material was agitated by the current of gas, it was occasionally shaken. When the treatment was complete, clamps were placed on the rubber connections leading to the glass tubes. A few lots of milk foamed considerably but as a rule no difficulty was encountered.

Commercial acetylmethylcarbinol was purified by washing with cold anhydrous ether, as suggested by Stahly and Werkman (5).

EXPERIMENTAL

The attempts to oxidize acetylmethylcarbinol to diacetyl in milk, without the action of bacteria, were carried out as follows: A quantity of sterile skimmilk was acidified to a pH satisfactory for the rapid production of acetylmethylcarbinol when the citric acid-fermenting streptococci are present. Usually a mixture of citric (0.15 percent) and sulfuric (0.28 to 0.30 percent) acids was employed to give a pH of 3.8 or 3.9 because under these conditions the citric acid-fermenting organisms produce the carbinol in relatively large amounts; in one case lactic acid was used to give about the pH found in a ripened butter culture. A solution of acetylmethylcarbinol was then added and various gases bubbled through different portions of the milk. After 48 to 72 hours at 21° C. determinations of acetylmethylcarbinol plus diacetyl and of diacetyl were made. Table 1 presents representative data.

In each trial the quantities of acetylmethylcarbinol plus diacetyl found in the various portions of milk were essentially the same. When commercial or partially purified acetylmethylcarbinol was added to the milk, diacetyl was found on distillation, but the quantities in the different portions of milk used in a trial showed no regular variations and bubbling carbon dioxide, hydrogen, nitrogen or oxygen through the milk did not significantly influence the amount. With the addition of purified acetylmethylcarbinol to the milk, appreciable quantities of diacetyl were not obtained with any of the gases.

The results show that when acetylmethylcarbinol was added to milk there was no appreciable formation of diacetyl in 48
TABLE 1. EFFECT OF VARIOUS GASES ON ACETYLMETHYLCARBINOL IN ACIDIFIED, STERILE SKIMMILK.

Acetylmethylcarbinol and acid added to sterile skim milk; various gases bubbled through different portions and containers sealed; amc* + ac2 and acs determined after holding 48 or 72 hours at 21°C.

<table>
<thead>
<tr>
<th>amc used</th>
<th>Acid used</th>
<th>pH at once</th>
<th>Hours held</th>
<th>Gas bubbled through milk</th>
<th>gm. Ni dimethylglyoximate =&gt; to</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>amc + ac2 per 200 gm.</td>
</tr>
<tr>
<td>Commercial</td>
<td>0.15% citric</td>
<td>3.8</td>
<td>48</td>
<td>none</td>
<td>0.1241</td>
</tr>
<tr>
<td></td>
<td>.29% sulfuric</td>
<td></td>
<td></td>
<td>CO₂</td>
<td>0.0080</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>H₂</td>
<td>0.1277</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>O₂</td>
<td>0.1274</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.0081</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.00815</td>
</tr>
<tr>
<td>Commercial</td>
<td>0.15% citric</td>
<td>3.8</td>
<td>48</td>
<td>none</td>
<td>.1222</td>
</tr>
<tr>
<td></td>
<td>.30% sulfuric</td>
<td></td>
<td></td>
<td>CO₂</td>
<td>.0050</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>H₂</td>
<td>.1193</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>O₂</td>
<td>.0058</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.00655</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.0070</td>
</tr>
<tr>
<td>Partially purified</td>
<td>0.15% citric</td>
<td>3.9</td>
<td>48</td>
<td>none</td>
<td>.1129</td>
</tr>
<tr>
<td></td>
<td>.30% sulfuric</td>
<td></td>
<td></td>
<td>CO₂</td>
<td>.00385</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>H₂</td>
<td>.1163</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>O₂</td>
<td>.00285</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.00335</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.0025</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.0032</td>
</tr>
<tr>
<td>Purified</td>
<td>0.15% citric</td>
<td>3.9</td>
<td>48</td>
<td>none</td>
<td>.1386</td>
</tr>
<tr>
<td></td>
<td>.30% sulfuric</td>
<td></td>
<td></td>
<td>CO₂</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>H₂</td>
<td>.1437</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>O₂</td>
<td>.1406</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>none</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>none</td>
</tr>
<tr>
<td>Purified</td>
<td>0.15% citric</td>
<td>3.9</td>
<td>48</td>
<td>none</td>
<td>.1343</td>
</tr>
<tr>
<td></td>
<td>.28% sulfuric</td>
<td></td>
<td></td>
<td>CO₂</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>H₂</td>
<td>.1345</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>O₂</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>none</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>none</td>
</tr>
<tr>
<td>Purified</td>
<td>0.15% citric</td>
<td>3.8</td>
<td>72</td>
<td>none</td>
<td>.1989</td>
</tr>
<tr>
<td></td>
<td>.30% sulfuric</td>
<td></td>
<td></td>
<td>CO₂</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>H₂</td>
<td>.1933</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>O₂</td>
<td>.1856</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>none</td>
</tr>
<tr>
<td>Purified</td>
<td>0.70% lactic</td>
<td>4.4</td>
<td>72</td>
<td>none</td>
<td>.1458</td>
</tr>
</tbody>
</table>

*amc = acetylmethylcarbinol.
acs = diacetyl.

to 72 hours at an acidity and a temperature satisfactory for the rapid production of the carbinol when the citric acid-fermenting streptococci are present.

Attempts to oxidize acetylmethylcarbinol to diacetyl in a short time were also carried out in water. Acetylmethylcarbinol was added to sterile water, various gases were bubbled through different portions and the acetylmethylcarbinol plus diacetyl and the diacetyl determined after 48 hours at 21°C. When purified acetylmethylcarbinol was used, diacetyl was not found with carbon dioxide, hydrogen, nitrogen, oxygen, or in the controls.
In some cases small quantities of oxidizing reagents were added to the water solutions (without the use of a gas) in an attempt to oxidize the acetylmethylcarbinol. Hydrogen peroxide and potassium permanganate did not produce diacetyl in 48 hours at 21°C. Potassium dichromate yielded a trace of diacetyl but as much diacetyl was obtained when the mixture was distilled at once as when it was distilled after 48 hours which suggests that the diacetyl was produced during the distillation process rather than by the effect of the potassium dichromate at 21°C.

The effect of various gases on the production of diacetyl by the citric acid-fermenting organisms in milk was studied as follows: Lots of sterile skimmilk were inoculated with the organism to be used and incubated at 21°C. After acidifying with citric (0.15 percent) and sulfuric (usually 0.30 percent) acids to a pH satisfactory for the rapid production of acetylmethylcarbinol, various gases were bubbled through the different lots. The usual determinations were made following 48 hours of incubation at 21°C. The data obtained are given in table 2.

In each trial there was some variation in the yields of acetylmethylcarbinol plus diacetyl with the various gases and in certain of the trials the variations were very large. None of the gases regularly gave either the highest or lowest production of the carbinol. There were relatively large variations in the yields of diacetyl and the largest yield was always obtained when oxygen had been bubbled through the culture while the second largest yield was always obtained with the culture exposed to the air. In a number of instances there was a comparatively low yield of acetylmethylcarbinol plus diacetyl with oxygen or exposure to air and at the same time the yield of diacetyl was relatively high. There was no regular variation in the yields of diacetyl with carbon dioxide, hydrogen, and nitrogen.

The data indicate that the production of diacetyl by the citric acid-fermenting streptococci was definitely modified by bubbling various gases through the cultures and that oxygen gave the largest yield of diacetyl, air gave the next largest yield, while carbon dioxide, hydrogen, and nitrogen gave relatively low yields.

Additional results on the effect of various gases on the production of diacetyl by the citric acid-fermenting organisms were obtained by inoculating lots of sterile skimmilk with one of the organisms, incubating 24 hours at 21°C, acidifying some lots with sulfuric acid (0.37 or 0.38 percent) and other lots
### TABLE 2. EFFECT OF VARIOUS GASES ON ACIDIFIED CULTURES OF THE CITRIC ACID-FERMENTING STREPTOCOCCI.

Sterile skim milk inoculated and held at 21°C; 0.15% citric acid and enough sulfuric acid (usually 0.30%) to give the desired pH then added; various gases bubbled through different portions and containers sealed; amc + ac, determined after holding 48 hours at 21°C.

<table>
<thead>
<tr>
<th>Organism used</th>
<th>Hours incub. before adding acids</th>
<th>pH after adding acid</th>
<th>Gas bubbled through milk</th>
<th>gm. Ni dimethylglyoximate to amc + ac per 200 gm.</th>
<th>ac per 200 gm.</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>24</td>
<td>3.4*</td>
<td>none</td>
<td>0.0649</td>
<td>0.0046</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CO₂</td>
<td>0.0669</td>
<td>0.0009</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>H₂</td>
<td>0.0830</td>
<td>0.0006</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>N₂</td>
<td>0.0869</td>
<td>0.0012</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>O₂</td>
<td>0.0420</td>
<td>0.0076</td>
</tr>
<tr>
<td>34</td>
<td>24</td>
<td>3.9</td>
<td>none</td>
<td>0.1153</td>
<td>0.00475</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CO₂</td>
<td>0.1056</td>
<td>0.0029</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>H₂</td>
<td>0.1094</td>
<td>0.0022</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>O₂</td>
<td>0.0943</td>
<td>0.00825</td>
</tr>
<tr>
<td>49</td>
<td>24</td>
<td>3.9</td>
<td>none</td>
<td>0.0901</td>
<td>0.00375</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CO₂</td>
<td>0.0840</td>
<td>0.00295</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>H₂</td>
<td>0.0912</td>
<td>0.00315</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>N₂</td>
<td>0.0933</td>
<td>0.0033</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>O₂</td>
<td>0.0738</td>
<td>0.00305</td>
</tr>
<tr>
<td>146</td>
<td>24</td>
<td>3.8</td>
<td>none</td>
<td>0.0822</td>
<td>0.0062</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CO₂</td>
<td>0.0876</td>
<td>0.0036</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>H₂</td>
<td>0.0860</td>
<td>0.00375</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>O₂</td>
<td>0.0909</td>
<td>0.01075</td>
</tr>
<tr>
<td>146</td>
<td>24</td>
<td>3.9</td>
<td>none</td>
<td>0.0771</td>
<td>0.0089</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CO₂</td>
<td>0.0957</td>
<td>0.0077</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>H₂</td>
<td>0.0975</td>
<td>0.00795</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>N₂</td>
<td>0.1010</td>
<td>0.00735</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>O₂</td>
<td>0.0881</td>
<td>0.0125</td>
</tr>
<tr>
<td>29</td>
<td>40</td>
<td></td>
<td>none</td>
<td>0.0653</td>
<td>0.0094</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CO₂</td>
<td>0.1194</td>
<td>0.0013</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>O₂</td>
<td>0.0771</td>
<td>0.0139</td>
</tr>
<tr>
<td>37</td>
<td>40</td>
<td></td>
<td>none</td>
<td>0.0431</td>
<td>0.0041</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CO₂</td>
<td>0.0673</td>
<td>0.0013</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>O₂</td>
<td>0.0981</td>
<td>0.0122</td>
</tr>
<tr>
<td>37</td>
<td>40</td>
<td></td>
<td>none</td>
<td>0.0916</td>
<td>0.0043</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CO₂</td>
<td>0.0684</td>
<td>0.0019</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>O₂</td>
<td>0.0790</td>
<td>0.0082</td>
</tr>
</tbody>
</table>

*0.40% sulfuric used to get low pH.

with citric (0.15 percent) and sulfuric (0.31 or 0.32 percent) acids, bubbling various gases through the different lots and then making the usual analyses after 48 hours at 21°C. Table 3 gives the data obtained with two organisms.

With each organism the addition of citric acid gave the expected increase in the production of acetyl methanecarbinol plus diacetyl. Either with or without the addition of citric acid there was some variation in the yields of acetyl methanecarbinol plus diacetyl in the presence of the various gases, but these were not large except in the case of one of the organisms without added citric acid. There were relatively large variations
TABLE 3. EFFECT OF VARIOUS GASES ON CULTURES OF THE CITRIC ACID-FERMENTING STREPTOCOCCI ACIDIFIED WITH SULFURIC ACID OR WITH CITRIC AND SULFURIC ACIDS.

Sterile skim milk inoculated and held 24 hours at 21°C.; sulfuric acid added to some portions and citric and sulfuric acids to others; various gases bubbled through different portions and containers sealed; acm+ac2 and ac2 determined after holding 48 hours at 21°C.

<table>
<thead>
<tr>
<th>Organism used</th>
<th>Acidity adjusted with</th>
<th>pH after adding acid</th>
<th>Gas bubbled through milk</th>
<th>gm. Ni dimethylglyoximate to acm+ac2 per 200 gm.</th>
<th>ac2 per 200 gm.</th>
</tr>
</thead>
<tbody>
<tr>
<td>D2 0.38% sulfuric</td>
<td>3.9</td>
<td>none</td>
<td>CO2</td>
<td>0.0364</td>
<td>trace</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>H2</td>
<td>0.0354</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>O2</td>
<td>0.0392</td>
<td>trace</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>none</td>
<td>0.0045</td>
<td></td>
</tr>
<tr>
<td>0.15% citric .32% sulfuric</td>
<td>3.9</td>
<td>none</td>
<td>CO2</td>
<td>0.0912</td>
<td>.0067</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>H2</td>
<td>1.026</td>
<td>trace</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>O2</td>
<td>1.081</td>
<td>trace</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>none</td>
<td>0.0115</td>
<td></td>
</tr>
<tr>
<td>29 0.37% sulfuric</td>
<td>3.9</td>
<td>none</td>
<td>CO2</td>
<td>0.0779</td>
<td>.0060</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>H2</td>
<td>0.0756</td>
<td>.0032</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>O2</td>
<td>0.0743</td>
<td>.0034</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>none</td>
<td>0.0181</td>
<td></td>
</tr>
<tr>
<td>0.15% citric .31% sulfuric</td>
<td>3.9</td>
<td>none</td>
<td>CO2</td>
<td>0.0779</td>
<td>.0060</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>H2</td>
<td>0.0756</td>
<td>.0032</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>O2</td>
<td>0.0743</td>
<td>.0034</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>none</td>
<td>0.0181</td>
<td></td>
</tr>
</tbody>
</table>

in the yields of diacetyl. The largest yield was regularly obtained when oxygen had been bubbled through the culture and in three of the four cases exposure to air gave a strikingly larger yield than carbon dioxide or hydrogen. Commonly there was more diacetyl present in the cultures containing a relatively large amount of acetylmethylcarbinol plus diacetyl, as the result of the addition of citric acid, than in the cultures containing a comparatively small amount of the carbinol. The differences were particularly striking with oxygen and exposure to air.

The effect of bubbling various gases through cultures of one of the citric acid-fermenting organisms on the production of diacetyl when citric acid alone was used to acidify the cultures is shown in table 4.

There was some variation in the yields of acetylmethylcarbinol plus diacetyl with the different gases and a very definite variation in the yields of diacetyl. The largest yield of diacetyl was obtained with oxygen and the next largest yield with exposure to air, while carbon dioxide, hydrogen and nitrogen did not give appreciable quantities of diacetyl. The relatively high yield of diacetyl when oxygen was bubbled through the culture accompanied a comparatively low yield of acetylmethylcarbinol plus diacetyl.

When acetylmethylcarbinol is added to an unacidified tomato
TABLE 4. EFFECT OF VARIOUS GASES ON A CULTURE OF ONE OF THE CITRIC ACID-FERMENTING STREPTOCOCCI ACIDIFIED WITH CITRIC ACID.

Sterile skimmilk inoculated and held 18 hours at 21°C; 0.7% citric acid added; various gases bubbled through different portions and containers sealed; acm+ac₂ and ac₂ determined after holding 48 hours at 21°C.

<table>
<thead>
<tr>
<th>Organism used</th>
<th>pH after adding acid</th>
<th>Gas bubbled through milk</th>
<th>gm. Ni dimethylglyoximate to amc+ac₂ per 200 gm.</th>
<th>ac₂ per 200 gm.</th>
</tr>
</thead>
<tbody>
<tr>
<td>32</td>
<td>3.7</td>
<td>none</td>
<td>0.0722</td>
<td>0.0020</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CO₂</td>
<td>0.0813</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td></td>
<td>H₂</td>
<td>0.0827</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td></td>
<td>N₂</td>
<td>0.0772</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td></td>
<td>O₂</td>
<td>0.0605</td>
<td>0.0059</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.0641</td>
<td>0.0057</td>
</tr>
</tbody>
</table>

bouillon or milk culture of one of the citric acid-fermenting organisms, there is a rapid reduction to 2,3-butylene glycol and, if diacetyl is added, there is a reduction to the glycol or to the carbinol (1). This general relationship makes it improbable that added acetylmethylcarbinol would be oxidized to diacetyl by the organisms in an unacidified culture but a few trials were carried out in an attempt to find small quantities of diacetyl in a culture in which the main change was a reduction of the carbinol. Both tomato bouillon and milk were used with carbon dioxide, hydrogen, nitrogen, oxygen and without added gas but appreciable quantities of diacetyl were never detected. The acetylmethylcarbinol largely disappeared during the holding period. Trials were also carried out with tomato bouillon, using cultures that had been acidified with sulfuric acid to a pH of about 3.9 in order to delay the reduction by the organisms, but appreciable quantities of diacetyl were not found; comparable trials with milk were not used because the presence of citric acid in the milk would have resulted in a production of acetylmethylcarbinol plus diacetyl at a low pH.

The results obtained with pure cultures of the citric acid-fermenting organisms are not directly applicable to butter cultures because (a) the typical lactic acid-producing organisms in a butter culture may influence the changes that occur and (b) there are smaller numbers of the citric acid-fermenting organisms per milliliter in a butter culture than in the pure cultures used. The action of various gases on butter cultures was studied as follows: Pasteurized skimmilk was inoculated with a butter culture and 0.15 percent citric acid added. Various gases were then bubbled through different portions, the cultures held at 21°C for 15 to 20 hours and the determinations made after holding the ripened cultures in a refrigerator for 19 to 24 hours. Table 5 gives the results obtained.
TABLE 5. EFFECT OF VARIOUS GASES ON BUTTER CULTURES.

Pasteurized skimmilk inoculated and 0.15% citric acid added; various gases bubbled through different portions and containers sealed; held from 15 to 20 hours at 21°C; removed to refrigerator and ame+aco and ac2 determined after 19 to 24 hours.

<table>
<thead>
<tr>
<th>Butter culture used</th>
<th>Gas bubbled through milk</th>
<th>pH on analysis</th>
<th>gm. Ni dimethylglyoximate ⇄ to ame+aco per 200 gm.</th>
<th>ac2 per 400 gm.</th>
</tr>
</thead>
<tbody>
<tr>
<td>H5</td>
<td>none</td>
<td>4.4</td>
<td>0.0747</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td>CO2</td>
<td>4.4</td>
<td>.0673</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td>H2</td>
<td>4.5</td>
<td>.0767</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td>N2</td>
<td>4.4</td>
<td>.0290</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td>O2</td>
<td>4.5</td>
<td>.0650</td>
<td>.00095</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>.0654</td>
<td>.00125</td>
</tr>
<tr>
<td>122-F</td>
<td>none</td>
<td>4.4</td>
<td>.0838</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td>CO2</td>
<td>4.5</td>
<td>.0686</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td>H2</td>
<td>4.5</td>
<td>.0876</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td>N2</td>
<td>4.4</td>
<td>.0892</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td>O2</td>
<td>4.5</td>
<td>.0882</td>
<td>.00295</td>
</tr>
<tr>
<td>122-F</td>
<td>none</td>
<td>4.4</td>
<td>.0843</td>
<td>.00695</td>
</tr>
<tr>
<td></td>
<td>CO2</td>
<td>4.4</td>
<td>.0694</td>
<td>.0045</td>
</tr>
<tr>
<td></td>
<td>H2</td>
<td>4.5</td>
<td>.0884</td>
<td>.0035</td>
</tr>
<tr>
<td></td>
<td>O2</td>
<td>4.5</td>
<td>.0900</td>
<td>.0065</td>
</tr>
<tr>
<td>146</td>
<td>none</td>
<td>4.3</td>
<td>.0628</td>
<td>.0022</td>
</tr>
<tr>
<td></td>
<td>CO2</td>
<td>4.4</td>
<td>.0485</td>
<td>.0013</td>
</tr>
<tr>
<td></td>
<td>H2</td>
<td>4.7</td>
<td>.0499</td>
<td>.0011</td>
</tr>
<tr>
<td></td>
<td>N2</td>
<td>4.3</td>
<td>.0638</td>
<td>.0018</td>
</tr>
<tr>
<td></td>
<td>O2</td>
<td>4.4</td>
<td>.0654</td>
<td>.0021</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>.0609</td>
<td>.00335</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>.0569</td>
<td>.0030</td>
</tr>
<tr>
<td>122-15</td>
<td>none</td>
<td>4.4</td>
<td>.0656</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td>O2</td>
<td>4.5</td>
<td>.0635</td>
<td>.0023</td>
</tr>
<tr>
<td>232</td>
<td>none</td>
<td>4.4</td>
<td>.1141</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td>O2</td>
<td>4.5</td>
<td>.1073</td>
<td>.0034</td>
</tr>
<tr>
<td>M1</td>
<td>none</td>
<td>4.3</td>
<td>.0609</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td>O2</td>
<td>4.4</td>
<td>.0642</td>
<td>.00085</td>
</tr>
</tbody>
</table>

The variations in the yields of acetylmethylcarbinol plus diacetyl with the various gases were rather large, particularly in certain of the trials. There were also variations in the yields of diacetyl, with the portions through which oxygen had been bubbled regularly showing the highest yields. The portions with which carbon dioxide, hydrogen, nitrogen or air had been used frequently did not show appreciable quantities of diacetyl but, when they did, air gave higher yields than carbon dioxide, hydrogen or nitrogen. The variations in the yields of diacetyl in the different trials are rather striking. They cannot be attributed to differences in the butter cultures employed since one of the trials with 122-F gave appreciable quantities of diacetyl only when oxygen was used while the other gave appreciable quantities under all the conditions and, with oxygen, yielded much more diacetyl than in the other trial.
The action of oxygen on butter cultures made with various amounts of citric acid was studied by inoculating pasteurized skimmilk, dividing it, adding different amounts of citric acid to different portions and bubbling oxygen through some portions; after incubation the cultures were removed to a refrigerator and the usual determinations made after 24 hours. The data obtained are given in table 6.

**TABLE 6. EFFECT OF OXYGEN ON BUTTER CULTURE MADE WITH VARIOUS AMOUNTS OF CITRIC ACID ADDED TO THE MILK.**

Pasteurized skimmilk inoculated with culture 122; divided and various amounts of citric acid added to different portions; oxygen bubbled through certain portions and containers sealed; held 20 hours at 21°C; removed to refrigerator and analyses determined after 24 hours.

<table>
<thead>
<tr>
<th>Citric acid added</th>
<th>No gas bubbled through</th>
<th>Oxygen bubbled through</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>gm. Ni dimethylglyoximate to</td>
<td>gm. Ni dimethylglyoximate to</td>
</tr>
<tr>
<td></td>
<td>acë per 200 gm.</td>
<td>acë per 400 gm.</td>
</tr>
<tr>
<td>none</td>
<td>0.0414</td>
<td>none</td>
</tr>
<tr>
<td>0.1%</td>
<td>.0699</td>
<td>none</td>
</tr>
<tr>
<td>.2</td>
<td>.0918</td>
<td>none</td>
</tr>
<tr>
<td>.3</td>
<td>.1015</td>
<td>none</td>
</tr>
</tbody>
</table>

Either with or without oxygen, the addition of the increasing amounts of citric acid gave a progressive increase in the yields of acetylmethylcarbinol plus diacetyl. Without oxygen no appreciable production of diacetyl occurred while with oxygen appreciable quantities were obtained in all cases, except the control to which no citric acid had been added, and the yields of diacetyl increased as the yields of acetylmethylcarbinol increased.

The influence of the addition of citric acid to the milk intended for butter culture when oxygen was bubbled through the culture was studied by inoculating pasteurized skimmilk and adding citric acid to some portions; after incubating 5 hours at 21°C, citric acid was added to the remaining portions and oxygen bubbled through all the lots; following additional incubation the cultures were removed to the refrigerator and subjected to the usual analyses after 6 hours and again after 24 hours. The butter culture used was one which appeared to be especially active in the production of diacetyl. Table 7 presents the data obtained.

The addition of citric acid regularly gave an increase in the yields of acetylmethylcarbinol plus diacetyl that was usually roughly proportional to the amounts of citric acid used. With either 0.2 or 0.3 percent citric acid the addition of the acid at the time of inoculation gave a larger yield of acetylmethyl-
TABLE 7. EFFECT OF VARIOUS AMOUNTS OF CITRIC ACID ON A BUTTER CULTURE WHEN OXYGEN WAS BUBBLED THROUGH.

Pasteurized skim milk inoculated with butter culture; various amounts of citric acid added to some portions at time of inoculation and to others 5 hours later; oxygen bubbled through all portions 5 hours after inoculation; incubated 21 hours at 21°C; removed to refrigerator and ame + ac2 and ac determined after 6 hours and again after 24 hours.

<table>
<thead>
<tr>
<th>Citric acid added</th>
<th>1st analysis</th>
<th>2nd analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>gm. Ni dimethylglyoximate =&gt; to</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ame + ac2 per 200 gm.</td>
</tr>
<tr>
<td>none</td>
<td>none</td>
<td>0.0342</td>
</tr>
<tr>
<td>0.1%</td>
<td>0.0646</td>
<td>0.00345</td>
</tr>
<tr>
<td>0.2</td>
<td>0.0954</td>
<td>0.0038</td>
</tr>
<tr>
<td>0.3</td>
<td>0.1360</td>
<td>0.0068</td>
</tr>
<tr>
<td>0.1%</td>
<td>0.0646</td>
<td>0.0024</td>
</tr>
<tr>
<td>0.2</td>
<td>0.0798</td>
<td>0.0035</td>
</tr>
<tr>
<td>0.3</td>
<td>0.0746</td>
<td>0.0071</td>
</tr>
</tbody>
</table>

carbinol plus diacetyl than the addition 5 hours after inoculation. Accompanying the increased production of acetylmethylcarbinol plus diacetyl there was an increase in the production of diacetyl that was especially striking in the comparison of the effects of 0.2 and 0.3 percent citric acid. The results also show the influence of holding a ripened butter culture in the refrigerator for some time. In all cases, more acetylmethylcarbinol plus diacetyl was found at the second analysis than at the first and as a rule the difference was striking; the yield of the control culture at the second analysis was unusually high for a culture made without added citric acid. The increased production of acetylmethylcarbinol plus diacetyl on extended holding in the refrigerator was regularly accompanied by an increase in the diacetyl content.

Because of the possibility that *Streptococcus lactis* is involved in the oxidation of acetylmethylcarbinol in a butter culture, a number of trials were carried out with this species. The procedure used was to add the carbinol to sterilized milk, inoculate with *S. lactis* and then divide the milk into portions and pass carbon dioxide through one portion and oxygen through another; a control, which was not treated with gas, was also employed. In addition, each *S. lactis* culture was grown in milk to which no carbinol had been added. Diacetyl and acetylmethylcarbinol plus diacetyl were determined at the time of inoculation and again after 24 hours at 21°C (when coagulation was complete) plus 24 hours in the refrigerator. There was no evidence of an oxidation of the carbinol to diacetyl in any of the trials. With one of the *S. lactis* cultures, a trace of diacetyl was produced in milk alone.
DISCUSSION OF RESULTS

The results presented indicate that the formation of diacetyl from acetylmethylcarbinol in a pure culture of a citric acid-fermenting Streptococcus, or in a butter culture, is due to the activity of organisms rather than to a simple chemical oxidation. In the case of a butter culture, S. lactis apparently is of no importance in this connection. Although accurate comparisons cannot be made, there appears to have been a relatively larger production of diacetyl in pure cultures of the citric acid-fermenting streptococci than in butter cultures. This may have been due to the comparatively small number of citric acid fermenters in the butter cultures, but the presence of S. lactis is a possible factor also. It should be noted that, because of the difficulties involved in the determination of extremely small amounts of diacetyl, the butter cultures in which appreciable quantities of diacetyl were not found may have contained enough of this compound to definitely influence the odor.

While the results obtained cannot be applied directly to butter, they suggest that in this product acetylmethylcarbinol is oxidized to diacetyl through the activity of organisms. This general relationship is in agreement with the many observations on the comparative flavor development in unsalted and normally salted butter. With unsalted butter, in which the butter culture organisms can multiply actively (4), a conspicuous increase in the volume of the desirable flavor is frequently noted when the butter is held at a temperature that is at all favorable for the growth of butter culture organisms, while with normally salted butter, in which the culture organisms fail to multiply, there is usually no significant increase in the desirable flavor. In butter with a relatively low salt content the culture organisms would be expected to multiply to some extent and such butter may show a definite increase in the volume of the desirable flavor.

If the action of butter culture organisms is necessary for the oxidation of acetylmethylcarbinol to diacetyl in butter, the presence of the carbinol in unsalted butter would be of questionable value, from the standpoint of flavor development, unless butter culture were used in the manufacture, and the same is true of its presence in butter containing culture together with sufficient salt to prevent the development of the culture organisms. Acetylmethylcarbinol may be present in butter made without culture as a result of bacterial action in the cream or the actual addition to either cream or butter. It appears that when conditions are unsatisfactory for the growth of the butter culture organisms in butter, the oxidation of acetylmethyl-
carbinol to diacetyl must occur in the butter culture or in the cream.

The conspicuous odor that is often noted in commercial preparations of acetylmethylcarbinol is commonly regarded as due to diacetyl formed through an oxidation of the carbinol. Diacetyl can be detected readily in such preparations by the usual analytical procedures. The formation of diacetyl in preparations of acetylmethylcarbinol without the action of organisms is not necessarily at variance with the idea that organisms are required for such an oxidation in a butter culture. The oxygen of the air may be more effective in oxidizing acetylmethylcarbinol in a concentrated form, especially in the absence of the complex compounds found in milk. However, it is difficult to understand how extensive oxidation could occur with the limited oxygen supply available in some of the containers used for preparations of acetylmethylcarbinol. A rearrangement of two molecules of the carbinol so as to yield one molecule of diacetyl and one of 2,3-butylene glycol is another possible source of diacetyl. It should be noted also that some preparations of purified acetylmethylcarbinol remain free from the odor of diacetyl for extended periods of time even with an abundant air supply.

LITERATURE CITED


Classification of the Organisms Important in Dairy Products

I. *Streptococcus liquefaciens*

By H. F. Long and B. W. Hammer

AGRICULTURAL EXPERIMENT STATION
IOWA STATE COLLEGE OF AGRICULTURE
AND MECHANIC ARTS

R. E. Buchanan, Director

DAIRY INDUSTRY SECTION

AMES, IOWA
## CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summary and conclusions</td>
<td>219</td>
</tr>
<tr>
<td>Introduction</td>
<td>221</td>
</tr>
<tr>
<td>Statement of problem</td>
<td>221</td>
</tr>
<tr>
<td>Historical</td>
<td>221</td>
</tr>
<tr>
<td>Methods</td>
<td></td>
</tr>
<tr>
<td>Detection of proteolytic bacteria on plates</td>
<td>225</td>
</tr>
<tr>
<td>Volatile acidity</td>
<td>225</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>225</td>
</tr>
<tr>
<td>Acetylmethylcarbinol plus diacetyl and diacetyl</td>
<td>225</td>
</tr>
<tr>
<td>Acidity</td>
<td>225</td>
</tr>
<tr>
<td>Isomeric form of lactic acid</td>
<td>226</td>
</tr>
<tr>
<td>Hydrolysis of fat</td>
<td>226</td>
</tr>
<tr>
<td>Protein breakdown in skimmilk</td>
<td>226</td>
</tr>
<tr>
<td>Hemolysis</td>
<td>226</td>
</tr>
<tr>
<td>Experimental</td>
<td></td>
</tr>
<tr>
<td>Isolation of the acid-proteolytic streptococci from dairy products</td>
<td>226</td>
</tr>
<tr>
<td>Sources of the cultures studied</td>
<td>228</td>
</tr>
<tr>
<td>General action of the organisms on milk</td>
<td>228</td>
</tr>
<tr>
<td>General description of the acid-proteolytic streptococci</td>
<td>229</td>
</tr>
<tr>
<td>Morphology</td>
<td>229</td>
</tr>
<tr>
<td>Cultural characteristics</td>
<td>229</td>
</tr>
<tr>
<td>Biochemical features</td>
<td>230</td>
</tr>
<tr>
<td>Growth conditions</td>
<td>230</td>
</tr>
<tr>
<td>Identity of the cultures</td>
<td>230</td>
</tr>
<tr>
<td>Special biochemical features</td>
<td>231</td>
</tr>
<tr>
<td>Production of volatile acid, carbon dioxide and acetylmethylcarbinol in skimmilk</td>
<td>231</td>
</tr>
<tr>
<td>Influence of temperature on the production of volatile acid, carbon dioxide and acetylmethylcarbinol in skimmilk</td>
<td>232</td>
</tr>
<tr>
<td>Volatile acid</td>
<td>232</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>234</td>
</tr>
<tr>
<td>Acetylmethylcarbinol</td>
<td>235</td>
</tr>
<tr>
<td>Influence of added citric acid on the production of volatile acid and acetylmethylcarbinol in skimmilk</td>
<td>236</td>
</tr>
<tr>
<td>Influence of acetaldehyde on the production of volatile acid and acetylmethylcarbinol in skimmilk</td>
<td>238</td>
</tr>
<tr>
<td>Volatile acid</td>
<td>238</td>
</tr>
<tr>
<td>Acetylmethylcarbinol</td>
<td>238</td>
</tr>
<tr>
<td>Effect of neutralizing cultures on the production of acetylmethylcarbinol in skimmilk</td>
<td>242</td>
</tr>
<tr>
<td>Examination of skimmilk cultures for 2,3-butylene glycol</td>
<td>243</td>
</tr>
<tr>
<td>Isomeric form of lactic acid produced in skimmilk</td>
<td>243</td>
</tr>
<tr>
<td>Action on fat</td>
<td>244</td>
</tr>
<tr>
<td>Protein breakdown in milk</td>
<td>245</td>
</tr>
<tr>
<td>General resistance of the organisms</td>
<td>247</td>
</tr>
<tr>
<td>Viability of the acid-proteolytic streptococci in culture media</td>
<td>247</td>
</tr>
<tr>
<td>Resistance to heat</td>
<td>248</td>
</tr>
<tr>
<td>Discussion</td>
<td>248</td>
</tr>
<tr>
<td>Literature cited</td>
<td>250</td>
</tr>
</tbody>
</table>
SUMMARY AND CONCLUSIONS

1. A satisfactory method was developed for the isolation of acid-proteolytic streptococci from dairy products. The organisms were found in milk and various derivatives of it, but always comprised only a relatively small percentage of the total flora; they were most regularly isolated from ripened cheddar cheese.

2. Litmus milk was reduced by some cultures before coagulation and by others after coagulation. The latter, from the standpoint of reduction, are comparable to Streptococcus lactis var. anoxyphillus. The acid-proteolytic streptococci coagulated milk by enzyme action rather than by the formation of acid. The titratable acidities of 15 cultures at the time of coagulation averaged 0.27 percent, while the pH values averaged 5.90.

3. The general characters of the 101 cultures studied were found to be identical, except for the rapidity of reduction of litmus milk and the fermentation of sucrose. The organisms were identified as Streptococcus liquefaciens Orla-Jensen.

4. When incubated 7 days at 21°C, the 101 cultures varied widely in the production of volatile acid, carbon dioxide and acetylmethylcarbinol in skim milk. Diacetyl was not produced by any of a number of cultures investigated. Volatile acid production was not correlated with the fermentation of sucrose or the rapidity of reduction of litmus milk. The production of carbon dioxide and acetylmethylcarbinol did not vary directly with the volatile acid produced; although high carbon dioxide and acetylmethylcarbinol production tended to accompany high volatile acid production, considerable intergradation existed. The production of volatile acid, carbon dioxide and acetylmethylcarbinol was generally lower at 37°C than at 21°C.

5. With an incubation of 7 days at 21°C, the addition of 0.2 (or in a few cases 0.4) percent citric acid to skim milk at the time of inoculation generally resulted in a decreased volatile acid production with the 39 cultures studied, although an occasional culture gave a definite increase. The production of acetylmethylcarbinol was increased by the addition of 0.2 percent citric acid with 9 of the 33 cultures employed, 4 of the increases being significant. The four cultures giving the signifi-
cant increases were the ones that gave an increased production of volatile acid with added citric acid.

6. With an incubation of 7 days at 21° C., the addition of 0.15 ml. of acetaldehyde to 300 ml. of skimmilk at the time of inoculation generally resulted in a decreased volatile acid production with the 33 cultures studied, while the addition of either 0.15 or 0.18 ml. of acetaldehyde increased the yield of acetylmethylcarbinol with 6 of the 24 cultures employed, 3 of the increases being striking. In a study of two cultures that were known to give an increased production of acetylmethylcarbinol on the addition of acetaldehyde to skimmilk cultures, the time of adding the aldehyde was found to have a pronounced effect, the highest production being obtained when the aldehyde was added 14 or 16 hours after inoculation, rather than either earlier or later.

7. The neutralization of two well ripened cultures to about the original acidity of the milk and subsequent incubation at 21° C. resulted in a slightly increased acetylmethylcarbinol production rather than in a destruction of the product. None of the five cultures studied produced 2,3-butylene glycol.

8. Either $d$ lactic acid or $d$ and $i$ acid was produced by the 15 cultures examined.

9. Butterfat and cottonseed oil were not hydrolyzed by the 101 cultures while tripropionin and tributyrin were hydrolyzed by some cultures and not by others.

10. The four cultures studied were found to greatly increase the soluble nitrogen in milk. Amino nitrogen was significantly increased as well as the fractions soluble in trichloracetic acid and the fractions soluble and insoluble in ethyl alcohol or phosphotungstic acid. Proteolysis was largely complete after a comparatively short incubation period. The distribution of the soluble nitrogen into various fractions was practically the same with the different cultures and was essentially the same at 37° and 21° C.

11. *S. liquefaciens* lived in cultures much longer than *S. lactis*. It remained viable at about 5° C. over a long period of time.

12. Resistance to heat was found to vary considerably with the culture used and with its age. All six of the cultures studied were killed in 40 minutes at 65.6° C.
Classification of the Organisms Important in Dairy Products

I. *Streptococcus liquefaciens*

By H. F. Long and B. W. Hammer

The protein of milk is attacked by many species of bacteria. The extent of the proteolysis varies greatly with the organisms bringing about the change. With some species proteolysis is clearly evident from the appearance of the milk, while with others it can be detected only by chemical analysis.

Many of the streptococci that grow rapidly in milk have no conspicuous action on the milk protein and if proteolysis occurs it is detectable only by chemical methods. There are streptococci closely related to *Streptococcus lactis*, both culturally and morphologically, however, which form an exception to the usual rule and are characterized by an ability to coagulate milk and then bring about extensive digestion. The coagulation is due to a sweet curdling enzyme, but there follows a rapid production of acid and cultures contain comparatively large amounts of acid before proteolysis is evident from the appearance of the milk. The streptococci are thus typically acid-proteolytic types.

STATEMENT OF PROBLEM

The studies herein reported were undertaken to determine the general relationships of a number of cultures of acid-proteolytic streptococci isolated from dairy products. Special attention was given to the changes produced in milk by the organisms, since these changes are relatively extensive and may be of importance from the standpoint of desirable or undesirable fermentations in various milk derivatives.

HISTORICAL

In 1894 von Freudenreich (28) isolated an organism from bitter cheese and named it *Micrococcus casei amari*. The organism was somewhat oval in form, having a diameter a little less than 1 micron, weakly motile, and liquefied gelatin rapidly. In an agar stab growth followed the line of inoculation and was very slight on the surface of the agar. The organism digested milk after coagulating it. At 37° C. milk was coagulated and slightly bitter after 24 hours and the bitterness became very pronounced after 48 hours. At 20° C. the action on milk was slowed,

---

1 Project No. 119 of the Iowa Agricultural Experiment Station.
neither coagulation nor bitterness being evident after 24 hours; however, the milk was both coagulated and bitter after 48 hours.

MacCallum and Hastings (19), in 1899, isolated an organism from a case of acute endocarditis and designated it *Micrococcus zymogenes*. It decolorized litmus milk within 4 hours after inoculation and coagulated the milk within 24 hours through the action of a rennin-like enzyme; then softening and liquefaction of the curd took place. On agar slopes a profuse, thin, somewhat moist, glistening, almost colorless growth developed. The cells were extremely minute, often somewhat elongated or elliptical, and occurred most frequently in pairs and short chains. The investigators noted especially that in the pairs and short chains the longer axis of the coccus was often transverse to that of the pair or chain. The organism was pathogenic for white mice but not for guinea pigs, white rats, pigeons or rabbits.

Since the work of MacCallum and Hastings, the organism which they designated *M. zymogenes* has apparently been isolated by various investigators. Harris and Longcope (11) reported five isolations. One culture was secured from a cesspool and the remaining four in autopsies on persons who had died of various causes; in none of the cases was the organism considered to be responsible for death. Birge (1) isolated a culture, which appeared to be *M. zymogenes*, from a crow. Hicks (12) concluded that an organism isolated by him from a case of malignant endocarditis was identical with that obtained by MacCallum and Hastings. He described the culture as a gram positive, non-motile Micrococcus, occurring singly, in pairs, masses and chains, and producing a thin, slightly elevated, moist, grayish growth on agar. At 37° C. litmus milk was rapidly decolorized and within 24 hours was curdled with a bluish layer at the top. Softening and liquefaction, with the acquisition of a red tinge, progressed day by day until there was a red stained precipitate at the bottom of the tube and a clear, reddish, supernatant liquid above. The organism was slightly pathogenic for white mice and not at all pathogenic for guinea pigs. The occurrence of *M. zymogenes* in a case of malignant endocarditis was also noted by Crowe (3).

Rogers and Dahlberg (22) made a study of the streptococci present in milk. They found that most of the liquefying streptococci came from the udder. The type which liquefied gelatin was able to ferment glucose, sucrose, lactose, mannitol, and usually glycerol.

Orla-Jensen (21) studied a number of bacterial cultures that liquefied gelatin and proteolyzed milk and designated them *Streptococcus liquefaciens*. He pointed out that the first isolation of an organism of this type was made by von Freudenreich (28). A
culture obtained from von Freudenreich was included in those studied and it had a Micrococcus-like appearance on agar streaks. 

*S. liquefaciens* was considered by Orla-Jensen to be similar in cultural and morphologic respects to *Streptococcus glycercinaceus*, the outstanding difference being that the former liquefied gelatin and proteolyzed milk while the latter did not.

Torrey (25), in 1926, reported the occurrence in fecal specimens of a gram positive diplococcus which he considered to be identical with *M. zymogenes* of MacCallum and Hastings. The organism produced an acid curd in milk in 24 hours. Digestion of the curd began within 1 to 3 days and continued for approximately a week, when the quantity of the curd was greatly reduced. Gelatin was completely liquefied in 7 to 14 days. Glucose, lactose, maltose, mannitol and salicin were fermented by most strains, while the action on sucrose was variable. The organism was repeatedly found in relatively large numbers in fecal specimens from 8 of 132 persons with abnormal intestinal conditions but was not found in specimens from normal persons.

Hucker (13) studied the cocci surviving pasteurization in the milk supplied to Copenhagen, Denmark and noted that *S. liquefaciens* was able to withstand an exposure of 61.1°C for 30 minutes.

The ability of certain of the streptococci to produce carbon dioxide from peptone and glucose was investigated by Hucker (14). No study was made of *S. liquefaciens*, but the related organisms, *Streptococcus apis* and *Streptococcus gracilis*, were included. *S. apis* and *S. gracilis* were both able to produce carbon dioxide from peptone, but little or none was produced from glucose. Hucker (15) reported that the gelatin liquefying streptococci produced a larger percentage of volatile acid than the non-hemolytic, non-gelatin liquefying types and noted that they were the most rapid acid producers of the entire genus. Traces of formic acid were found to be present in the volatile acid produced by *S. apis*. The three species of gelatin liquefying streptococci studied—*S. liquefaciens*, *S. apis* and *S. gracilis*—produced dextro lactic acid. *S. liquefaciens* was found to have a far greater proteolytic power than the others. In milk cultures this organism produced a 70 percent increase in soluble nitrogen over the control and a 30 percent increase in amino nitrogen. *S. apis* gave an equally high percentage increase in soluble nitrogen but only a 5.5 percent increase in amino nitrogen, while *S. gracilis* did not give as high a percentage increase in either soluble or amino nitrogen.

Of 15 strains of acid-proteolytic streptococci received from Gorini, Hucker (16) listed 4 as identical with *S. liquefaciens*. He pointed out that the gelatin liquefying streptococci found in milk
constitute a homogeneous group with definite characteristics and suggested that the group may represent but a single species.

In 1928, Frobisher and Denny (6) made a study of *M. zymogenes* with the object of determining its relationship to *S. liquefaciens*. Two of the cultures of *M. zymogenes* studied were isolated from tonsils and two from the female genital tract. Another *M. zymogenes* culture, isolated from feces, was obtained from Crowe and a culture of *S. liquefaciens* was obtained from the American type culture collection. *M. zymogenes* was found to ferment glucose, lactose, sucrose, glycerol, mannitol and salicin, but not raffinose, starch or inulin. There was little or no growth on potato, nitrates were not reduced, and the organism would not survive 65° C. The pathogenicity for mice and rabbits varied. *S. liquefaciens* was found to be identical in biochemical features with *M. zymogenes*, but the former showed no pathogenicity for mice. The investigators concluded that *M. zymogenes* was either a variety of *S. liquefaciens* or identical with it and, in either case, should be classed as a Streptococcus.

Hammer (7) noted that *S. liquefaciens* produced considerable amounts of lactic acid, the isomeric form being variable as both dextro and inactive acids were found. The fact that *S. liquefaciens* is very similar to *S. lactis* in morphologic and cultural characteristics, other than the proteolysis of milk, was emphasized.

Thomson and Thomson (24) reported that *Streptococcus zymogenes* is identical with *S. gracilis* of Winslow and also "that *Streptococcus zymogenes* is identical with the *Streptococcus apis* (Kralx) and the *Streptococcus liquefaciens*.''

Sherman and Stark (23) found that *S. zymogenes* resembled *S. liquefaciens* in that both reduce litmus before curdling the milk, liquefy gelatin and casein, have a final pH of about 4.2, grow at 10° and 45° C., produce ammonia from peptone, ferment glucose, maltose, lactose, sucrose, raffinose, glycerol, mannitol and salicin, but do not ferment inulin or starch. They differ in that *S. zymogenes* hemolyzes blood and ferments arabinose while *S. liquefaciens* does not.

In 1932, Hucker (17) studied agglutination as a means of differentiating the species of streptococci. The investigation showed *S. liquefaciens* and *S. apis* to be almost identical. Reciprocal agglutinations to the full titre of the serum were obtained with serums prepared from each strain. The close relationship between *S. glycerinaceus* and *S. liquefaciens* was indicated by the fact that the serum of *S. liquefaciens* agglutinated a typical *S. glycerinaceus* culture to the complete titre of the serum.

Torrey and Montu (26) studied the cultural and agglutinative relationships of intestinal streptococci and concluded that *M.*
zymogenes is an intestinal type. They noted that the organism may produce a beta, alpha or gamma reaction on blood agar plates.

Elser and Thomas (5) reported that S. zymogenes could be divided into two groups on the basis of the rate of fermentation of lactose in litmus milk cultures. On blood agar plates all of the 17 strains of S. zymogenes studied produced a greenish discoloration of the red blood cells. When an attempt was made to establish a relationship between S. zymogenes and other streptococci by serological tests, the results obtained were inconclusive.

METHODS

DETECTION OF PROTEOLYTIC BACTERIA ON PLATES

Proteolyzing bacteria were detected on agar plates through the use of skimmilk. When the plates were poured, approximately 0.5 ml. of sterile skimmilk was added to each plate; beef infusion rather than standard agar was employed, as the former was found to be more satisfactory for the growth of the acid-proteolytic streptococci.

VOLATILE ACIDITY

The volatile acidity was determined by the method used by Michaelian and Hammer (20). The results were expressed as the milliliters of n/10 sodium hydroxide required to neutralize the first liter of distillate from 250 gm. of culture.

CARBON DIOXIDE

The production of carbon dioxide was measured by means of Eldredge tubes (4), using 10 ml. of skimmilk in one arm and a known amount of n/10 barium hydroxide in the other arm. The back titrations were made with n/10 hydrochloric acid, using phenolphthalein, and the results were expressed as the milliliters of n/10 barium hydroxide neutralized by the carbon dioxide formed in 10 ml. of skimmilk.

ACETYL METHYL CARBINOL PLUS DIACETYL AND DIACETYL

Acetylmethylcarbinol plus diacetyl was determined with the procedure used by Michaelian and Hammer (20), and the same procedure was used for diacetyl except that ferric chloride was not added. The results were expressed as milligrams of nickel dimethylglyoximate per 200 gm. of culture.

ACIDITY

The pH determinations were made electrometrically with the
quinhydrone electrode. The acidities were titrated on 9 gm. samples, using n/10 sodium hydroxide and phenolphthalein, and calculated as the percentage of lactic acid.

ISOMERIC FORM OF LACTIC ACID

In studying the isomeric form of lactic acid produced, the method described by Hammer (8) was followed.

HYDROLYSIS OF FAT

The hydrolysis of fat was investigated by a modified nile-blue sulfate procedure (10), and also by using copper sulfate as an indicator instead of nile-blue sulfate.

PROTEIN BREAKDOWN IN SKIMMILK

Total nitrogen was determined by the Kjeldahl method and amino nitrogen by the Van Slyke gasometric method (27). The nitrogen was fractionated according to the procedure used by Lane and Hammer (18).

HEMOLYSIS

Hemolysis was studied by streaking the cultures on plates prepared by adding 0.5 ml. defibrinated rabbit blood or sheep blood to each plate before pouring with beef infusion agar.

EXPERIMENTAL

ISOLATION OF ACID-PROTEOLYTIC STREPTOCOCCI FROM DAIRY PRODUCTS

The original attempts to isolate acid-proteolytic streptococci from normal dairy products consisted of plating milk and cream, using beef infusion agar plus 0.5 ml. of sterile skimmilk per plate with 48 hours incubation at 37° C., and picking promising colonies into litmus milk. With this procedure the organisms were obtained only occasionally and always constituted a very small percentage of the total flora. Presumably, in some samples that failed to yield them, the organisms were diluted out in the plates suitable for picking. Proteolyzing micrococci were often present and were frequently obtained in the attempts to pick acid-proteolytic streptococci.

Enrichment procedures were also used. Raw milk and cream were incubated at 6° to 7° C. for from one to several days, plated and colonies picked. The results indicated that at these temperatures there was no relative increase in the acid-proteolytic streptococci. Tubes of raw milk and cream were sealed with agar to limit the air supply, incubated at 21° or 37° C. for several days,
plated and colonies picked. *S. lactis* grew rapidly under these conditions, and the isolation of the acid-proteolytic streptococci was not simplified.

The heating of milk and cream at 62.5° C. for 30 minutes in cotton-stoppered tubes and the plating of the material after incubation for several days at 10°, 21°, 37°, or 45° C. yielded acid-proteolytic streptococci only occasionally, and was no more satisfactory as an isolation procedure than the direct plating of milk and cream. Pure cultures of the organisms had been found to survive 62.5° C. for 30 minutes, when heated in cotton-stoppered tubes.

Fourteen samples of aseptically drawn milk, obtained from 10 cows, were plated and colonies picked. No acid-proteolytic streptococci were found.

Thirty-nine samples of high quality butter were plated in dilutions of 1:10 and 1:100, the plates incubated at 37° C. for approximately 20 hours and proteolyzing colonies, suggesting streptococci, picked. None of the cultures proved to be acid-proteolytic streptococci. In three instances, however, a culture of an acid-proteolytic *Streptococcus* was obtained from a plate poured with butter for the purpose of studying the general types of bacteria present; in each instance only one culture was obtained from a plate.

The acid-proteolytic streptococci were frequently isolated from various cheeses. The most satisfactory method used was to grind about 1 gm. of the cheese with sterile sand and then plate the ground cheese in dilutions of 1:100, 1:1,000 and 1:10,000. After incubating at 37° C. for 16 to 24 hours, proteolyzing colonies that suggested streptococci were picked into tubes of litmus milk. With a relatively short incubation of the plates at 37° C., the acid-proteolytic streptococci had developed very well, while the other organisms ordinarily had not developed to such an extent that they interfered with the picking of the desired organisms from the heavily seeded plates; it was usually necessary to use heavily seeded plates because of the relatively small numbers in which the acid-proteolytic streptococci were present. With longer incubation, the desired organisms were frequently so over-shadowed by the other types that they could not be detected. Acid-proteolytic streptococci were obtained from cheddar, blue, camembert and brick cheeses but were not found in the two samples of swiss cheese examined.

The method of using a short incubation period at 37° C. and heavily seeded plates was fairly satisfactory for obtaining the desired organisms from raw milk and cream. It was not possible, however, to obtain acid-proteolytic streptococci from as large a percentage of the samples of raw milk and cream as of cheese.
SOURCES OF THE CULTURES STUDIED

The 101 cultures studied were isolated or collected from various sources as shown in table 1.

Ninety-one cultures were isolated from dairy products. Of the 65 cultures from cheese, 23 were from Iowa cheddar, 23 from Wisconsin cheddar, 3 from New York cheddar, 7 from cheddar of unknown origin, 4 from Iowa blue, 3 from camembert of unknown origin, and 2 from Wisconsin brick. The cheese varied widely in age and some of the cheddar was known to be at least a year old at the time of the sampling. The 23 cultures isolated from milk and cream came from Iowa products with the exception of 2 cultures from Colorado milk. Of the 3 cultures from butter, 2 were from Iowa butter and 1 was from Oregon butter. The remaining 10 cultures studied were obtained from various laboratories.

<table>
<thead>
<tr>
<th>Source</th>
<th>Total cultures</th>
<th>Culture numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISOLATED FROM:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cheddar cheese</td>
<td>56</td>
<td>16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 30, 31, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 62*, 73, 74, 75, 76, 77, 78, 82, 83, 85, 86, 87, 88, 89, 90, 91, 92, 94, 95, 96, 97, 98, 99, 100, 101</td>
</tr>
<tr>
<td>Raw milk</td>
<td>19</td>
<td>1, 2, 5, 7, 11, 12, 13, 14, 15, 45, 46, 47, 48, 49, 50, 51, 79, 80, 81</td>
</tr>
<tr>
<td>Blue cheese</td>
<td>4</td>
<td>26, 27, 28, 29</td>
</tr>
<tr>
<td>Camembert cheese</td>
<td>3</td>
<td>32, 33, 34</td>
</tr>
<tr>
<td>Butter</td>
<td>3</td>
<td>3, 6, 63</td>
</tr>
<tr>
<td>Pasteurized cream</td>
<td>3</td>
<td>8, 9, 10</td>
</tr>
<tr>
<td>Brick cheese</td>
<td>2</td>
<td>58, 59</td>
</tr>
<tr>
<td>Raw cream</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>RECEIVED FROM:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iowa State College stock</td>
<td>3</td>
<td>64, 65, 93</td>
</tr>
<tr>
<td>J. M. Sherman</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cornell University</td>
<td>3</td>
<td>67, 68, 69 (Labeled S. liquefaciens 812, 817 and 827 respectively)</td>
</tr>
<tr>
<td>M. Frohbişner, Jr.</td>
<td>3</td>
<td>70, 71 (Labeled S. zymogenes) and 72 (Labeled S. liquefaciens No. 799 Am. Type Culture Col.)</td>
</tr>
<tr>
<td>Johns Hopkins U.</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>W. C. Frazier, U. S. D. A.</td>
<td>1</td>
<td>66 (Labeled S. liquefaciens)</td>
</tr>
</tbody>
</table>

*Culture 62 came from cheddar cheese made from pasteurized milk. With the other cheddar cheese used for isolations, the type of milk was not definitely known but was undoubtedly raw in most cases.

GENERAL ACTION OF THE ORGANISMS ON MILK

The general action of the organisms on litmus milk was a rapid coagulation followed by proteolysis. Commonly, the coagulation was preceded by a reduction of the litmus, which was complete except at the surface of the milk, but with some cultures reduction was delayed and was not complete until after coagulation; from the standpoint of the reduction of litmus milk, the slow reducing cultures are comparable to S. lactis var. anoxyphilus (9).
For a time after coagulation, rapidly reducing cultures of the acid-proteolytic streptococci appeared essentially the same as typical cultures of *S. lactis*. With a relatively young culture of the former type, however, the colored band at the surface often showed a less definitely acid reaction than with the latter organism. The slow reducing cultures varied in the time required for reduction, and with some of them reduction did not occur until proteolysis was very evident.

Coagulation was soon followed by proteolysis, which was usually first evident along one side of the tube. It increased in extent and the mass of curd became smaller and smaller as it contracted from the wall of the tube and from the surface of the liquid. The top portion of the curd was definitely red, but the lower portion sometimes showed a reduction of the litmus for an extended period. The proteolyzed milk did not have an objectionable odor but was very bitter.

The active proteolysis of milk by the acid-proteolytic streptococci and the color of the band at the surface of a freshly coagulated milk culture suggest that the coagulation is due to an enzyme rather than to the formation of acid. The acidities of milk cultures, at the time of coagulation, were studied by inoculating tubes of sterile plain skimmed milk, watching them closely for coagulation and then titrating and determining the pH as soon as coagulation was definite. With the 15 cultures studied, the titratable acidities at coagulation ranged from 0.25 to 0.29 percent and averaged 0.27 percent, while the pH values ranged from 6.02 to 5.85 and averaged 5.90; essentially the same results were obtained at 21° and 37° C. The data indicate very definitely that coagulation was not due to the acid produced, although at the time of coagulation the acidity was higher than it was originally. The acidity continued to increase until it was essentially the same as the acidity of a mature milk culture of *S. lactis*.

**GENERAL DESCRIPTION OF THE ACID-PROTEOLYTIC STREPTOCOCCI**

**MORPHOLOGY**

*Form*: Cocci; longer axis at right angles to plane of division.

*Arrangement*: Singly, in pairs and short chains.

*Staining reactions*: Stain readily with common stains; gram positive.

*Spores*: Not produced.

**CULTURAL CHARACTERISTICS**

*Agar slant*: A scanty, dull, filiform, non-viscid, white growth on beef infusion agar after 1 to 2 days at 37° C., with the
type of growth not changing on extended incubation.

**Agar slab:** A scanty growth extending along the line of inoculation after 1 to 2 days at 37° C. on beef infusion agar; no surface growth.

**Agar colony:** White, non-viscid, round colonies with entire edge, about 0.5 to 1 mm. in diameter, after 1 to 2 days at 37° C. on beef infusion agar. Subsurface colonies oval, white, non-viscid and smaller than the surface colonies.

**Gelatin stab:** Infundibuliform liquefaction changing to stratiform and becoming complete at 21° C. in 7 days or less.

**Beef extract broth:** Slight turbidity with sediment.

**Potato:** No visible growth.

**Litmus milk:** Reduced by some cultures before coagulation and by others after coagulation, with a colored band at the surface. Coagulation in 18 to 20 hours at 37° C. and in 2 days at 21° C.; proteolysis follows coagulation.

**BIOCHEMICAL FEATURES**

- **Hydrogen sulfide:** Not produced.
- **Nitrites:** Not reduced.
- **Volatile acid:** Produced.
- **Lactic acid:** d lactic acid or l and i lactic acid produced.
- **Acetylethylcarbinol:** Produced, sometimes in relatively large amounts, especially at 21° C.
- **Diacetyl:** Not produced.
- **Fermenting power:** Acid but no gas from galactose, glucose, glycerol, lactose, levulose, maltose, mannitol and salicin; neither acid nor gas from arabinose, inulin, raffinose and starch; acid but no gas from sucrose with some strains but not with others.
- **Hemolysis:** Red cells hemolyzed in approximately 3 days at 37° C.
- **Fat:** Natural fats not hydrolyzed.
- **Simple triglycerides:** Tripropionin and tributyrin hydrolyzed by some cultures but not by others.
- **pH:** The pH in milk cultures after 7 days at 21° C. approximated 4.5.

**GROWTH CONDITIONS**

- **Oxygen relationship:** Organisms facultative; grew well aerobically.
- **Growth temperatures:** Growth at 10° C., at 45° C. and at temperatures in between.

**IDENTITY OF THE CULTURES**

The morphology, cultural characteristics, biochemical features
and growth conditions of the acid-proteolytic streptococci isolated from dairy products indicate that they are *Streptococcus liquefaciens* Orla-Jensen. The two cultures received with the designation *S. zymogenes* also showed characters that identify them as *S. liquefaciens*; these results confirm the conclusion of Frobisher and Denny (6) and others that *S. zymogenes* and *S. liquefaciens* are the same.

While the name *S. liquefaciens* does not have the advantage of priority (see Historical), the wide use of this name makes its retention advisable.

**SPECIAL BIOCHEMICAL FEATURES**

Studies on the action of the acid-proteolytic streptococci on various media indicated that the group was fairly homogeneous. With the exception of the rate of reduction of litmus milk and the fermentation of sucrose, the cultural reactions were identical. The organisms were then investigated to determine whether the same homogeneity existed with reference to the production of various products in milk and its derivatives.

**PRODUCTION OF VOLATILE ACID, CARBON DIOXIDE AND ACETYL METHYL CARBINOL IN SKIMMILK**

The production of volatile acid, carbon dioxide and acetyl-methylcarbinol in skimmilk was studied with all of the cultures, using an incubation of 7 days at 21° C.; the results obtained are given in table 2.

The volatile acidities produced varied widely with the values ranging from 6.1 to 27.9. Of the 101 cultures, 49 gave values from 5.1 to 10.0, 26 gave values from 10.1 to 15.0, 9 gave values from 15.1 to 20.0, 10 gave values from 20.1 to 25.0, and 7 gave values from 25.1 to 30.0. These results indicate that there was a gradual variation from the cultures that produced a relatively low volatile acidity to those that produced a relatively high volatile acidity, although a relatively low volatile acid production was more common than a relatively high one. The amount of volatile acid produced was not correlated with the action on sucrose; while all of the cultures producing a relatively high volatile acidity fermented sucrose, some of those producing a relatively low volatile acidity fermented this material and some did not. There was no correlation between the amount of volatile acid produced and the rapidity of reduction of litmus milk.

The carbon dioxide values ranged from 2.7 to 8.4. The following summary compares the production of volatile acid and of carbon dioxide by the organisms:
Cultures producing volatile acid from
5.1 to 10.0
10.1 to 15.0
15.1 to 20.0
20.1 to 25.0
25.1 to 30.0

Produced carbon dioxide from
2.7 to 5.5
2.8 to 5.9
3.5 to 8.4
3.9 to 7.6
4.9 to 7.4

From the results it is evident that the carbon dioxide produced did not vary directly with the volatile acid produced. Although there was a tendency for a high carbon dioxide production to accompany a high volatile acid production, considerable intergradation existed.

All of the cultures formed appreciable quantities of acetyl-methylcarbinol. Trials in which no ferric chloride was added to the distillation flask indicated that the organisms did not produce diacetyl and the odors of cultures never suggested diacetyl. Accordingly, the nickel salt was regarded as representing only acetyl-methylcarbinol. The milligrams of nickel salt equivalent to the acetyl-methylcarbinol varied widely, ranging from 3.9 to 71.0. A comparison of the production of volatile acid and of acetylmethylcarbinol is given in the following summary:

<table>
<thead>
<tr>
<th>Cultures producing volatile acid from</th>
<th>Yielded mg. of Ni salt from</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1 to 10.0</td>
<td>3.9 to 15.5</td>
</tr>
<tr>
<td>10.1 to 15.0</td>
<td>4.0 to 18.3</td>
</tr>
<tr>
<td>15.1 to 20.0</td>
<td>19.1 to 71.0</td>
</tr>
<tr>
<td>20.1 to 25.0</td>
<td>18.5 to 56.2</td>
</tr>
<tr>
<td>25.1 to 30.0</td>
<td>17.5 to 55.1</td>
</tr>
</tbody>
</table>

The acetylmethylcarbinol production did not vary directly with the volatile acid production. As was the case with carbon dioxide, however, the cultures producing large amounts of volatile acid tended to produce large amounts of acetylmethylcarbinol, although there was considerable intergradation.

INFLUENCE OF TEMPERATURE ON THE PRODUCTION OF VOLATILE ACID, CARBON DIOXIDE AND ACETYLME'fHYLCARBINOL IN SKIM MILK

Since the acid-proteolytic streptococci grow much more rapidly at 37° C. than at 21° C., certain of the cultures were investigated to determine the relative amounts of volatile acid, carbon dioxide and acetylmethylcarbinol produced at these temperatures.

VOLATILE ACID

The influence of temperature on the formation of volatile acid
TABLE 2. PRODUCTION OF VOLATILE ACID, CARBON DIOXIDE AND ACETYL METHYL CARBINOL IN SKIM MILK.
Cultures incubated 7 days at 21°C.

<table>
<thead>
<tr>
<th>Culture no.</th>
<th>Volatile acid*</th>
<th>Carbon dioxide*</th>
<th>mg. Ni salt equiv. to amc** per 200 gm.</th>
<th>Culture no.</th>
<th>Volatile acid*</th>
<th>Carbon dioxide*</th>
<th>mg. Ni salt equiv. to amc** per 200 gm.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8.6</td>
<td>3.5</td>
<td>9.8</td>
<td>51</td>
<td>10.8</td>
<td>3.8</td>
<td>10.0</td>
</tr>
<tr>
<td>2</td>
<td>9.7</td>
<td>3.9</td>
<td>8.0</td>
<td>52</td>
<td>8.3</td>
<td>4.0</td>
<td>10.7</td>
</tr>
<tr>
<td>3</td>
<td>25.2</td>
<td>7.4</td>
<td>30.3</td>
<td>53</td>
<td>7.6</td>
<td>4.7</td>
<td>9.9</td>
</tr>
<tr>
<td>4</td>
<td>12.0</td>
<td>3.1</td>
<td>14.0†</td>
<td>54</td>
<td>12.9</td>
<td>3.5</td>
<td>12.0</td>
</tr>
<tr>
<td>5</td>
<td>10.6</td>
<td>4.1</td>
<td>4.0</td>
<td>55</td>
<td>23.6</td>
<td>5.8</td>
<td>23.3</td>
</tr>
<tr>
<td>6</td>
<td>19.6</td>
<td>5.7</td>
<td>26.3†</td>
<td>56</td>
<td>22.3</td>
<td>7.0</td>
<td>21.9</td>
</tr>
<tr>
<td>7</td>
<td>10.4</td>
<td>4.1</td>
<td>14.5†</td>
<td>57</td>
<td>22.1</td>
<td>5.4</td>
<td>56.2</td>
</tr>
<tr>
<td>8</td>
<td>8.4</td>
<td>3.8</td>
<td>12.2</td>
<td>58</td>
<td>6.4</td>
<td>3.6</td>
<td>6.1</td>
</tr>
<tr>
<td>9</td>
<td>8.0</td>
<td>3.7</td>
<td>7.8</td>
<td>59</td>
<td>6.1</td>
<td>3.3</td>
<td>5.3</td>
</tr>
<tr>
<td>10</td>
<td>8.3</td>
<td>3.5</td>
<td>7.8</td>
<td>60</td>
<td>9.0</td>
<td>4.3</td>
<td>9.8</td>
</tr>
<tr>
<td>11</td>
<td>8.9</td>
<td>3.4</td>
<td>6.3</td>
<td>61</td>
<td>8.7</td>
<td>4.1</td>
<td>9.8</td>
</tr>
<tr>
<td>12</td>
<td>9.9</td>
<td>3.5</td>
<td>9.3</td>
<td>62</td>
<td>9.9</td>
<td>3.5</td>
<td>9.8</td>
</tr>
<tr>
<td>13</td>
<td>6.9</td>
<td>3.2</td>
<td>6.2</td>
<td>63</td>
<td>17.5</td>
<td>8.4</td>
<td>66.9</td>
</tr>
<tr>
<td>14</td>
<td>9.4</td>
<td>3.5</td>
<td>11.5†</td>
<td>64</td>
<td>22.4</td>
<td>5.2</td>
<td>53.7†</td>
</tr>
<tr>
<td>15</td>
<td>7.5</td>
<td>3.2</td>
<td>13.4†</td>
<td>65</td>
<td>20.7</td>
<td>6.3</td>
<td>40.5</td>
</tr>
<tr>
<td>16</td>
<td>7.9</td>
<td>4.1</td>
<td>8.5</td>
<td>66</td>
<td>7.3</td>
<td>3.0</td>
<td>3.9</td>
</tr>
<tr>
<td>17</td>
<td>11.0</td>
<td>3.0</td>
<td>6.1</td>
<td>67</td>
<td>21.9</td>
<td>7.6</td>
<td>33.5†</td>
</tr>
<tr>
<td>18</td>
<td>9.3</td>
<td>3.2</td>
<td>7.1</td>
<td>68</td>
<td>18.9</td>
<td>4.9</td>
<td>19.5</td>
</tr>
<tr>
<td>19</td>
<td>9.6</td>
<td>4.1</td>
<td>7.5</td>
<td>69</td>
<td>18.7</td>
<td>5.4</td>
<td>19.1</td>
</tr>
<tr>
<td>20</td>
<td>8.0</td>
<td>3.3</td>
<td>6.9</td>
<td>70</td>
<td>11.4</td>
<td>4.0</td>
<td>12.5</td>
</tr>
<tr>
<td>21</td>
<td>10.0</td>
<td>3.5</td>
<td>8.2</td>
<td>71</td>
<td>10.4</td>
<td>4.0</td>
<td>8.8</td>
</tr>
<tr>
<td>22</td>
<td>10.5</td>
<td>3.5</td>
<td>8.6</td>
<td>72</td>
<td>19.1</td>
<td>7.7</td>
<td>47.5</td>
</tr>
<tr>
<td>23</td>
<td>10.0</td>
<td>3.4</td>
<td>12.6</td>
<td>73</td>
<td>11.0</td>
<td>2.8</td>
<td>13.7</td>
</tr>
<tr>
<td>24</td>
<td>9.1</td>
<td>3.2</td>
<td>6.5</td>
<td>74</td>
<td>16.7</td>
<td>3.9</td>
<td>26.7</td>
</tr>
<tr>
<td>25</td>
<td>9.1</td>
<td>3.1</td>
<td>9.5</td>
<td>75</td>
<td>11.2</td>
<td>3.7</td>
<td>16.2</td>
</tr>
<tr>
<td>26</td>
<td>9.4</td>
<td>3.6</td>
<td>7.3</td>
<td>76</td>
<td>13.7</td>
<td>3.8</td>
<td>12.8</td>
</tr>
<tr>
<td>27</td>
<td>8.5</td>
<td>3.7</td>
<td>9.4</td>
<td>77</td>
<td>10.7</td>
<td>5.2</td>
<td>13.8</td>
</tr>
<tr>
<td>28</td>
<td>10.5</td>
<td>3.8</td>
<td>7.8</td>
<td>78</td>
<td>10.4</td>
<td>5.9</td>
<td>11.8</td>
</tr>
<tr>
<td>29</td>
<td>9.9</td>
<td>3.3</td>
<td>8.1</td>
<td>79</td>
<td>25.4</td>
<td>5.2</td>
<td>25.9</td>
</tr>
<tr>
<td>30</td>
<td>10.8</td>
<td>3.4</td>
<td>5.2</td>
<td>80</td>
<td>22.5</td>
<td>4.5</td>
<td>18.5</td>
</tr>
<tr>
<td>31</td>
<td>8.2</td>
<td>3.5</td>
<td>5.5</td>
<td>81</td>
<td>20.9</td>
<td>6.8</td>
<td>38.9</td>
</tr>
<tr>
<td>32</td>
<td>25.1</td>
<td>6.1</td>
<td>44.4</td>
<td>82</td>
<td>16.0</td>
<td>3.5</td>
<td>26.1</td>
</tr>
<tr>
<td>33</td>
<td>27.7</td>
<td>6.8</td>
<td>55.1†</td>
<td>83</td>
<td>7.4</td>
<td>3.2</td>
<td>11.1</td>
</tr>
<tr>
<td>34</td>
<td>25.3</td>
<td>6.7</td>
<td>47.0</td>
<td>84</td>
<td>15.8</td>
<td>4.7</td>
<td>31.2</td>
</tr>
<tr>
<td>35</td>
<td>11.5</td>
<td>3.8</td>
<td>6.4</td>
<td>85</td>
<td>9.5</td>
<td>4.6</td>
<td>8.5</td>
</tr>
<tr>
<td>36</td>
<td>10.3</td>
<td>4.1</td>
<td>8.3†</td>
<td>86</td>
<td>14.1</td>
<td>3.2</td>
<td>10.2</td>
</tr>
<tr>
<td>37</td>
<td>9.6</td>
<td>4.2</td>
<td>5.2</td>
<td>87</td>
<td>25.4</td>
<td>6.0</td>
<td>18.2</td>
</tr>
<tr>
<td>38</td>
<td>9.7</td>
<td>3.6</td>
<td>6.1</td>
<td>88</td>
<td>22.8</td>
<td>4.3</td>
<td>49.9</td>
</tr>
<tr>
<td>39</td>
<td>9.0</td>
<td>3.7</td>
<td>5.4</td>
<td>89</td>
<td>9.1</td>
<td>5.1</td>
<td>13.7</td>
</tr>
<tr>
<td>40</td>
<td>11.8</td>
<td>3.9</td>
<td>7.3</td>
<td>90</td>
<td>12.5</td>
<td>3.7</td>
<td>15.4</td>
</tr>
<tr>
<td>41</td>
<td>11.5</td>
<td>4.1</td>
<td>5.0</td>
<td>91</td>
<td>22.0</td>
<td>3.9</td>
<td>45.8</td>
</tr>
<tr>
<td>42</td>
<td>11.7</td>
<td>3.9</td>
<td>9.3</td>
<td>92</td>
<td>17.3</td>
<td>4.3</td>
<td>39.2</td>
</tr>
<tr>
<td>43</td>
<td>8.6</td>
<td>4.7</td>
<td>6.0</td>
<td>93</td>
<td>8.5</td>
<td>5.5</td>
<td>9.8</td>
</tr>
<tr>
<td>44</td>
<td>9.8</td>
<td>2.7</td>
<td>6.7</td>
<td>94</td>
<td>27.9</td>
<td>4.9</td>
<td>17.5</td>
</tr>
<tr>
<td>45</td>
<td>8.3</td>
<td>3.8</td>
<td>8.3</td>
<td>95</td>
<td>9.1</td>
<td>3.7</td>
<td>7.4</td>
</tr>
<tr>
<td>46</td>
<td>8.4</td>
<td>3.8</td>
<td>9.4</td>
<td>96</td>
<td>10.8</td>
<td>3.8</td>
<td>15.9</td>
</tr>
<tr>
<td>47</td>
<td>8.1</td>
<td>3.8</td>
<td>9.0</td>
<td>97</td>
<td>12.3</td>
<td>4.0</td>
<td>18.3</td>
</tr>
<tr>
<td>48</td>
<td>8.6</td>
<td>3.4</td>
<td>8.0</td>
<td>98</td>
<td>8.4</td>
<td>4.8</td>
<td>13.5</td>
</tr>
<tr>
<td>49</td>
<td>8.4</td>
<td>4.8</td>
<td>6.6</td>
<td>99</td>
<td>9.7</td>
<td>5.0</td>
<td>13.5</td>
</tr>
<tr>
<td>50</td>
<td>9.9</td>
<td>3.6</td>
<td>8.4</td>
<td>100</td>
<td>8.7</td>
<td>3.1</td>
<td>15.5</td>
</tr>
</tbody>
</table>

*The "methods" give the procedure used for the determination.
**amc = acetyl methyl carbinol.
† = Determination run after incubating 8 days.
TABLE 3. INFLUENCE OF TEMPERATURE ON THE PRODUCTION OF VOLATILE ACID IN SKIMMILK.

<table>
<thead>
<tr>
<th>Culture no.</th>
<th>Volatile acid 3 days at 37°C</th>
<th>Volatile acid 7 days at 21°C</th>
<th>Culture no.</th>
<th>Volatile acid 3 days at 37°C</th>
<th>Volatile acid 7 days at 21°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.2</td>
<td>8.6</td>
<td>36</td>
<td>5.1</td>
<td>10.3</td>
</tr>
<tr>
<td>3</td>
<td>11.9</td>
<td>25.2</td>
<td>63</td>
<td>18.0</td>
<td>17.5</td>
</tr>
<tr>
<td>4</td>
<td>5.8</td>
<td>12.0</td>
<td>64</td>
<td>17.7</td>
<td>22.4</td>
</tr>
<tr>
<td>6</td>
<td>6.7</td>
<td>19.6</td>
<td>67</td>
<td>10.6</td>
<td>21.9</td>
</tr>
<tr>
<td>8</td>
<td>5.7</td>
<td>8.4</td>
<td>68</td>
<td>10.1</td>
<td>18.9</td>
</tr>
<tr>
<td>14</td>
<td>4.5</td>
<td>9.4</td>
<td>69</td>
<td>9.4</td>
<td>18.7</td>
</tr>
<tr>
<td>15</td>
<td>5.1</td>
<td>7.5</td>
<td>70</td>
<td>5.6</td>
<td>11.4</td>
</tr>
<tr>
<td>32</td>
<td>10.3</td>
<td>25.1</td>
<td>71</td>
<td>6.6</td>
<td>10.4</td>
</tr>
<tr>
<td>33</td>
<td>12.7</td>
<td>27.7</td>
<td>72</td>
<td>18.2</td>
<td>19.1</td>
</tr>
</tbody>
</table>

†Figures taken from table 2.

was studied by determining the volatile acid production of 18 cultures after 3 days at 37°C and after 7 days at 21°C; different incubation periods were used because of the slower growth of the organisms at 21°C than at 37°C. Table 3 presents the data obtained.

Except for culture 63, the volatile acidities produced in 3 days at 37°C were lower than those produced in 7 days at 21°C, although in some cases the differences were small. In general, the cultures giving relatively high volatile acidities at 21°C also gave comparatively high values at 37°C, but the ratios between the yields at the two temperatures varied widely.

CARBON DIOXIDE

The effect of temperature on the production of carbon dioxide was investigated by comparing, with 8 cultures, the quantities

TABLE 4. INFLUENCE OF TEMPERATURE ON THE PRODUCTION OF CARBON DIOXIDE IN SKIMMILK.

<table>
<thead>
<tr>
<th>Culture no.</th>
<th>Carbon dioxide 7 days at 37°C</th>
<th>Carbon dioxide 7 days at 21°C†</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1.3</td>
<td>3.0</td>
</tr>
<tr>
<td>4</td>
<td>1.7</td>
<td>3.1</td>
</tr>
<tr>
<td>6</td>
<td>2.2</td>
<td>5.7</td>
</tr>
<tr>
<td>14</td>
<td>1.8</td>
<td>3.5</td>
</tr>
<tr>
<td>17</td>
<td>2.0</td>
<td>3.0</td>
</tr>
<tr>
<td>34</td>
<td>2.9</td>
<td>5.2</td>
</tr>
<tr>
<td>39</td>
<td>2.6</td>
<td>3.7</td>
</tr>
<tr>
<td>64</td>
<td>1.5</td>
<td>3.1</td>
</tr>
</tbody>
</table>

†Figures taken from table 2.
produced in 7 days at 37° C. and at 21° C. The results obtained are given in table 4.

With each organism the production of carbon dioxide was lower at 37° C. than at 21° C. The values obtained at 37° C. varied from 1.3 to 2.9, while those obtained at 21° C. ranged from 3.0 to 6.7.

ACETYL METHYL CARBINOL

The relationship of temperature to the production of acetyl methyl carbinol was studied with each of 20 cultures, as follows: Six bottles of skimmilk were inoculated and 4 of the bottles incubated at 37° C., while 2 were held at 21°C.; the acetyl methyl carbinol and titratable acidity were usually determined after 1, 2, 4, and 7 days at 37° C. and after 3 and 7 days at 21° C. The results obtained are given in table 5.

The data show that at 37° C. the amount of acetyl methyl carbinol produced was commonly much lower than the amount pro-

| TABLE 5. INFLUENCE OF TEMPERATURE ON THE PRODUCTION OF ACETYL METHYL CARBINOL IN SKIM MILK. |
|------------------------------------------|-----------------|----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Culture number                          | 37°C.           | 21°C.          | 37°C.           | 21°C.          | 37°C.           | 21°C.          | 37°C.           | 21°C.          | 37°C.           | 21°C.          |
|                                        | mg. Ni salt equiv. to ame per 200 gm. | mg. Ni salt equiv. to ame per 200 gm. | NaOH per g gm. | mg. Ni salt equiv. to ame per 200 gm. | NaOH per g gm. | mg. Ni salt equiv. to ame per 200 gm. | NaOH per g gm. | mg. Ni salt equiv. to ame per 200 gm. | NaOH per g gm. | mg. Ni salt equiv. to ame per 200 gm. | NaOH per g gm. |
|                                        | mg. Ni salt equiv. to ame per 200 gm. | mg. Ni salt equiv. to ame per 200 gm. | NaOH per g gm. | mg. Ni salt equiv. to ame per 200 gm. | NaOH per g gm. | mg. Ni salt equiv. to ame per 200 gm. | NaOH per g gm. | mg. Ni salt equiv. to ame per 200 gm. | NaOH per g gm. | mg. Ni salt equiv. to ame per 200 gm. | NaOH per g gm. |
| 1                                      | 0.8             | 4.8            | 1.0             | 3.3            | 1.7             | 5.5            | 5.5             | 5.5            | 6.5             | 6.5            |
| 2                                      | 2.2             | 5.3            | 1.6             | 3.3            | 2.8             | 5.5            | 5.5             | 5.5            | 6.5             | 6.5            |
| 3                                      | 3.0             | 5.2            | 1.7             | 3.3            | 1.7             | 6.4            | 6.4             | 6.4            | 7.4             | 7.4            |
| 4                                      | 4.0             | 4.9            | 1.7             | 3.3            | 3.4             | 6.5            | 6.5             | 6.5            | 7.4             | 7.4            |
| 5                                      | 5.0             | 4.9            | 1.7             | 3.3            | 1.7             | 6.4            | 6.4             | 6.4            | 7.4             | 7.4            |
| 6                                      | 6.0             | 6.0            | 1.7             | 3.3            | 2.2             | 6.5            | 6.5             | 6.5            | 7.4             | 7.4            |
| 7                                      | 7.0             | 7.0            | 1.7             | 3.3            | 1.7             | 6.4            | 6.4             | 6.4            | 7.4             | 7.4            |
| 8                                      | 8.0             | 8.0            | 1.7             | 3.3            | 2.2             | 6.5            | 6.5             | 6.5            | 7.4             | 7.4            |

*Figures taken from table 2.
†Determination run after incubating 8 days.
duced at 21°C. After incubating 7 days at 37°C, the amount of nickel salt equivalent to the acetyl methylcarbinol produced varied from 0.5 to 12.4 mg., while after 7 days at 21°C, the values obtained varied from 3.9 to 71.0 mg. In general, there was an increase in the amount of acetyl methylcarbinol produced at either temperature as the period of incubation increased, but the cultures that produced large quantities at 21°C yielded almost as much after incubating 3 days as after incubating 7 days. With any of the incubation periods there was no correlation between the titratable acidities and the yields of acetyl methylcarbinol of the various cultures.

INFLUENCE OF ADDED CITRIC ACID ON THE PRODUCTION OF VOLATILE ACID AND ACETYL METHYL CARBINOL IN SKIM MILK

The influence of the addition of citric acid on the production of volatile acid and acetyl methylcarbinol was studied with 39 cultures; the citric acid was usually added at the time of inoculation, but with 4 cultures the trials were repeated and the acid added 24 hours after inoculation. Because of the greater production of volatile acid and acetyl methylcarbinol at 21°C than at 37°C, an incubation of 7 days at 21°C was employed. Table 6 presents the data obtained.

The addition of citric acid increased the volatile acid production of a few of the cultures, but decreased the production of most of them, due presumably to the inhibitory effect of the acid. When 0.2 percent citric acid was added at the time of inoculation, 2 of the 31 cultures gave an increased production of volatile acid. In one case, the increase was not very large, but with organism 81 the increase was striking. When 0.4 percent acid was added, 2 of the 8 cultures used gave an increased production, but one of the increases was not significant. With the addition of the acid 24 hours after inoculation there was apparently less inhibitory effect and 3 of the 4 cultures gave an increased production of volatile acid, but the increase was significant only with organism 81. In this instance the volatile acid production was about doubled; the culture also gave an increased volatile acid production when the acid was added at the time of inoculation.

The addition of 0.2 percent citric acid at the time of inoculation gave an increased production of acetyl methylcarbinol with 9 of the 33 cultures used, but the increases were significant with only 4 of the cultures; in these cases, however, the increases were very large. The four cultures giving the significant increases were the cultures which gave an increased production of volatile acid with added citric acid (0.2 or 0.4 percent). When citric acid was added 24 hours after inoculation, one of the cult-
tures (organism 81) gave a striking increase in acetylmethylcarbinol production; this culture also gave a large increase when the citric acid was added at the time of inoculation.

**TABLE 6. INFLUENCE OF ADDED CITRIC ACID ON THE PRODUCTION OF VOLATILE ACID AND ACETYLMETHYLCARBINOL IN SKIM MILK.**

Cultures incubated 7 days at 21°C.

<table>
<thead>
<tr>
<th>Culture no.</th>
<th>Skimmilk</th>
<th>Skimmilk + 0.2% added citric acid</th>
<th>Skimmilk + 0.4% added citric acid</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Volatile acid</td>
<td>mg. Ni salt equiv. to ame per 200 gm.</td>
<td>Volatile acid</td>
</tr>
<tr>
<td>57</td>
<td>23.0</td>
<td>50.4</td>
<td>30.2</td>
</tr>
<tr>
<td>59</td>
<td>6.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>9.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>61</td>
<td>8.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>62</td>
<td>7.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>63</td>
<td>17.5</td>
<td>46.9</td>
<td>74.8</td>
</tr>
<tr>
<td>66</td>
<td>11.6</td>
<td>6.5</td>
<td>8.6</td>
</tr>
<tr>
<td>69</td>
<td>11.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>71</td>
<td>10.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>72</td>
<td>19.1</td>
<td>43.8</td>
<td></td>
</tr>
<tr>
<td>73</td>
<td>12.9</td>
<td>13.7</td>
<td>11.5</td>
</tr>
<tr>
<td>74</td>
<td>18.6</td>
<td>26.7</td>
<td>18.8</td>
</tr>
<tr>
<td>75</td>
<td>13.2</td>
<td>16.2</td>
<td>11.0</td>
</tr>
<tr>
<td>76</td>
<td>15.6</td>
<td>12.8</td>
<td>10.2</td>
</tr>
<tr>
<td>77</td>
<td>12.6</td>
<td>13.8</td>
<td>8.5</td>
</tr>
<tr>
<td>78</td>
<td>12.3</td>
<td>11.8</td>
<td>10.3</td>
</tr>
<tr>
<td>79</td>
<td>27.3</td>
<td>25.9</td>
<td>11.1</td>
</tr>
<tr>
<td>80</td>
<td>24.4</td>
<td>18.5</td>
<td>10.6</td>
</tr>
<tr>
<td>81</td>
<td>22.8</td>
<td>35.9</td>
<td>36.5</td>
</tr>
<tr>
<td>82</td>
<td>17.9</td>
<td>26.1</td>
<td>8.9</td>
</tr>
<tr>
<td>83</td>
<td>9.3</td>
<td>11.1</td>
<td>7.8</td>
</tr>
<tr>
<td>84</td>
<td>17.7</td>
<td>31.2</td>
<td>11.5</td>
</tr>
<tr>
<td>85</td>
<td>11.4</td>
<td>8.5</td>
<td>8.8</td>
</tr>
<tr>
<td>86</td>
<td>15.0</td>
<td>10.2</td>
<td>12.1</td>
</tr>
<tr>
<td>87</td>
<td>27.3</td>
<td>18.2</td>
<td>14.6</td>
</tr>
<tr>
<td>88</td>
<td>24.7</td>
<td>49.9</td>
<td>19.7</td>
</tr>
<tr>
<td>89</td>
<td>11.0</td>
<td>13.7</td>
<td>10.5</td>
</tr>
<tr>
<td>90</td>
<td>14.4</td>
<td>15.4</td>
<td>10.7</td>
</tr>
<tr>
<td>91</td>
<td>23.9</td>
<td>45.8</td>
<td>12.0</td>
</tr>
<tr>
<td>92</td>
<td>19.2</td>
<td>30.2</td>
<td>8.8</td>
</tr>
<tr>
<td>93</td>
<td>10.4</td>
<td>9.8</td>
<td>6.3</td>
</tr>
<tr>
<td>94</td>
<td>28.0</td>
<td>11.1</td>
<td>10.7</td>
</tr>
<tr>
<td>95</td>
<td>11.0</td>
<td>7.4</td>
<td>7.0</td>
</tr>
<tr>
<td>96</td>
<td>13.6</td>
<td>18.3</td>
<td>11.9</td>
</tr>
<tr>
<td>97</td>
<td>14.2</td>
<td>18.3</td>
<td>11.2</td>
</tr>
<tr>
<td>98</td>
<td>11.5</td>
<td>13.8</td>
<td>7.8</td>
</tr>
<tr>
<td>99</td>
<td>12.7</td>
<td>16.1</td>
<td>7.9</td>
</tr>
<tr>
<td>100</td>
<td>10.6</td>
<td>6.8</td>
<td>8.6</td>
</tr>
<tr>
<td>101</td>
<td>12.3</td>
<td>9.2</td>
<td>8.8</td>
</tr>
</tbody>
</table>

Reagent added about 24 hours after inoculation

<table>
<thead>
<tr>
<th></th>
<th>24.0</th>
<th>25.3</th>
<th>26.5</th>
<th>18.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>22.7</td>
<td>47.7</td>
<td>45.5</td>
<td>101.1</td>
</tr>
<tr>
<td>83</td>
<td>8.7</td>
<td>9.0</td>
<td>9.7</td>
<td>10.2</td>
</tr>
<tr>
<td>91</td>
<td>18.7</td>
<td>27.9</td>
<td>15.5</td>
<td>19.0</td>
</tr>
</tbody>
</table>
INFLUENCE OF ACETALDEHYDE ON THE PRODUCTION OF VOLATILE ACID AND ACETYL METHYL CARBINOL IN SKIM MILK

The effect of acetaldehyde\(^2\) on the production of volatile acid and acetylmethylcarbinol in skim milk by the acid-proteolytic streptococci was investigated, as follows: Two bottles of skim milk were inoculated with each of the cultures to be studied; one bottle was held as a control and acetaldehyde was added to the other at the rate of 0.15 ml. of aldehyde to 300 ml. of milk, either at the time of inoculation or about 24 hours later. Determinations of volatile acid or acetylmethylcarbinol were made after an incubation period of 7 days at 21° C.

**VOLATILE ACID**

The data obtained on volatile acid production are presented in table 7.

In general, when acetaldehyde was added at the time of inoculation, there was a decrease in volatile acid production. The extents of the decreases varied considerably. With 3 of the 33 cultures the addition of acetaldehyde resulted in an increase in volatile acid, but 2 of the increases were negligible while the third was only from 27.3 to 34.3. The acetaldehyde lengthened the time required for coagulation of the milk and evidently had an inhibitory effect. When the acetaldehyde was added 24 hours after inoculation there was a small decrease in the volatile acid production with 2 of the 4 cultures and a small increase with 2. Apparently the acetaldehyde had less of an inhibitory effect when added about 24 hours after inoculation than when added at the time of inoculation.

**ACETYL METHYL CARBINOL**

Table 8 presents the results obtained on acetylmethylcarbinol production.

The addition of acetaldehyde at the time of inoculation resulted in a decrease in the yield of acetylmethylcarbinol with most of the 24 cultures, but with 6 cultures there was an increase. Three of these cultures—34, 65 and 87—gave striking increases, while 3—40, 66 and 85—gave relatively small ones. The acetaldehyde regularly lengthened the time required for coagulation of the milk. When the acetaldehyde was added about 24 hours after inoculation, there was an increase in the acetylmethylcarbinol production with 8 of the 9 cultures. While some of the increases were rather large on a percentage basis, the actual increases were not large.

\(^2\) The acetaldehyde used was obtained from the Eastman Kodak Company.
TABLE 7. INFLUENCE OF ACETALDEHYDE ON THE PRODUCTION OF VOLATILE ACID IN SKIMMILK.

0.15 ml. acetaldehyde added per 300 ml. milk. Cultures incubated 7 days at 21°C.

<table>
<thead>
<tr>
<th>Culture no.</th>
<th>Volatile acid</th>
<th>Skimmilk</th>
<th>Skimmilk + acetaldehyde</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reagent added at time of inoculation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>57</td>
<td>23.0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>63</td>
<td>22.4</td>
<td>5.5</td>
<td></td>
</tr>
<tr>
<td>66</td>
<td>11.6</td>
<td>7.3</td>
<td></td>
</tr>
<tr>
<td>72</td>
<td>25.0</td>
<td>18.8</td>
<td></td>
</tr>
<tr>
<td>73</td>
<td>12.9</td>
<td>7.9</td>
<td></td>
</tr>
<tr>
<td>74</td>
<td>18.6</td>
<td>10.3</td>
<td></td>
</tr>
<tr>
<td>75</td>
<td>13.2</td>
<td>8.4</td>
<td></td>
</tr>
<tr>
<td>76</td>
<td>15.6</td>
<td>9.4</td>
<td></td>
</tr>
<tr>
<td>77</td>
<td>12.6</td>
<td>7.5</td>
<td></td>
</tr>
<tr>
<td>78</td>
<td>12.3</td>
<td>8.2</td>
<td></td>
</tr>
<tr>
<td>79</td>
<td>27.3</td>
<td>9.5</td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>24.4</td>
<td>9.8</td>
<td></td>
</tr>
<tr>
<td>81</td>
<td>22.8</td>
<td>12.4</td>
<td></td>
</tr>
<tr>
<td>82</td>
<td>17.9</td>
<td>8.5</td>
<td></td>
</tr>
<tr>
<td>83</td>
<td>9.3</td>
<td>6.5</td>
<td></td>
</tr>
<tr>
<td>84</td>
<td>17.7</td>
<td>9.2</td>
<td></td>
</tr>
<tr>
<td>85</td>
<td>11.4</td>
<td>7.5</td>
<td></td>
</tr>
<tr>
<td>86</td>
<td>15.0</td>
<td>7.8</td>
<td></td>
</tr>
<tr>
<td>87</td>
<td>27.3</td>
<td>34.3</td>
<td></td>
</tr>
<tr>
<td>88</td>
<td>24.7</td>
<td>9.8</td>
<td></td>
</tr>
<tr>
<td>89</td>
<td>11.0</td>
<td>7.7</td>
<td></td>
</tr>
<tr>
<td>90</td>
<td>14.4</td>
<td>8.3</td>
<td></td>
</tr>
<tr>
<td>91</td>
<td>23.9</td>
<td>9.6</td>
<td></td>
</tr>
<tr>
<td>92</td>
<td>19.2</td>
<td>8.5</td>
<td></td>
</tr>
<tr>
<td>93</td>
<td>10.4</td>
<td>11.9</td>
<td></td>
</tr>
<tr>
<td>94</td>
<td>28.0</td>
<td>23.6</td>
<td></td>
</tr>
<tr>
<td>95</td>
<td>11.0</td>
<td>8.0</td>
<td></td>
</tr>
<tr>
<td>96</td>
<td>13.6</td>
<td>10.0</td>
<td></td>
</tr>
<tr>
<td>97</td>
<td>14.2</td>
<td>10.1</td>
<td></td>
</tr>
<tr>
<td>98</td>
<td>11.5</td>
<td>9.0</td>
<td></td>
</tr>
<tr>
<td>99</td>
<td>12.7</td>
<td>10.5</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>10.6</td>
<td>8.9</td>
<td></td>
</tr>
<tr>
<td>101</td>
<td>12.3</td>
<td>13.4</td>
<td></td>
</tr>
</tbody>
</table>

Reagent added about 24 hours after inoculation

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>79</td>
<td>24.0</td>
<td>29.7</td>
</tr>
<tr>
<td>81</td>
<td>22.7</td>
<td>26.8</td>
</tr>
<tr>
<td>83</td>
<td>8.7</td>
<td>8.5</td>
</tr>
<tr>
<td>91</td>
<td>18.7</td>
<td>16.2</td>
</tr>
</tbody>
</table>

RELATIONSHIP OF TEMPERATURE TO THE INFLUENCE OF ACETALDEHYDE ON THE PRODUCTION OF ACETYL METHYL CARBINOL

The relationship of temperature to the influence of acetaldehyde on the production of acetyl methylcarbinol in skimmilk was studied with four cultures that were known to give an increased yield of acetyl methylcarbinol when the aldehyde was added. The production was compared at 37°C and 21°C, the aldehyde being added at the time of inoculation and the cultures incubated 7 days. At either temperature, the aldehyde increased the pro-
duction of acetylmethylcarbinol, but the increases were much larger at 21° C. than at 37° C. At either temperature, the acidities developed were much lower in the presence of the acetaldehyde than in the controls.

INFLUENCE OF THE TIME OF ADDITION OF ACETALDEHYDE ON THE PRODUCTION OF ACETYLMETHYLCARBINOL

The results presented in table 8 suggest that the time at which acetaldehyde is added to a culture may influence the yield of acetylmethylcarbinol, so two detailed trials were carried out. The data obtained are given in table 9.

**TABLE 8. INFLUENCE OF ACETALDEHYDE ON THE PRODUCTION OF ACETYLMETHYLCARBINOL IN SKIMMILK.**

0.15 ml. acetaldehyde added per 300 ml. milk. Cultures incubated 7 days at 21°C.

<table>
<thead>
<tr>
<th>Culture no.</th>
<th>mg. Ni salt equiv. to ame per 200 gm.</th>
<th>Skimmilk</th>
<th>Skimmilk + acetaldehyde</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reagent added at time of inoculation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>47.9</td>
<td>72.6†</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>7.3</td>
<td>14.7†</td>
<td></td>
</tr>
<tr>
<td>65</td>
<td>40.5</td>
<td>73.1†</td>
<td></td>
</tr>
<tr>
<td>66</td>
<td>3.9</td>
<td>5.0†</td>
<td></td>
</tr>
<tr>
<td>73</td>
<td>13.7</td>
<td>12.0</td>
<td></td>
</tr>
<tr>
<td>74</td>
<td>26.7</td>
<td>15.9</td>
<td></td>
</tr>
<tr>
<td>75</td>
<td>16.2</td>
<td>12.8</td>
<td></td>
</tr>
<tr>
<td>76</td>
<td>12.8</td>
<td>12.0</td>
<td></td>
</tr>
<tr>
<td>77</td>
<td>13.8</td>
<td>9.8</td>
<td></td>
</tr>
<tr>
<td>78</td>
<td>11.8</td>
<td>10.9</td>
<td></td>
</tr>
<tr>
<td>79</td>
<td>25.9</td>
<td>10.5</td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>18.5</td>
<td>12.3</td>
<td></td>
</tr>
<tr>
<td>81</td>
<td>38.9</td>
<td>26.7</td>
<td></td>
</tr>
<tr>
<td>82</td>
<td>26.1</td>
<td>10.8</td>
<td></td>
</tr>
<tr>
<td>83</td>
<td>11.1</td>
<td>7.9</td>
<td></td>
</tr>
<tr>
<td>84</td>
<td>31.2</td>
<td>11.0</td>
<td></td>
</tr>
<tr>
<td>85</td>
<td>8.5</td>
<td>10.4</td>
<td></td>
</tr>
<tr>
<td>86</td>
<td>10.2</td>
<td>10.2</td>
<td></td>
</tr>
<tr>
<td>87</td>
<td>18.2</td>
<td>42.4</td>
<td></td>
</tr>
<tr>
<td>88</td>
<td>49.9</td>
<td>14.5</td>
<td></td>
</tr>
<tr>
<td>89</td>
<td>13.7</td>
<td>12.4</td>
<td></td>
</tr>
<tr>
<td>90</td>
<td>15.4</td>
<td>11.5</td>
<td></td>
</tr>
<tr>
<td>91</td>
<td>45.8</td>
<td>16.2</td>
<td></td>
</tr>
<tr>
<td>92</td>
<td>39.2</td>
<td>16.8</td>
<td></td>
</tr>
</tbody>
</table>

| Reagent added about 24 hours after inoculation | | | |
| 93 | 9.8 | 15.3 | |
| 94 | 11.1 | 18.8 | |
| 95 | 7.4 | 10.3 | |
| 96 | 8.3 | 11.4 | |
| 97 | 18.3 | 14.8 | |
| 98 | 13.8 | 18.0 | |
| 99 | 16.1 | 21.6 | |
| 100 | 6.8 | 15.5 | |
| 101 | 9.2 | 11.0 | |

†0.18 ml. acetaldehyde added per 300 ml. culture.
Influence of the Time of Addition of Acetaldehyde on the Production of Acetylemethylcarbinol in Skimmilk.

Cultures incubated at 21°C.

<table>
<thead>
<tr>
<th>mg. Ni salt equiv. to amc per 200 gm.</th>
<th>Trial 1, culture 33</th>
<th>Trial 2, culture 65</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>At time acetaldehyde was added</td>
<td>7 days after inoculation</td>
</tr>
<tr>
<td>No acetaldehyde added to culture</td>
<td>65.0</td>
<td>61.2</td>
</tr>
<tr>
<td>No acetaldehyde added to culture</td>
<td>64.0</td>
<td></td>
</tr>
<tr>
<td>0.15 ml. acetaldehyde added at time of inoc.</td>
<td>none</td>
<td>38.7</td>
</tr>
<tr>
<td>0.15 ml. acetaldehyde added 8 hrs. after inoc.</td>
<td>none</td>
<td>55.6</td>
</tr>
<tr>
<td>0.15 ml. acetaldehyde added 16 hrs. after inoc.</td>
<td>none</td>
<td>107.4</td>
</tr>
<tr>
<td>0.15 ml. acetaldehyde added 24 hrs. after inoc.</td>
<td>4.6</td>
<td>94.9</td>
</tr>
<tr>
<td>0.15 ml. acetaldehyde added 48 hrs. after inoc.</td>
<td>41.1</td>
<td>70.1</td>
</tr>
<tr>
<td>0.15 ml. acetaldehyde added 72 hrs. after inoc.</td>
<td>56.9</td>
<td>71.3</td>
</tr>
<tr>
<td>0.1 ml. acetaldehyde added at time of inoc.</td>
<td>85.6</td>
<td></td>
</tr>
<tr>
<td>0.1 ml. acetaldehyde added 8 hrs. after inoc.</td>
<td>96.6</td>
<td></td>
</tr>
<tr>
<td>0.1 ml. acetaldehyde added 14 hrs. after inoc.</td>
<td>103.1</td>
<td></td>
</tr>
<tr>
<td>0.1 ml. acetaldehyde added 24 hrs. after inoc.</td>
<td>87.6</td>
<td></td>
</tr>
<tr>
<td>0.1 ml. acetaldehyde added 48 hrs. after inoc.</td>
<td>64.9</td>
<td></td>
</tr>
<tr>
<td>0.1 ml. acetaldehyde added 72 hrs. after inoc.</td>
<td>67.0</td>
<td></td>
</tr>
</tbody>
</table>

†The amounts of acetaldehyde were used per 300 ml. of milk.

*Acetaldehyde added 14 hrs. after inoculation.

In trial 1, 14 bottles of skimmilk were inoculated with culture 33, an organism known to produce a large amount of acetylemethylcarbinol. Two of the 14 bottles were held as controls for 7 days at 21°C. The remaining 12 bottles were divided into 6 pairs and acetaldehyde was added to 1 bottle of each pair (in the proportion of 0.15 ml. of acetaldehyde to 300 ml. of culture) after 0, 8, 16, 24, 48, and 72 hours. At the time of the addition of aldehyde, the remaining bottle in each pair (to which no aldehyde had been added) was analyzed for acetylemethylcarbinol. For the final values the total incubation time after the cultures were inoculated was 7 days at 21°C. The data obtained in the trial indicate that there was a definite relationship between the time at which acetaldehyde was added and the yield of acetylemethylcarbinol. When the aldehyde was added at the time of inoculation or 8 hours after, there was a decrease in the production of acetylemethylcarbinol. The highest yield of nickel salt (equivalent to acetylemethylcarbinol) per 200 gm. of culture was 107.4 mg., and was obtained when acetaldehyde was added to the culture 16 hours after inoculation; at this time there was no acetylemethylcarbinol present in the control sample analyzed when the aldehyde was added. The yield in the culture to which acetaldehyde was added 24 hours after inoculation was slightly less than the value obtained when the aldehyde was added after 16 hours; some acetylemethylcarbinol had been formed at the
time the aldehyde was added. When the aldehyde was added 48 or 72 hours after inoculation the yields were somewhat greater than the yields obtained in 7 days without the addition of aldehyde; considerable acetylmethylcarbinol had been formed, however, when the aldehyde was added.

In trial 2, organism 65, also known to produce a large quantity of acetylmethylcarbinol in skimmilk, was employed. Two amounts of acetaldehyde were added at various times after inoculation and the amount of acetylmethylcarbinol present in the culture at the time of the addition was not determined. In this trial the highest yield of nickel salt (equivalent to the acetylmethylcarbinol) was obtained in both series when the aldehyde was added 14 hours after inoculation. When 0.15 ml. of acetaldehyde per 300 ml. of milk was added 72 hours after inoculation, the yield of nickel salt was slightly less than that obtained from the control; when the amount of acetaldehyde added after 72 hours was decreased to 0.1 ml., however, the value obtained was slightly higher than that of the control.

EFFECT OF NEUTRALIZING CULTURES ON THE PRODUCTION OF ACETYLMETHYLCARBINOL IN SKIMMILK

When the acetylmethylcarbinol produced by a culture was determined at various periods, there was commonly an increase as the time of incubation was extended. These results suggested a study of the effect, on the acetylmethylcarbinol production, of neutralizing a culture that had coagulated. Trials were carried out with cultures 33 and 65, using the following procedure with each: About 1,200 ml. of skimmilk were inoculated and incubated 7 days at 21° C.; the culture was then divided into 5 portions and the acetylmethylcarbinol determined on 1 portion; 2 of the remaining portions were neutralized to 0.16 to 0.19 percent acid (calculated as lactic) with sodium hydroxide; after holding 3 days at 21° C., 1 neutralized and 1 unneutralized portion were analyzed for the acetylmethylcarbinol present and after 7 days at 21° C., the remaining portions were analyzed. Table 10 gives the data obtained.

With each unneutralized culture there was only a very slight increase in the acetylmethylcarbinol content from 7 to 14 days so that the cultures had reached approximately their maximum content in 7 days. With each neutralized culture, however, there was a small increase in the acetylmethylcarbinol content, the increase over the control being larger with culture 33 than with culture 65. There was no evidence of a disappearance of acetylmethylcarbinol in either the normal or neutralized cultures.
TABLE 10. EFFECT OF NEUTRALIZATION ON THE PRODUCTION OF ACETYL METHYL CARBINOL IN SKIMMILK.

Cultures neutralized after 7 days incubation.

<table>
<thead>
<tr>
<th>Culture no.</th>
<th>7 days at 21°C.</th>
<th>10 days at 21°C.</th>
<th>14 days at 21°C.</th>
</tr>
</thead>
<tbody>
<tr>
<td>mg. Ni salt equiv. to amc per 200 gm.</td>
<td>Acidity calc. as percent lactic acid</td>
<td>Percent acidity after neutralization</td>
<td>mg. Ni salt equiv. to amc per 200 gm.</td>
</tr>
<tr>
<td>neutralized sample</td>
<td>Neutralized sample</td>
<td>Control</td>
<td>Neutralized sample</td>
</tr>
<tr>
<td>------------------</td>
<td>------------------</td>
<td>--------</td>
<td>------------------</td>
</tr>
<tr>
<td>33</td>
<td>40.4</td>
<td>0.92</td>
<td>0.16</td>
</tr>
<tr>
<td>65</td>
<td>47.7</td>
<td>0.95</td>
<td>0.19</td>
</tr>
</tbody>
</table>

EXAMINATION OF SKIMMILK CULTURES FOR 2,3-BUTYLENE GLYCOL

The production of 2,3-butylene glycol in skimmilk was investigated with five cultures, as follows: Two bottles of skimmilk were inoculated with each culture to be examined and incubated at 21°C. After about 7 and 21 days, 2,3-butylene glycol determinations were carried out. The results indicated that this compound had not been formed.

ISOMERIC FORM OF LACTIC ACID PRODUCED IN SKIMMILK

The isomeric form of lactic acid produced in skimmilk was studied by inoculating the organisms in skimmilk, incubating 7 days at either 37°C or 21°C, preparing the zinc salts (8), and then drying and analyzing them. The data obtained are given in table 11.

With the cultures grown at 37°C, the percentages of water of crystallization in the zinc salts were in close agreement with the theoretical for the salts of active lactic acid, and the rotations of the salts were regularly l so the acid was of the d type. The percentages of zinc oxide in the salts agreed with the theoretical for zinc lactate. With the cultures grown at 21°C, the percentages of water of crystallization in the salts were variable. Some of the values agreed rather closely with the theoretical for active acids, while others indicated a mixture of active and inactive acids. The rotations of the salts were regularly l so that the acid was of the d type, or there was an excess of the d type in the mixture. In the two cases in which there were two trials on an organism, the agreement between the trials was satisfactory. The percentages of zinc oxide indicated the salts were lactates.

---

8 The 2,3-butylene glycol determinations were made by C. H. Werkman and G. L. Stahly of the Department of Bacteriology, Iowa State College, using the method suggested by Brockman and Werkman (2).
TABLE 11. ISOMERIC FORM OF LACTIC ACID PRODUCED IN SKIM MILK.

<table>
<thead>
<tr>
<th>Culture no.</th>
<th>Percent of water of crystallization in zinc salt*</th>
<th>Percent ZnO in water-free salt</th>
<th>Rotation of zinc salt</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Determination A</td>
<td>Determination B</td>
<td>Average</td>
</tr>
<tr>
<td>In incubated at 37°C.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>13.05</td>
<td>13.03</td>
<td>13.04</td>
</tr>
<tr>
<td>21</td>
<td>13.07</td>
<td>13.13</td>
<td>13.10</td>
</tr>
<tr>
<td>68</td>
<td>13.32</td>
<td>13.35</td>
<td>13.33</td>
</tr>
<tr>
<td>70</td>
<td>13.24</td>
<td>13.33</td>
<td>13.28</td>
</tr>
<tr>
<td>71</td>
<td>13.02</td>
<td>12.95</td>
<td>12.98</td>
</tr>
<tr>
<td>In incubated at 21°C.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>13.77</td>
<td>13.87</td>
<td>13.82</td>
</tr>
<tr>
<td>3</td>
<td>13.36</td>
<td>13.31</td>
<td>13.33</td>
</tr>
<tr>
<td>4</td>
<td>15.20</td>
<td>15.44</td>
<td>15.32</td>
</tr>
<tr>
<td>5</td>
<td>14.69</td>
<td>14.85</td>
<td>14.77</td>
</tr>
<tr>
<td>6</td>
<td>14.03</td>
<td>14.29</td>
<td>14.16</td>
</tr>
<tr>
<td>7 trial a</td>
<td>14.89</td>
<td>14.74</td>
<td>14.81</td>
</tr>
<tr>
<td>7 trial b</td>
<td>14.51</td>
<td>14.57</td>
<td>14.54</td>
</tr>
<tr>
<td>9</td>
<td>15.28</td>
<td>15.20</td>
<td>15.24</td>
</tr>
<tr>
<td>11</td>
<td>14.27</td>
<td>14.48</td>
<td>14.37</td>
</tr>
<tr>
<td>19</td>
<td>14.40</td>
<td>14.36</td>
<td>14.38</td>
</tr>
<tr>
<td>21 trial a</td>
<td>15.06</td>
<td>15.09</td>
<td>15.07</td>
</tr>
<tr>
<td>21 trial b</td>
<td>14.41</td>
<td>14.36</td>
<td>14.38</td>
</tr>
<tr>
<td>28</td>
<td>13.44</td>
<td>13.69</td>
<td>13.56</td>
</tr>
<tr>
<td>30</td>
<td>13.40</td>
<td>13.50</td>
<td>13.45</td>
</tr>
<tr>
<td>68</td>
<td>13.18</td>
<td>13.05</td>
<td>13.11</td>
</tr>
<tr>
<td>70</td>
<td>13.32</td>
<td>13.28</td>
<td>13.30</td>
</tr>
<tr>
<td>71</td>
<td>13.18</td>
<td>13.24</td>
<td>13.21</td>
</tr>
</tbody>
</table>

*Theoretical for zinc salts of active lactic acid = 12.88 percent; for zinc salt of inactive lactic acid = 18.18 percent.
**Theoretical for zinc lactate = 33.46 percent.

ACTION ON FAT

The acid-proteolytic streptococci, like various other cocci (both streptococci and micrococci), are greatly inhibited by nile-blue sulfate, so the usual nile-blue sulfate technique (10) is not adapted to the study of their ability to hydrolyze fat.

The action of the 101 cultures on fat was studied by inoculating a loop of each culture as a "spot" on a plate poured with beef infusion agar in which fat had been dispersed as small globules. After incubating at 21°C for 4 to 6 days, the plates were flooded with saturated aqueous copper sulfate solution for 10 minutes and rinsed with distilled water. None of the cultures, with either butterfat or cottonseed oil in the medium, changed any of the globules so that they took on a blue color, as is the case when hydrolysis occurs. Tests with cultures of bacteria capable of splitting fat showed the expected blue color in the fat globules.
Fifteen of the cultures were "spotted" on beef infusion agar plates containing dispersed butterfat. The plates were incubated 4 days at 21° C., flooded for 30 minutes with an aqueous solution of nile-blue sulfate, of an approximate strength of 1 to 1,500, and rinsed with distilled water. All of the globules in the plates took on a pink color, indicating that the organisms had not attacked the fat, while globules near the colonies of lipolytic bacteria, used as controls, were stained blue.

Each of the 101 cultures was studied for its ability to hydrolyze tripropionin and tributyrin by "spotting" the organisms on plates poured with beef infusion agar in which tripropionin or tributyrin had been dispersed. Since the products of the hydrolysis of either of these simple triglycerides are soluble in the agar, hydrolysis is indicated by the disappearance of the globules near a colony. Sixty-four of the cultures evidently hydrolyzed both tripropionin and tributyrin; there was considerable variation in the activity of the cultures, as judged by the areas around the colonies from which the globules had disappeared, but hydrolysis was never extensive. Seven of the cultures did not hydrolyze either of the compounds and the remaining 30 hydrolyzed one or the other, 24 hydrolyzing only tripropionin and 6 hydrolyzing only tributyrin.

**PROTEIN BREAKDOWN IN MILK**

The protein breakdown in skimmilk was studied with four representative cultures. Milk, in approximately 200 ml. portions, was sterilized in pint bottles after the weight of each bottle and its contents had been recorded. Several bottles were then inoculated with each culture to be studied and incubated at 37° or 21° C. Analyses were made on serum from each culture after various incubation periods. The serum from a culture was recovered by bringing the weight to the original with distilled water, adding 3 ml. of glacial acetic acid and heating in boiling water with frequent agitation. The culture was then cooled and filtered through paper. The following determinations were made on the serum: Total nitrogen, amino nitrogen, and the nitrogen soluble and insoluble in trichloracetic acid, ethyl alcohol or phosphotungstic acid. The values were expressed as the milliliters of n/10 acid equivalent to the nitrogen in 5 ml. of serum. The results obtained are given in table 12.

The data show that the organisms greatly increased the soluble nitrogen in the serum of the milk. In general, the degree of proteolysis did not vary significantly with the different cultures. With cultures 6 and 20, which were studied at more frequent intervals than the others, the proteolysis was largely com-
TABLE 12. PROTEIN BREAKDOWN IN MILK.

<table>
<thead>
<tr>
<th>Culture no.</th>
<th>Incubation time, (days)</th>
<th>Total nitrogen</th>
<th>Trichloracetic acid</th>
<th>Ethyl alcohol</th>
<th>Phosphotungstic acid</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Nitrogen fractionated into sol. and insol. portions with</td>
<td>mg. amino nitrogen in 5 cc. serum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Check</td>
<td>0</td>
<td>1.9</td>
<td>1.4</td>
<td>0.3</td>
<td>0.9</td>
</tr>
<tr>
<td>2</td>
<td>14</td>
<td>13.1</td>
<td>12.6</td>
<td>0.4</td>
<td>9.3</td>
</tr>
<tr>
<td>63</td>
<td>14</td>
<td>13.4</td>
<td>13.0</td>
<td>0.4</td>
<td>9.4</td>
</tr>
<tr>
<td>Check</td>
<td>14</td>
<td>1.8</td>
<td>1.7</td>
<td>0.4</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Trial I
Incubated at 37°C.

| Check       | 0                       | 11.2 | 10.9 | 0.5 | 7.4 | 3.8 | 2.9 | 8.3 | 2.02 |
| 2           | 14                      | 11.6 | 11.3 | 0.4 | 8.0 | 3.8 | 2.9 | 8.6 | 2.19 |
| 63          | 14                      | 11.8 | 11.3 | 0.3 | 8.6 | 3.3 | 3.0 | 8.8 | 2.18 |
| 63          | 28                      | 12.3 | 12.0 | 0.4 | 8.6 | 3.6 | 3.3 | 9.1 | 2.19 |
| Check       | 28                      | 1.7 | 1.6 | 0.2 | 0.8 | 1.0 | 0.7 | 1.0 | 0.19 |

Incubated at 21°C.

| Check       | 0                       | 1.9 | 1.6 | 0.4 | 0.9 | 1.2 | 0.8 | 1.2 | 0.19 |
| 6           | 2                       | 11.1 | 11.0 | 0.3 | 7.6 | 3.5 | 2.6 | 8.4 | 1.76 |
| 6           | 5                       | 11.4 | 11.1 | 0.3 | 8.1 | 3.5 | 2.6 | 8.8 | 1.81 |
| 6           | 14                      | 11.6 | 11.2 | 0.5 | 7.8 | 3.8 | 2.6 | 9.2 | 2.09 |
| 6           | 28                      | 11.5 | 11.3 | 0.5 | 7.4 | 4.2 | 2.5 | 9.1 | 2.05 |
| 20          | 2                       | 11.9 | 11.9 | 0.3 | 8.0 | 3.8 | 2.7 | 9.2 | 2.04 |
| 20          | 5                       | 12.5 | 12.2 | 0.3 | 8.5 | 4.0 | 3.0 | 9.2 | 2.22 |
| 20          | 14                      | 12.7 | 12.3 | 0.4 | 8.4 | 4.1 | 3.4 | 9.3 | 2.55 |
| 20          | 28                      | 12.9 | 12.4 | 0.6 | 8.5 | 4.6 | 3.6 | 9.5 | 2.61 |
| Check       | 28                      | 2.0 | 1.5 | 0.4 | 0.9 | 1.1 | 1.0 | 1.2 | 0.16 |

Trial II
Incubated at 37°C.

| Check       | 0                       | 10.6 | 10.2 | 0.4 | 7.5 | 3.0 | 2.7 | 8.2 | 1.57 |
| 6           | 5                       | 12.0 | 11.6 | 0.5 | 8.1 | 3.8 | 3.2 | 8.8 | 2.13 |
| 20          | 5                       | 8.8 | 8.7 | 0.3 | 6.2 | 2.6 | 2.1 | 7.0 | 1.21 |
| 20          | 28                      | 11.4 | 10.9 | 0.5 | 7.6 | 3.7 | 3.0 | 8.4 | 2.02 |
| Check       | 28                      | 1.9 | 1.5 | 0.4 | 0.9 | 1.0 | 0.9 | 1.2 | 0.21 |

Incubated at 21°C.

| 6           | 5                       | 12.0 | 11.6 | 0.5 | 8.1 | 3.8 | 3.2 | 8.8 | 2.13 |
| 20          | 5                       | 8.8 | 8.7 | 0.3 | 6.2 | 2.6 | 2.1 | 7.0 | 1.21 |
| 20          | 28                      | 11.4 | 10.9 | 0.5 | 7.6 | 3.7 | 3.0 | 8.4 | 2.02 |
| Check       | 28                      | 1.9 | 1.5 | 0.4 | 0.9 | 1.0 | 0.9 | 1.2 | 0.21 |

complete after 2 days at 37°C and was extensive after 5 days at 21°C. After 14 days cultures 2 and 63 showed slightly more proteolysis at 37°C than at 21°C, while after 28 days culture 6 showed slightly less proteolysis at 37°C than at 21°C, while culture 20 showed slightly more.

The distribution of the nitrogen in the various fractions was essentially the same with the different organisms and with the different incubation temperatures. The amino nitrogen was significantly increased by the organisms as were the fractions soluble and insoluble in the various reagents, with the exception of the fraction insoluble in trichloracetic acid in which no increase
would be expected. There was little change in the various fractions with the different incubation periods.

A summary of the effects of the four cultures on the amounts and percentages of nitrogen in the various fractions after extensive growth of the organisms in milk is given in table 13.

The data show that essentially the same percentage distribution of the nitrogen was obtained with one organism as with another, and that the temperature had no significant influence on the distribution. The largest fraction was regularly the one soluble in ethyl alcohol but not in phosphotungstic acid, while the next largest was the fraction soluble in trichloracetic acid but not in ethyl alcohol. There was also considerable nitrogen soluble in phosphotungstic acid but not amino nitrogen, while the amino nitrogen and nitrogen insoluble in trichloracetic acid were present in only small amounts.

GENERAL RESISTANCE OF THE ORGANISMS

VIABILITY OF THE ACID-PROTEOLYTIC STREPTOCOCCI IN CULTURE MEDIA

The acid-proteolytic streptococci lived in cultures for much longer periods than S. lactis. Litmus milk cultures of several

<table>
<thead>
<tr>
<th>Table 13. Amounts and Percentages of Various Forms of Nitrogen in Serum.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Culture 2</td>
</tr>
<tr>
<td>-----------------</td>
</tr>
<tr>
<td>ml. of 0.1 normal acid equivalent to nitrogen fractions of 3 cc. serum</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>14 days</td>
</tr>
<tr>
<td>2.85</td>
</tr>
<tr>
<td>5.8</td>
</tr>
<tr>
<td>3.3</td>
</tr>
<tr>
<td>13.0</td>
</tr>
<tr>
<td>In incubated 28 days at 21°C.</td>
</tr>
<tr>
<td>2.3</td>
</tr>
<tr>
<td>5.1</td>
</tr>
<tr>
<td>3.3</td>
</tr>
<tr>
<td>11.7</td>
</tr>
</tbody>
</table>
strains were held at 37° C. and were viable for approximately 18 days, while at 21° C. the same strains lived about 45 days. At about 5° C. the organisms lived for extended periods, both in litmus milk and on beef infusion agar; when litmus milk was inoculated from a culture held about 2.5 years at this temperature, it was curdled within 24 hours at 37° C.

RESISTANCE TO HEAT

The heat resistance of the acid-proteolytic streptococci was determined in the following manner: Strains 1, 6, 16, 20, 23 and 70, representing the various types from the standpoint of rate of reduction of litmus, action on sucrose and amount of acetylmethylcarbinol produced, were used; 0.1 ml. of a 1-day and of a 6-day culture of each strain, grown at 21° C., was placed in 10 ml. of milk and 2 ml. of each suspension were placed in a series of agglutination tubes; the tubes were then sealed and exposed in a water bath for various periods at the desired temperature.

At 61.7° C. all of the cultures survived an exposure of 20 minutes and all except the 1-day and the 6-day cultures of strain 70 survived a 50 minute exposure. At 65.6° C. all except the 1-day culture of strain 70 survived a 5-minute exposure. After 40 minutes at 65.6° C., however, all of the cultures were killed.

DISCUSSION

The data presented indicate that the acid-proteolytic streptococci which were isolated from dairy products represent a rather homogeneous group. From the standpoint of the general characters studied, the variations that occurred were in the rapidity of reduction of litmus milk and in the fermentation of sucrose; the former variation is comparable to one of the variations found with *S. lactis* and is additional evidence of a relationship between the acid-proteolytic streptococci and the *S. lactis* group. The identity of the acid-proteolytic streptococci with *S. liquefaciens* appears to be clearly established.

*S. liquefaciens* is evidently widely distributed in dairy products, but in normal materials is ordinarily not found in large numbers. Since this organism has been isolated from such a variety of sources by various investigators, it is evidently widely distributed in nature and there is no reason to regard it as primarily present in dairy products.

*S. liquefaciens* is important in dairy products because of its ability to form lactic acid (either d or d and l) and various pro-
tein degradation products. The protein decomposition yields compounds of varying complexities and, presumably, the different compounds are important under different conditions. In at least some instances, the more complex compounds may be responsible for bitterness. The less complex compounds may be desirable in cheddar cheese and the frequent presence of the organism in cheddar cheese suggests that it plays a role in the ripening. In large numbers, the organism undoubtedly would be definitely objectionable.

In addition to the production of volatile acid and carbon dioxide, as previously noted by Hucker (14) (15), all of the 101 cultures studied formed appreciable quantities of acetyl methylcarbinol in milk. With a majority of the cultures the amount produced was rather small, but with a few it was comparatively large. Since the few cultures studied in detail neither oxidized the acetyl methylcarbinol to diacetyl nor reduced it to 2,3-butyleneglycol, the compound is evidently an end product. The increased production of volatile acid and acetyl methylcarbinol with a few of the cultures, when citric acid was added to milk in which the organisms were growing, indicates that there are citric acid-fermenting organisms among the acid-proteolytic streptococci, just as there are among other groups of bacteria. Added acetaldehyde gave an increased production of acetyl methylcarbinol with a few cultures, but no increase in volatile acid; there was no correlation, however, between the utilization of acetaldehyde and the fermentation of citric acid.

Although certain of the 101 cultures studied hydrolyzed tripropionin, tributyrin or both, none of them was able to attack cottonseed oil or butterfat. Therefore, the species is considered to be non-lipolytic.
LITERATURE CITED


Masonry Barn Design and Construction

BY HENRY GIESE, H. J. BARRE AND J. BROWNLEE DAVIDSON

AGRICULTURAL EXPERIMENT STATION
IOWA STATE COLLEGE OF AGRICULTURE
AND MECHANIC ARTS

R. E. BUCHANAN, Director

AGRICULTURAL ENGINEERING SECTION

AMES, IOWA
<table>
<thead>
<tr>
<th>CONTENTS</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summary and conclusions</td>
<td>255</td>
</tr>
<tr>
<td>Barn design</td>
<td>257</td>
</tr>
<tr>
<td>Preliminary considerations</td>
<td>257</td>
</tr>
<tr>
<td>Size of barn</td>
<td>257</td>
</tr>
<tr>
<td>Shape of roof</td>
<td>260</td>
</tr>
<tr>
<td>Wind loads</td>
<td>261</td>
</tr>
<tr>
<td>Structural design</td>
<td>266</td>
</tr>
<tr>
<td>Construction problems</td>
<td>279</td>
</tr>
<tr>
<td>Roof forms</td>
<td>279</td>
</tr>
<tr>
<td>Model arch</td>
<td>283</td>
</tr>
<tr>
<td>Full sized arch</td>
<td>284</td>
</tr>
<tr>
<td>Experimental barn</td>
<td>286</td>
</tr>
<tr>
<td>Waterproofing problems</td>
<td>290</td>
</tr>
<tr>
<td>Cost of materials for the roof</td>
<td>294</td>
</tr>
<tr>
<td>Literature cited</td>
<td>296</td>
</tr>
</tbody>
</table>
SUMMARY AND CONCLUSIONS

In 1913 an investigation was begun with the object of developing an all masonry barn which could be constructed at a reasonable cost and yet have the advantages of permanent and fire resistant construction. The studies which have been conducted pertain chiefly to the roof structure, with particular emphasis on the method of construction.

In addition to a number of design studies, models of roof sections were built to develop a method of roof construction. Strength tests were made on roof models to check the reliability of the designs. The information obtained served as the basis of the design and method of constructing an experimental barn, which was built at Iowa State College in 1926-27. Common overall dimensions and a desirable roof shape were established to make the roof forms usable for a number of barns; wind load assumptions were adapted from reliable wind pressure investigations to permit a more intelligent and efficient roof design.

The results of the design studies, construction and tests on models and roof sections, and the construction of the experimental barn, together with other related experiences, seem to warrant the following general conclusions:

1. The masonry arch is a very stable type of roof structure as shown by the tests on sections, which check closely the design calculations.

2. The construction of the roof is difficult and involves a large amount of labor because of:
   a. The use of heavy steel forms to carry a large part of the roof weight.
   b. The manipulation of the forms in erection, moving, dismantling and transporting.
   c. The handling and placing of roof materials.

3. The additional cost of the roof over a wood frame type construction is due not so much to the cost of materials, as to the cost of the unproductive labor in handling the materials and in manipulation of the steel forms. The overhead cost of the forms becomes a large item in the first cost if they are used for only one or a few barns.
4. Experiments in the methods of making a roof watertight have not as yet indicated an entirely successful method. A heavy fibered asphalt has been found the best of the waterproof coatings which have been used. Leaks appear to be due to slight openings in the joints and to the development of fine cracks.

5. The construction of the roof should be directed by one who is familiar with masonry construction.

6. A roof with a span of 34 ft. and a height of 20 ft. provides enough storage space for most conditions.
Masonry Barn Design and Construction

By Henry Giese, H. J. Barre and J. Brownlee Davidson

This bulletin reports the results of a study, initiated in 1913, of the design of an all masonry barn which might be constructed at reasonable first cost with the advantages of permanent and fire resistant construction. This investigation is only a step in the development in this type of barn, and since studies were confined largely to the roof, the solutions to a number of other problems remain incomplete. The basic principle of arches—the placing of all of the materials in compression—was used in the design of the roof. Reinforced concrete ribs were added for additional stability and to resist eccentric loads such as those caused by wind.

BARN DESIGN

PRELIMINARY CONSIDERATIONS

In most types of masonry roof construction economy depends largely on the use of forms which may be used for a large number of barns, thus reducing the form cost per structure. A roof of standard dimensions in cross section is highly desirable, so that this economy in use of forms may be obtained.

SIZE OF BARN

A study of the size of barns to establish roof dimensions which may satisfy a large percentage of farm needs involves first a study of barn widths, since the principal dimensions of the roof, with respect to its cross section, are determined by the width of the first floor structure and the amount of storage space to be provided in the upper story.

1 Project 24 of the Iowa Agricultural Experiment Station.
2 The following contributions to the study of the masonry barn are acknowledged: W. W. Ashby and J. B. Kelley, who studied designs of an all masonry barn for their senior theses in Agricultural Engineering; W. G. Kaiser, A. W. Clyde and L. J. Fletcher, who designed and constructed a full sized roof section of hollow clay blocks; the Structural Clay Tile Association for its support of a research fellowship held by Bruce Russell, who designed the experimental barn for partial fulfillment of the requirements for a master’s degree.
Two general methods were used in attempting to determine a barn width which is generally accepted in practice and therefore likely to be used, namely: (a) Plans of barns recommended by the United States Department of Agriculture and state experiment stations (13), together with observations of barns in use; and (b) a study of interior dimensions of both the “face in” and “face out” arrangements. The observations on actual barns were taken from the following: “Dairy barns from a manufacturing point of view” (20), “An economic study of farm buildings in New York” (9), and the dairy barn survey made by the Structures Division of the American Society of Agricultural Engineers (1).

Observations of barns and plans by common widths are shown in fig. 1. These show that 34 and 36-foot widths are generally recommended for dairy and general purpose barns and that there is in existence a large number of barns of widths narrower than those generally recommended. The average of the 30, 32, 34, and 36-foot widths is 34.3 ft., while the average of all barns included in the plans is 33.9 ft. A barn of 34 ft. gives ample work space and conforms well to present practice.

Interior dimensions affecting barn widths for both the “face in” and “face out” arrangement are given in fig. 2. The largest variations occur in the length of the stall and width of litter and feed alleys, the latter depending on the type of arrangement used.

From the above and previous studies a choice of either the 34 or 36-foot barn would seem satisfactory. Because a narrower barn requires less material per cow housed and is warmer due to less exposed wall area, a width of 34 ft. was selected.
The amount of storage space necessary for feed for the livestock housed in the barn may be a determining factor in establishing the height of the barn roof. Other factors to be consid-
ered are appearance, economical use of material and possible changes in hay storage practices.

A survey of barn plans from several sources shows a variation from 21 to 35 ft. in the height of the ridge above the mow floor in gambrel roof barns with a width of 36 ft. (table 1). The cross sectional area of the mow for the most common height of 29 to 30 ft. is about 770 sq. ft. This value is indicative of the amount of storage space provided and should be approximately the same for barns of different widths.

A calculation of the amount of roughage required under average conditions (10) shows that the storage space necessary per cow is less than ordinarily provided in a barn. A 1,200 lb. cow, fed 1 1/2 lbs of hay per 100 lbs. live weight, daily through a feeding period of 220 days, would consume 3,960 lbs. or 990 cu. ft. of loose hay, with silage fed in ample quantities. The barn length chargeable to a cow is approximately 2.35 ft. The necessary mow area in cross section required per cow would be 422 sq. ft.

Additional mow space, above the amount required, may be desirable in many instances for surplus hay, grain, equipment or bedding. The mow should provide the necessary space for loose hay and still not have much waste space when chopped or baled hay is used. For good appearance, stability, and the above requirements, a roof height of 20 ft. would be a reasonable choice. It gives a cross sectional area of 462 sq. ft. for a curved roof conforming to the shape of an inverted catenary.

**SHAPE OF ROOF**

The shape of the barn roof should conform to some symmetrical curve suitable for arches, especially when masonry materials are used. The selection of such a curve involves the consideration of the roof with respect to its structural stability, ap-
pearance and economical use of material for the amount of mow storage space provided.

A light high arch roof differs from a low massive arch used for bridges, chiefly in the loading and the stresses. The design in the latter is governed largely by the direct stresses in compression from its own dead weight, whereas that of the former is governed almost entirely by the bending stresses due to eccentric live loads produced by the wind. Reinforcing must be supplied in the roof structure to resist these bending stresses, either in the roof slab itself or in arch ribs spaced at intervals along the roof. Since masonry materials are comparatively weak in tension, a roof shape, which would be stable under its own weight (that is, subjecting all materials to compressive loads only) would offer some advantage in design.

Of the curves presented in fig. 3 for the proposed shapes, the parabola and the inverted catenary most nearly satisfy this condition. The catenary is a curve formed by a flexible, inextensible cord or chain of uniform weight per unit of length when suspended at the ends. The parabola is similar with the exception that the weight is distributed uniformly along the span, rather than along the length of the cord or chain. The inverted catenary satisfies the condition of stability for a light and high arch under its own dead weight as shown in fig. 16. It provides slightly greater cross sectional area than the parabola for a given height and presents a more pleasing appearance.

The semi-ellipse, with its major axis vertical, is suitable from the standpoint of mow space, but not desirable from the standpoint of stability because the resultant of the dead loads deviates considerably from the arch axis and subjects certain portions of the arch to tensile stresses.

WIND LOADS

Although the conventional method of wind load assumptions, by which only impact pressures are considered, was used in the design of the model arches, an attempt was made in succeeding designs to extend information obtained from results of numerous wind pressure investigations on structures for load assumptions which approximate actual conditions. Wind load formulas do not take into account "negative" or outward pressures,
nor are they comprehensive enough to account for variation of pressure distribution and form variation of structures.

A few of the studies in this connection are mentioned briefly. Prof. A. Smith (15) at Purdue University conducted, in 1913, a series of tests in natural winds on a model of a building

---

ELLIPSE (Major Axis Vertical)

Fig. 3. Curves for the shape of the roof cross section.
with a roof semi-circular in section. The results are shown graphically in fig. 4. The positive or impact pressure constituted a very small part of the total wind load.

Similar results were obtained in Carl Arnstein’s (19) wind tunnel experiments on the model of the large airship hangar at Akron, Ohio. (See fig. 4.) The positive or impact pressure constituted a very small part of the total wind load.

Dryden and Hill of the United States Bureau of Standards (7), in their tests on circular cylinders, found that the larger pressures were directed outward. Similar results were found in their tests on a model mill building (6). In many instances the loads on appreciable areas of a face were often as great as twice the average over the entire face.

The most important phenomenon noted by Sylvester (16), in his wind tunnel tests on model airship hangars, was the large negative pressures. He explains: “The extensive area over which these pressures are exerted is surprising, but the extent to which their consideration has been neglected is even more surprising.”

![Diagram](https://example.com/diagram1.png)

**Fig. 4.** Wind pressure distribution on models of buildings and the distribution and magnitude of wind pressures on the barn roof.
The Building Research Board (4) of London, England, in their attempt to determine how results obtained from small scale models may be applied to full sized buildings, found that pressure on the leeward side of a full sized building is greater, on the whole, by about 50 percent.

Experiments on aerofoils in aerodynamics indicate that 60 to 70 percent of the total lifting force is due to a reduced pressure on the upper side (fig. 4).

Other investigations have shown that negative pressure constitutes a large part of the total force acting and that wind pressure distribution for a structure varies considerably with its shape, and must, in many cases, be determined experimentally.

The wind load assumptions which were used in connection with this investigation and the recommendations set forth for roof structures of similar shapes are described in the following paragraphs.

The conventional method of assuming a pressure of 30 lbs./sq. ft. on the vertical surface and reducing the normal pressure on the inclined surface on the windward side by Duchemin's formula,\(^3\) was used on the small and full sized model arches. No wind loads were assumed on the leeward side.

The assumptions on the experimental barn roof differed from those made in previous designs, in that outward pressures were considered on the leeward side of the roof identical in other respects with those on the windward side, and that a pressure of 7 lbs./sq. ft. on a vertical surface was assumed instead of 30 lbs./sq. ft. This large difference in the two values may be accounted for by (a) the large factor of safety in the 30 lbs./sq. ft. value, (b) the low assumed value of 60 mi./hr. for the probable maximum wind velocity, and (c) the fact that wind exerts less force on a three dimensional object than on a flat plate.

The basis on which the value of 7 lbs./sq. ft. was derived was the pressure exerted on a square flat plate by a wind normal to it of an assumed wind speed, and the comparison of its wind resistance to that of a roof model. Dryden and Hill (8) reported that a square flat plate has a wind resistance of about 10 lbs./sq. ft. in a wind stream of a true velocity of 60 mi./hr.

\[^3\text{P_n} = P \frac{2 \sin \theta}{1 + \sin^2 \theta}\]
A comparison of the wind resistances was obtained by constructing a small model of the roof, equal in shape and area to the vertical projection of the model. They were made equal in weight and when suspended as pendulums in a wind stream, it was found that the displacement of the model was about two-thirds that of the plate. On the basis of these displacements, the value of 7 lbs./sq. ft. was established as the pressure on a vertical surface; the normal pressures were determined by Duchemin's formula.

In view of more recent data on wind pressures and weather records, the above assumptions can be improved and a better set of recommendations set forth for wind load assumptions on a roof of this shape.

The assumed wind velocity of 60 mi./hr. appears to be too low, especially since the maximum wind velocity recorded by the United States Weather Bureau stations in Iowa is 68 mi./hr. (18). This value, unquestionably, is exceeded for short intervals of time, since the Weather Bureau anemometer records enable one to determine only an average velocity over the period necessary for a mile of wind to pass the anemometer. The maximum velocity of gusts in high winds should be considered also. There is very little precedent to make an assumption to take gusts into account, but a value of 70 mi./hr. would seem to be a reasonable assumption for maximum velocity.

Figure 4 shows the magnitude and distribution of pressures for a wind velocity of 70 mi./hr., as determined on the basis of results of the above described experiments. Note that pressures differ radically from those assumed on the experimental barn roof, especially at the crown.

Attention is called to the so-called "resistance coefficients" which appear on the diagram (fig. 4). These coefficients are the ratios of the actual pressure to the theoretical or "velocity" pressure, which is expressed by the relation

\[ P = 0.001189 \left( \frac{V}{15} \right)^2, \]

where \( P \) is in lbs./sq. ft., \( V \) the true wind speed in mi./hr., and 0.001189 is the density of air in lbs./cu. ft. corresponding to 15° C., 76 cm. Hg. These coefficients are the same for different wind velocities, and once these have been determined for various
points on the structure, the pressures for different wind velocities can be determined conveniently.

STRUCTURAL DESIGN

The studies reported here pertained largely to the design of the roof structure. It has been the aim to simplify technique of construction and to observe possible economies in labor and materials, as well as to obtain a structurally sound roof.

The procedure in designing the roof structure is essentially the same as that for arches, a description of which is given in Turneaure and Maurer, "Principles of Reinforced Concrete" (17). A preliminary design of the roof is assumed similar to that in arches, which are made either by the aid of past designs or empirical formulae. An exact analysis is then made and the results used in correcting the design. By successive designs and analyses the correct roof section for a particular load condition may be determined.

In the tile roof design, reinforced concrete arch ribs were supplied at intervals to resist the bending moments caused by the eccentric wind loads. (See fig. 12.)

Lightness in weight of roof and saving of form work would be obtained by placing hollow clay blocks between the ribs. In addition to the reinforcing in the supporting ribs, wire reinforcing would be placed in each mortar joint, extending from

![Fig. 5. Comparison of bending moments with ends free and ends restrained.](image-url)
rib to rib. The arch supports would frame in at the mow floor and be high enough to give ample hay mow capacity.

The method of calculation used in this, as well as the other types of construction, assumes fixed ends; that is, the abutments of the arch are so massive or rigid that they will not yield when the arch is loaded. This condition may be approximately fulfilled in massive arches, but in the barn roof it is probable that the part below the spring line will yield considerably. Such yielding of the abutments would make the bending stresses at the spring line less than the calculated values, and increase them at some point higher up on the arch. This can be illustrated roughly by comparing the arch to a beam. A certain load on a beam with fixed ends will produce bending moments at the ends and at the center of the beam. If the ends of the beam are not fixed, however, the moment at the ends will be zero, while the moment at the center will be increased under the same load. (See fig. 5.)

Figures 6 and 7 show the design and some of the important results of the analysis of the model arch (3), which was intended for a barn 30 ft. wide and a roof 20 ft. in height above the mow floor. The shape of the roof conformed to an inverted catenary. The arch ribs reinforced with 4 3/8-in. round bars were spaced 6 ft. 6 in. on the centers. The ribs were 6 in. wide and varied in depth from 13 in. at the supports to 4 in. at the crown. Four-inch hollow clay blocks were placed between the ribs. In the stress analyses a positive wind pressure of 30 lbs./sq. ft. on a vertical surface was assumed, other loads including the weight of the blocks being neglected. A check of the stresses for the loads assumed, showed the roof structure to be amply strong.

Two weeks after the arch had been constructed, 23 sacks of sand, each weighing 100 lbs., were placed on one side of the roof to simulate wind load conditions (fig. 8). No cracks or severe deflections could be detected at any point along the arch ribs.

To obtain a larger load application, a system of levers was used, since it was difficult to add sacks of sand (fig. 9). Under a concentrated load of 2,200 lbs., the steel on the inside of the rib split away from the concrete. This shows the importance
of wiring the reinforcing bars in the top and bottom sides together. Had this been done and the concrete permitted to set at least 2 weeks longer, the roof would probably have resisted double the load at failure, which was equivalent to a wind load of 84 lbs./sq. ft. on a vertical surface.

After further failure had occurred in the ribs through the application of a greater load, the roof still remained in an upright position, although the crown had been displaced a few inches. A 100-pound sack of sand dropped from the top floor of the adjacent building, a height of about 30 ft., broke only 2 clay blocks.

These results indicate that the arch was designed and con-
Fig. 7. The model arch roof.

Fig. 8. Manner of loading the model roof for the strength tests.
Fig. 9. Apparatus for larger load application.

structured with a satisfactory factor of safety, and that there were no apparent weaknesses in the arch.

Various possibilities were considered before proceeding with the design of the full sized arch (11). A design similar to that of the model arch appeared to be most promising. A span of 36 ft., with a rise of 24 ft. 7 in. above the mow floor, was chosen for the test section. The arch ribs, spaced 6 ft. on centers (fig. 10), were 10 in. wide and varied in depth from 8 in. at the crown to 14 in. at the springing line. They were reinforced with 8 1/2-inch twisted bars, half of the bars being near the top and half near the bottom of the rib section. Clay blocks, 5 x 8 x 12-inch, with a no. 6 wire extending from rib to rib in each horizontal mortar joint provided the sheathing between the ribs.

Stress analyses were made by assuming a wind load of 30 lbs./sq. ft. of vertical surface. The weight of the blocks was neglected. The shape of the arch conformed essentially to the inverted catenary, with slight modification to bring it nearer the equilibrium polygon or the line of thrust under its own weight. The final design and the results of the analysis are given in fig. 10.

The tests on this arch were made more carefully than in the previous test on the model arch (5). One concentrated load was applied at the point of application of the resultant of wind loads, 12 ft. 9 in. above springing line and normal to the sur-
Fig. 10. Dead and wind load analysis of the full sized section of the arch roof.

Fig. 11. Diagram of test apparatus.
face. The apparatus used for this purpose was a set of levers (ratio 10:1) anchored to the ground and connected to the arch by means of 4 $\frac{5}{8}$-inch rods and an I-beam. The applied load consisted of 50-pound sand bags (figs. 11 and 12).

Deflections were measured at the point of application of the load by means of wires running from each of the three ribs to an instrument board. Tensions on all three wires were equalized and kept uniform throughout the test (fig. 11). Movement at the crown was measured by focusing a transit on a sheet of ruled coordinate paper fastened to one end of the roof section at the crown.

Deflections were proportional to the applied load un-
til the load reached 27,000 lbs., at which load the arch failed. Owing to the short distance of travel of the levers and the slack in the apparatus, it was necessary to unload, take up slack, and reload. This was repeated a number of times. After deflecting more than 2 in., the arch regained almost its original shape.

The failure which occurred slightly above the point of application of the load (fig. 13) was not typical of a reinforced concrete beam, but seemed due to the fact that all laps in reinforcing bars were made in one place, making such a mass of steel that the individual bars were not surrounded with concrete.

A slab of concrete approximately 3 ft. in length, as wide as the rib and as thick as the layer of concrete below the steel shelled off as a result.

The structure was so thoroughly bound together that destruction was accomplished only by crushing each piece individually with sledges (fig. 14). Dynamite could not be used on account of the structure being in close proximity to greenhouses.

Although an effort was made to salvage the tile, not one came out intact. Of particular interest was the quality of bond between the mortar and the hard burned clay blocks (fig. 15). In practically all cases, breaks would occur in the tile, in the mortar, or across both. Very few instances could be found in which the mortar had separated from the tile.

The breaking load of 27,000 lbs., which is nearly equal to six times the total wind load assumed, shows that the design was considerably heavier than that required in roof construction.

The experiences in the design and construction of the full sized section of the roof, together with the results of the strength tests, were very helpful when designing the roof of the experimental barn (14). The overall dimensions of the arch were very nearly the same as that of the latter; the size of the arch ribs was decreased considerably, because of lower values used in the wind load assumptions and the design of the full sized section was heavier than necessary. The ribs with a width of 6 in. varied in depth from 12 in. at the springing line to 8 in. at the crown, and were spaced 6 ft. 3 in. on centers, permitting 5½ 12-inch hollow clay blocks to be placed between
the ribs. Two ½-inch square bars placed in each of the top and bottom halves of the rib constituted the reinforcing.

In the dead load analysis the weights of the laid-up tile and the reinforced concrete rib were assumed to be 25 lbs./sq. ft. and 150 lbs./cu. ft., respectively. The results of the analysis presented in fig. 16 show that the line of thrust is very near the center line of the arch rib. The eccentricity, which is the

Fig. 14. Destruction of the full sized roof section.
Fig. 15. The good quality of bond between the tile and the mortar is shown by these broken pieces.

Fig. 16. Stress analysis for dead loads.
greatest at the crown, does not exceed 4 in. This indicates that the roof, conforming in shape to a catenary curve, is subjected to very small bending stresses under its own dead weight.

The wind loads used in the combined dead and wind load analysis have been discussed in a preceding section and are shown graphically in fig. 17.

An inspection of the equilibrium polygon and the bending moment diagram (fig. 17) reveals that the greatest external moment occurs at the rib support on the windward side. A check on the unit stresses at this point shows that the maximum stress in the concrete on the compression side is 838 lbs./sq. in., and the stress due to thrust is 77 lbs./sq. in., giving a total unit stress of 915 lbs./sq. in. This value exceeds the allowable working stress of 800 lbs./sq. in. for concrete. It is doubtful, however, whether this stress will be exceeded under the loads considered, since the supports were assumed to be rigidly fixed. A slight amount of rotation at the support due to the elasticity of the materials would materially decrease the unit stress. The cross sectional area of the concrete can be expected to be somewhat

Fig. 17. Stress analysis for combined dead and wind loads of the roof for the experimental barn.
larger due to the concrete which runs into the open ends of the tile. Hence, the arch was considered to resist the loads with the proper degree of safety, and a check on the stresses of the steel and other points along the arch shows the materials to be under much smaller stresses.

The lower structure of the experimental barn, including the mow floor, was designed to carry much heavier loads than the usual hay loads for which most barns are designed, because of the contemplated use of the barn as a grain storage building. The ceiling height was fully 2 ft. greater than the usual height of 7 1/2 to 8 ft. Although the barn is considered a tile building, reinforced concrete was used for the important structural members. The details in fig. 18 show that the type of construction for the building other than the roof is quite conventional.

In view of studies conducted subsequent to the design and construction of the experimental barn, an analysis was made

---

Fig. 18. Cross section and typical details of the experimental barn.
to determine the reduction in stresses with the recommended wind load assumptions and span and height of roof set forth in preceding sections of this report. (See figs. 3 and 4.)

The roof which is for a barn 34 ft. in width has a span of 31 ft. 6 in. at the mow floor, because the arch rib is continuous through the mow floor to the top of the foundation. The spacing, size and reinforcing of the arch ribs are the same as that of the experimental barn roof.

The results of the analysis for the combined dead and wind loads and other related data are given in fig. 19. The bending moment diagram shows that the greatest stress occurs at the support on the windward side. The calculated unit stresses of 356 lbs./sq. in. for concrete and 8,018 lbs./sq. in for steel are very low in comparison with the allowable unit stresses. The assumed section of the arch rib at this point is capable of resisting over twice the external bending moment of 82,400 in. lbs.

It appears, therefore, that the arch rib could be decreased

Fig. 19. Stress analysis for combined dead and wind loads of a revised design of the masonry arch barn roof.
considerably at the supports for the loads assumed. The same is true for the arch rib at the haunch and crown, since the bending moments at these points are less than one-third of that at the left support.

CONSTRUCTION PROBLEMS

The method of constructing a masonry barn, especially the roof, has been a very important consideration in the design with respect to initial cost, manipulation, transportation of forms and necessary scaffolding and handling of materials. The essential difference in the initial cost of a masonry and a wood barn is in the cost of the roof construction, rather than in the cost of materials.

ROOF FORMS

The design of this type of construction presupposes that form work will be used for casting the arch ribs and for supporting the tile. A large part of the weight of the roof must be carried by the forms until the roof is completed and all of the concrete and mortar have hardened.

Roof forms should have the following essentials: Light weight, ease of manipulation, ease of transportation and durability. The cost of constructing forms for the entire barn roof is prohibitive. Economy of roof construction might be accomplished if the forms could be used in successive units in a barn, and be moved and used in other barns.

Two types, termed the "closed" and "open" forms (fig. 20), were considered as possibilities in the construction of the experimental barn. The following description pertains to the design of these forms. Changes made in those used in the construction of the barn are indicated in the description of the construction of the model and the roof section.

The closed form has one notable advantage in that it separates into only two sections. These sections, when moved, make for speed in construction without the laborious task of handling a large number of pieces. This advantage is offset, however, by the disadvantages of moving large and very heavy pieces, not only from section to section, but from barn to barn. This type of form does not permit convenient scaffolding.
The open forms, although requiring considerable unproductive labor in erecting and dismantling in moving each unit, have a number of advantages over the other type. Scaffolding is easily accomplished by placing planks on the horizontal members of the forms. (See fig. 20.) The necessary support for laying of the tile is furnished by laying boards just ahead as the tile is being laid. The forms can be transported easily by entirely dismantling them. The amount of labor involved in moving the forms is partially overcome by leaving them in large units. These advantages seemed to warrant the choice of the open over the closed type.

The magnitude and direction of the combined dead and wind loads which either half of the forms may be expected to carry are shown graphically in fig. 21. An approximate check of the stresses in the members, which was obtained by considering either half of the forms as a truss with a span of 29 feet, shows them to be well below the allowable working stresses.

Fig. 20. The closed and open type of roof forms.
Figure 21 gives a detailed elevation of the forms with the sizes of the members as indicated. The accompanying detail shows that the side plates for forming the concrete rib have been given a batter of 2 degrees to make the removal of forms easier. Although these plates are in several sections, they constitute a continuous form for the arch rib. The auxiliary framing members give added rigidity to the plates, act as supports when the forms are being moved and serve as scaffolding supports. The joint in the forms at the crown is inclined sufficiently to permit the clearing of the right half of the form as it is being removed.

Several minor changes were made in the design of the forms before they were constructed. A few of the angles in the lower part of the truss were made heavier and a few additional angles and struts were supplied to increase the rigidity as well as the strength of the forms. These changes necessitated the use of a gusset plate at one of the joints.

The total weight of the steel of the forms for one roof section is about 3,028 lbs. An estimate of the total cost, including the necessary lumber and the labor for assembling, is about $265.
Figure 22. Details of steel roof forms.

Figure 23 shows the method of dismantling the open forms in the construction of the roof. The top section, fastened at its lower end by a hinged joint, is thus held in place while being removed. By removing the two temporary longitudinal braces near the top, the entire form can be moved through the central opening of the adjacent form and again erected. This particular feature gives it the advantages of the closed form. A more detailed description of the manipulation of the forms is given under the construction of the roof of the experimental barn.
MODEL ARCH

A model of one section of the roof of the proposed design was constructed to a scale (4 inches = 1 foot). (See fig. 7.) In recommending a method for the construction of the roof, the following problems seemed to deserve the greatest consideration: (1) The cost of the materials and labor for the construction of the forms; (2) the necessary scaffolding for the mason; and (3) placing the materials within the mason’s reach.

As a solution to the first two problems, the combined forms and scaffolding were recommended. These consisted of a truss framework made in two sections conforming to the shapes of the roof, and kept in place at the top by a pair of jack screws. Boards of 1-inch thickness were to be placed, one at a time, as the mason worked over them from a scaffold supported by the inside framework of the forms. After completing a section of the roof, the forms would be tipped down at the top, moved to
the next position, and the adjacent section would be constructed in like manner.

It was suggested that the materials be placed within the mason’s reach from a carrier suspended from a cable supported by two gin poles, one on each side of the roof. The carrier could be manipulated with two ropes, one for hoisting and the other for pulling it along the cable.

FULL SIZED ARCH

The forms for the construction of the full sized arch were quite complicated, and the necessary lumber cost over $100. An attempt was made to build them in such a manner as to permit easy manipulation when erecting and disassembling, and to

Fig. 24. Wood forms for the construction of the full sized arch.
make them usable for roofs of the same overall dimensions as well as other sections of the same roof.

Good bracing was necessary to withstand the heavy loads without objectionable deflection (fig. 24). Up until the time that a section of the arch is completed, a large part of the weight must be sustained by the form work.

The tile were laid in each section, keeping both sides of the arch about the same height in order to better distribute the loading on the forms (fig. 25). The concrete for the ribs was
poured after the sections of blocks were laid. This ran back into the openings of the tile, securing a good bond between the rib and the hollow clay block sheathing. The completed section is shown in fig. 26.

**EXPERIMENTAL BARN**

An experimental barn was constructed on the college farm in 1926-27 (fig. 27).

The discussion of the construction which follows is confined mainly to the roof, since that of the first story does not differ materially from regular construction practices.

The roof was built in sections, beginning at one end and progressing along the length of the barn, building one section per day. By this method the roof could be built for any length of barn with two sets of forms. The following general steps were
necessary in building the roof: (1) Assembling of the forms, (2) laying of the tile, (3) pouring of the arch ribs, and (4) the disassembling of the forms.

The lower trusses of the forms were assembled individually on the floor of the barn before placing them upright in position. The separate trusses were bolted together with struts before any of the parts of the upper truss were added. The scaffolding on the lower section of the trusses could be used to advantage in erecting the upper truss. (See figs. 28 and 29.)

The forms were placed at one end of the barn floor and the ends of the barn roof, with its windows and doors, were constructed at the same time that the adjacent sections were being built (fig. 30). Scaffolding could be placed easily on the forms for the construction of the ends. Wood forms were used for the pilasters and cornices.

With the forms in place, the tiles were laid. Boards, 2x6-inch, were laid in the forms ahead of the tile to allow laying operations from the scaffolding on the inside. A piece of straightened no. 7 wire about 7 ft. long was laid in every mor-
tar joint with each end bent around the reinforcing rods of the rib. An entire section of the roof was laid before the rib was poured. A concrete slab was placed last for the ridge.

The reinforcing bars of the arch rib were bent and placed to conform to the shape of the roof at the same time that the tiles
Fig. 29. The steel forms in place.

Fig. 30. Beginning of the construction of the roof.
were being laid. The necessary operations for placing the concrete in the arch ribs were performed on the outside of the roof. The form work for the outside of the rib consisted of 1 x 10-inch boards of about 14-foot lengths, the ends fastened to the reinforcing bars in the rib by wire. The concrete could be taken from the hoist and poured into the rib by means of a ladder construction (fig. 31). Since the portion of the rib at the crown was nearly horizontal, no forms were necessary.

After the concrete had been permitted to harden, the forms on the outside of the ribs and the steel forms supporting the roof from below were removed. Since the materials in a completed section will be self-supporting, the forms could be removed after a short time of hardening of the mortar and concrete without subjecting the structure to severe stresses. In general, the forms were removed by proceeding in the reverse order from that used in assembling. The lower truss as well as the upper was disassembled, piece by piece, instead of being removed as a unit. The parts so removed were then placed in immediate readiness for use in the construction of the next adjacent section.

Considerable difficulty was experienced in removing the forms from the ribs adjacent to the first section constructed, because of the bonding of the concrete to the flange of the steel forms. This difficulty was overcome by cutting off a part of the flange. The concrete was then permitted to run against the ends of the 2 x 6-inch planks which support the "laid-up" tile. (See fig. 32.)

WATERPROOFING PROBLEMS

The roof of the experimental barn, as well as the full sized arch, has been found to leak rather freely in several places, due to the development of cracks where the tile joins the reinforced concrete ribs. Frequent expansion and contraction due to changes in temperature cause cracks and make it necessary to provide a waterproof coating which will be sufficiently elastic to avoid breaking of the coat. Some attempts have been made throughout this investigation to devise a practical as well as economical waterproofing, which will either preserve the
Fig. 31. The masonry arch roof under construction.

Fig. 22. Section of roof form of arch rib in place.
natural color of the tile or present a pleasing appearance in itself.

Three methods of waterproofing were tried on separate areas of the roof of the full sized masonry arch, namely: A cement wash, a bituminous roof paint, and a commercial integral waterproofing compound. These treatments were fairly satisfactory for the short time in which they were observed. Dampness could be detected on the lower side of the roof after rains.

Numerous leaks were observed under the roof of the experimental barn after rains, and it soon became evident that some sort of waterproofing was necessary. The bad leaks, apparently caused by cracks along the ribs, were more numerous on the south side. A majority of the leaks which occurred after the various treatments seemed to result from cracks, exposed by the failure of the waterproof coatings.

The roof received two principal treatments, extending over the entire roof. The first consisted of the application of two coats of raw linseed oil, after the roof had been washed with a diluted solution of hydrochloric acid and the open joints had been pointed with a cement mortar. Such a treatment preserved the natural appearance of the tile. Since this treatment failed to give protection, the roof was treated with an asphalt paint followed by application of aluminum paint. The asphalt paint was of a consistency which permitted it to be

Fig. 33. Poor condition of the asphalt and aluminum paint.
applied with a paint brush. It dried rapidly upon application and failed to exhibit the elastic properties of asphalts. Consequently, the complete treatment failed to give proper protection (fig. 33).

In furthering the attempts to seal the cracks and otherwise make the roof watertight, a heavier and fibered asphalt was used in treating the leaky areas (fig. 34). Its consistency was such as to permit application with a brush. The leaky areas which had been noted and other visible cracks were treated with one coat of this material. A coat of aluminum paint was applied after sufficient drying.

After almost a year's exposure, further leaks, some of which appeared after the failure of the previous treatment, were in evidence. These were temporarily repaired with the same fibered asphalt and aluminum paint.

The linseed oil and the asphalt paint have proved to be unsatisfactory as waterproof coatings for the barn roof. The condition of the coatings on the south side was much worse, apparently due to the more severe sun exposure. Both treatments after a year's exposure failed to give the necessary protection. The linseed oil was largely gone and that which remained had curled and was valueless. Similarly the asphalt had hardened quickly in drying and later had curled. Nearly all of the asphalt and paint were removed over a large part of the roof on the south side.

The condition of the fibered asphalt was fairly good after a year's exposure. In a few places it had become firm and dry and had partially cracked, exposing former cracks.

Raw linseed oil and asphalt paint are not satisfactory for roof waterproofing, since they are not able to withstand, without breaking, the heat of the sun and the expansion and con-
traction of the joints. A heavier and a fibered asphalt seems to be more satisfactory for sealing the cracks.

**COST OF MATERIALS FOR THE ROOF**

An estimate of the cost of the materials used in the construction of the masonry roof of the experimental barn is presented in table 2. Table 3 gives an estimate of the cost of materials in the part of the structure above the mow floor of a typical gambrel roof barn of braced rafter construction, which is very nearly the same in overall dimensions and cross sectional area as the roof of the experimental barn. Plan no. 72121 of the Midwest Farm Building Plan Service Catalogue (2) was selected as a typical gambrel roof barn.

The unit prices used in both tables are those for which ma-

**TABLE 2. ESTIMATE OF MATERIAL COST OF THE ROOF OF THE EXPERIMENTAL BARN 36’x64’-6”, HEIGHT 24’-6”, CROSS SECTIONAL AREA 632 SQ. FT.**

<table>
<thead>
<tr>
<th>Kind of material</th>
<th>Quantity</th>
<th>Unit price</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Structural clay tile 5x8x12’</td>
<td>7,248</td>
<td>$85.00/M</td>
<td>$616.08</td>
</tr>
<tr>
<td>2. Portland cement (sacks)</td>
<td>230</td>
<td>.50</td>
<td>115.10</td>
</tr>
<tr>
<td>3. Sand (yds.)</td>
<td>20.4</td>
<td>1.50</td>
<td>30.60</td>
</tr>
<tr>
<td>4. Gravel (yds.)</td>
<td>23.8</td>
<td>1.50</td>
<td>35.70</td>
</tr>
<tr>
<td>5. Lump lime (bbls.)</td>
<td>1.5</td>
<td>2.75</td>
<td>4.13</td>
</tr>
<tr>
<td>6. Reinforcing bars (lbs.)</td>
<td>5,679</td>
<td>.03</td>
<td>170.37</td>
</tr>
<tr>
<td>7. Drawn steel wire No. 7 (lbs.)</td>
<td>620</td>
<td>.05</td>
<td>31.00</td>
</tr>
<tr>
<td>8. Dimension lumber (bd. ft.)</td>
<td>100</td>
<td>5.50/M</td>
<td>5.50</td>
</tr>
<tr>
<td>9. Waterproofing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asphalt paint (gals.)</td>
<td>40</td>
<td>.75</td>
<td>30.00</td>
</tr>
<tr>
<td>Aluminum paint (gals.)</td>
<td>5</td>
<td>4.95</td>
<td>24.75</td>
</tr>
<tr>
<td>10. Ready mixed paint (gals.)</td>
<td>2</td>
<td>3.30</td>
<td>6.60</td>
</tr>
<tr>
<td>11. Doors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5’-0” by 5’-9” panel doors</td>
<td>2</td>
<td>4.00</td>
<td>8.00</td>
</tr>
<tr>
<td>8’-0” by 10’-0” panel hay door</td>
<td>1</td>
<td>12.00</td>
<td>12.00</td>
</tr>
<tr>
<td>12. Windows</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2’-10½” by 4’-6” by 1 3/8” 12 ft. 2 piece</td>
<td>5</td>
<td>2.76</td>
<td>13.80</td>
</tr>
<tr>
<td>13. Roof ventilators, 24-inch flues</td>
<td>2</td>
<td>54.00</td>
<td>108.00</td>
</tr>
<tr>
<td>14. I-beam, 3-inch St. 7’-5½”/ft. 20 ft. (lbs.)</td>
<td>150</td>
<td>.04</td>
<td>6.00</td>
</tr>
<tr>
<td>15. Wire for tying reinforcing No. 11 (lbs.)</td>
<td>25</td>
<td>.06</td>
<td>1.50</td>
</tr>
<tr>
<td>16. Hardware</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14-inch strap hinges (prs.)</td>
<td>2</td>
<td>.90</td>
<td>1.80</td>
</tr>
<tr>
<td>10-inch T-hinges (prs.)</td>
<td>2</td>
<td>.65</td>
<td>1.30</td>
</tr>
<tr>
<td>6-inch hooks and staples</td>
<td>4</td>
<td>.10</td>
<td>.40</td>
</tr>
<tr>
<td>Nails (lbs.)</td>
<td>10</td>
<td>.04</td>
<td>.40</td>
</tr>
<tr>
<td><strong>Total cost</strong></td>
<td></td>
<td></td>
<td>$1,279.03</td>
</tr>
</tbody>
</table>
TABLE 3. ESTIMATE OF MATERIAL COST OF THE PART OF THE STRUCTURE ABOVE THE MOW FLOOR IN A GAMBREL ROOF BARN (MIDWEST PLAN NO. 72121) 36’x64’, HEIGHT 23’-6”, CROSS SECTIONAL AREA 637 SQ. FT.

<table>
<thead>
<tr>
<th>Kind of material</th>
<th>Quantity</th>
<th>Unit price</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Dimension lumber No. 1 com. (bd. ft.)</td>
<td>7,746</td>
<td>$50.00/M</td>
<td>$387.30</td>
</tr>
<tr>
<td>2. Rough boards No. 1 com. (bd. ft.)</td>
<td>342</td>
<td>55.00/M</td>
<td>18.81</td>
</tr>
<tr>
<td>3. Surfaced boards No. 1 com. (bd. ft.)</td>
<td>103</td>
<td>53.00/M</td>
<td>5.46</td>
</tr>
<tr>
<td>4. Drop siding, 1x6” No. 2 com. (bd. ft.)</td>
<td>2,510</td>
<td>55.00/M</td>
<td>138.05</td>
</tr>
<tr>
<td>5. Roof sheathing 1x8” shiplap No. 3 com. (bd. ft.)</td>
<td>4,610</td>
<td>42.00/M</td>
<td>193.62</td>
</tr>
<tr>
<td>6. Wood shingles No. 1—16”—5/2” (sqs.)</td>
<td>39</td>
<td>5.40</td>
<td>210.60</td>
</tr>
<tr>
<td>7. Matched lumber 1x8” No. 1 com. (bd. ft.)</td>
<td>88</td>
<td>55.00/M</td>
<td>4.44</td>
</tr>
<tr>
<td>8. Windows 9 ft. —9x12” single sash</td>
<td>4</td>
<td>2.70</td>
<td>10.80</td>
</tr>
<tr>
<td>9. Ready mixed paint (3 coats) (gals.)</td>
<td>10</td>
<td>1.10</td>
<td>11.00</td>
</tr>
<tr>
<td>10. Roof ventilators 24-inch flues</td>
<td>2</td>
<td>54.00</td>
<td>108.00</td>
</tr>
<tr>
<td>11. Galvanized ridge roll (ft.)</td>
<td>70</td>
<td>.05</td>
<td>3.50</td>
</tr>
<tr>
<td>12. Hardware</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bolts 1/2x10”</td>
<td>16</td>
<td>.05</td>
<td>.80</td>
</tr>
<tr>
<td>Steel track for hay door (set)</td>
<td>1</td>
<td>6.80</td>
<td>6.80</td>
</tr>
<tr>
<td>Guard rail for hay door (ft.)</td>
<td>20</td>
<td>.15</td>
<td>3.00</td>
</tr>
<tr>
<td>Nails (lbs.)</td>
<td>615</td>
<td>.04</td>
<td>24.60</td>
</tr>
<tr>
<td><strong>Total cost</strong></td>
<td></td>
<td></td>
<td><strong>$1,126.78</strong></td>
</tr>
</tbody>
</table>

Materials would be delivered on the job in Ames, Iowa, in the summer of 1935. Blank spaces are supplied in the table for substitution of different unit prices and costs of each item, since these vary with different localities.

The total cost values presented in the tables show that the estimated cost for materials of the masonry roof is nearly $1,280, which is 13½ percent greater than the estimated cost for materials of the structure above the mow floor in a gambrel roof barn of wood type construction. This shows that the additional initial cost including labor, of a masonry roof is due, not so much to the cost of material, but rather to the cost of additional labor and the amount chargeable to equipment.


19. Watson, W. J. Erecting the world’s largest roof. Civil Engr. n. s. 1:71-76. 1930.

The Relation of Reserves to Cold Resistance in Alfalfa

BY J. J. MARK

AGRICULTURAL EXPERIMENT STATION
IOWA STATE COLLEGE OF AGRICULTURE
AND MECHANIC ARTS

R. E. Buchanan, Director

BOTANY AND PLANT PATHOLOGY SECTION
AND FARM CROPS SUBSECTION

AMES, IOWA
The Relation of Research to College

Education in America
CONTENTS

Summary ................................................. 304
Review of pertinent literature .................. 305
Materials and methods ............................. 308
  Materials ........................................... 308
  Sampling and preserving ......................... 309
  Methods for the analyses of root reserves .... 309
Experimental results ............................... 310
  Effect of fall cutting upon Grimm alfalfa ... 310
    The effect of fall cutting upon the growth of Grimm alfalfa ... 310
    Effect of fall cutting on cold resistance of Grimm alfalfa ... 312
    Effect of fall cutting upon the root reserves of Grimm alfalfa ... 314
    Seasonal changes in the root reserves of cut and uncut Grimm alfalfa ... 316
Studies of hardy and tender alfalfa varieties .. 320
  The root reserves of hardy and non-hardy varieties of alfalfa ... 320
    The insoluble carbohydrates ................... 321
    Nitrogen ......................................... 322
  Seasonal changes in the root reserves of a hardy and a tender alfalfa variety ... 323
Studies of protoplasmic differentiation in cold resistance ......................... 325
  Tests of the stability of the proteins of alfalfa ... 326
  The relation of certain water soluble substances to cold resistance in alfalfa ... 327
    Substances precipitated from the dextrin extract by neutral lead acetate ... 327
    Pectins ........................................... 328
Discussion of results .............................. 329
Literature cited .................................... 333
SUMMARY

Cutting Grimm alfalfa in late August and early October prevented the normal fall accumulation of reserve proteins and carbohydrates, and resulted in complete winterkilling of plants during the winter 1934-35.

The roots of the plants which were not cut after Aug. 29 were 75 percent larger than those given a second late cutting on Oct. 8. In addition the roots of the early cut plants contained approximately 30 percent more carbohydrate and nitrogenous reserves on a green weight basis.

The percentage of both soluble and insoluble nitrogen was higher in the uncut plants than in the cut plants throughout the test period. There was no evidence that protein splitting was a factor in cold resistance.

The reducing sugars constituted a progressively smaller portion of the root reserves as fall advanced. The non-reducing sugars (sucrose) increased during the fall, and were constant during the winter with a slight increase toward spring.

Starch began disappearing in early fall and constituted a very small portion of the root reserves in any variety after October. Digestion was most rapid in the hardy varieties. Analyses for starch in the spring showed no tendency toward reconversion of sugar to starch.

Analytical data on varieties offered no criteria by which the varieties could be placed in their proper order of hardiness as exhibited in the field tests. Non-hardy varieties were consistently higher in some of the reserve fractions than the hardier ones. Hardy varieties were not significantly higher than the non-hardy groups in any of the reserve fractions.

Although possibly important in cold resistance, the pectin and water-soluble gum fractions showed fluctuations among varieties that would not justify the use of these fractions as indexes of the hardiness of varieties at the present time. Attempts to test protoplasm stability directly were unsuccessful.

The results of the experiments support the protoplasm differentiation hypothesis of winter hardiness, which assumes that both an available reserve and a genetic ability to use these reserves in the building of a stable protoplasm are essential factors contributing to winter hardiness.
The Relation of Reserves to Cold Resistance in Alfalfa

By J. J. Mark

Many theories of cold resistance in plants have been advanced and supported by various workers, but none has gained general acceptance. The level of the reserves within the alfalfa root and other plant organs at the time they go into the winter condition appears to have some relation to winter hardiness although more quantitative studies of this relationship are needed. It seems hardly probable that any form of reserve can be directly responsible for the marked ability shown by the tissues of many alfalfa varieties to endure low temperatures, and the formation of secondary materials within the protoplasm under the stimulus of high sugar levels has been postulated (19). The attempt by various workers to connect this cold-resistance, differentiation product with total capacity of the tissue to hold water against freezing has not been entirely successful, thus suggesting either that not all of the water-binding compounds are concerned in hardiness, or that the accumulation of these compounds is only incidental to the protoplasmic changes concerned.

The present study was undertaken to obtain more quantitative data on the relation of reserve levels to winter hardiness in alfalfa, and to determine, if possible, the type of differentiation reactions stimulated by high sugar levels and considered to be actually responsible for cold resistance. It was recognized that this last reaction, if present, might vary in different varieties with the same reserve level; hence two series of experiments were run—the first with Grimm alfalfa, fall clipped to induce varying reserve levels, and the second with varieties of known cold resistance—to study the types of differentiation in material of varying genetic constitution.

REVIEW OF PERTINENT LITERATURE

The literature on the temperature relations of plants is so extensive that no attempt has been made in this paper to refer to

1 Taken from a thesis submitted to the graduate faculty of Iowa State College in partial fulfillment of the requirements for the degree, doctor of philosophy. Project 353 of the Iowa Agricultural Experiment Station.

2 The writer wishes to express thanks to Prof. H. D. Hughes and Dr. W. E. Loomis who suggested this problem and the methods of attack and analysis, and whose supervision and encouragement have made the study possible. Thanks are due Prof. F. S. Wilkins, who provided the material for the variety study.
any large percentage of the works on this subject. Harvey’s bibliography (17) should be consulted for an extensive citation of the literature of cold resistance.

The formation of ice and its desiccating effect have been emphasized in connection with studies on cold injury. Wiegand (44) states that death in plants is due to the withdrawal of water from the protoplasm to form ice. Chandler (5), Wright and Taylor (45), Beach and Allen (2), Molisch (24), Bay (1), and others concur on this point.

Pfeffer (34) maintained that death by low temperatures is due to changes or disturbances produced in the protoplasm, but owing to the dissimilar character of different plants, death need not always be produced in the same way. Maximov (23), after reviewing previous communications by himself and others, came to the conclusion that killing by cold was probably due, not to low temperature as such, but to physicochemical changes set up in the plasma colloids during dehydration by ice formation.

Rosa (36) emphasized the value of water retention as a protection against cold injury. Dunn and Bakke (10) suggest the importance of the cell colloids in imbibi ng water and the prevention of freezing. Newton (26), also Newton and Gortner (31), found a high positive correlation between the hydrophilous colloid content of the expressed sap of wheat leaves and their resistance to cold. Tysdale and Salmon (42) reported a definite relation between hardness on the one hand and low moisture content, quantity and viscosity of press juice on the other. Newton and Brown (28) stated that the most important quantitative relations of the various plant constituents are the reduction in moisture content and the resulting concentration of colloids and sugars, which increases resistance to freezing.

Harvey (16) reported cleavage of the proteins in hardened vegetable plants; the hardened plants contained more than twice as much amino nitrogen as the unhardened plants. Newton (27), on the other hand, did not find any consistent differences in the amino-acid nitrogen content of hardy and tender wheat varieties, although the amino-nitrogen increased in all varieties with the approach of winter. Gorke (12) was among the first to emphasize the precipitation of proteins as a cause of the death of the cell. He thought that this was brought about by increasing the concentration and acidity of the cell sap. Schaffnit (38) ascribed the protective action of hardening to the splitting of complex proteins into less readily precipitated forms.

The protective value of osmotically active substances has been studied rather extensively. Gassner and Grimme (11) found that seeds which germinate at low temperatures nor-
mally have a high sugar content. Crepin and associates (6) stated that the plants most severely injured in their experiments were those having the lowest cell sap concentration and lowest osmotic values. Chandler (5) thought that the density of the cell sap had an influence on the temperature at which killing takes place in plants. Blackman (3), however, pointed out that too much emphasis should not be placed on the sugar content as related to winter-hardiness because sugar cane and sugar beets possess very little resistance to cold. Salmon and Fleming (37) found no definite relation between sap density and hardiness in various wheat varieties as grown in the field. Zacharowa (46) found the meristematic tissue of the root tip more resistant to cold than the cortex, notwithstanding the fact that the cortex contained large quantities of reducing sugars. The hardy meristematic tissue contained very little carbohydrate but was rich in protein material.

Cryoscopic measurements of plant sap have yielded conflicting data. Newton (27) claimed to be able to place hardened wheat varieties in their correct order of hardiness on the basis of their bound water content as measured by the cryoscopic method. Salmon and Fleming (37) did not find any relation between the freezing point depression of sap from winter grain varieties grown in the field and their ability to resist cold. Weimer (43) failed to find any correlation between the freezing point of alfalfa root tissue when in a hardened condition and the known hardiness of the variety. Robinson (35) showed that winter hardiness of insects was correlated with their ability to retain water in the unfrozen state when subjected to freezing temperatures. Stark (39), however, was unable to place apple varieties in their order of hardiness by measuring their freezable and unfreezable water contents. Steinmetz (40), working with alfalfa, failed to find any consistent relation between bound water, freezing point depression and viscosity of the expressed sap on the one hand and hardiness on the other.

Some workers have suggested that dormancy has a possible relationship to the ability of plants to survive freezing temperatures. Govorov (13) reported that the hardy winter cereals accumulated glucose and reduced their respiration during cold weather. Delong and associates (7) worked with apple twigs and found that the hardier varieties showed a lower peak of carbon dioxide production at low temperatures than did the more tender varieties.

Graber and his colleagues (14) conducted experiments on the effect of cutting practices upon the organic food reserves
of plants. They concluded that top removal lowered the organic food reserves to the extent that the plants were subject to severe winterkilling. Nelson (25) found that cutting alfalfa in the succulent state was far more injurious to the stand than cutting at a more mature stage. Steinmetz (40) analyzed the root reserves of Grimm and Kansas Common varieties over an extended period and concluded that a hardy variety of alfalfa cannot be distinguished from a tender variety by differences in chemical composition. Tysdale (41) determined the original and protected diastatic activity of alfalfa varieties. He concluded that the hardy varieties had a greater protected diastatic power when in a hardened condition than the tender varieties. Protected diastatic power, as measured by Tysdale, is a measure of the resistance of the enzyme to precipitation. His results suggest a correlation between enzyme stability and protoplasm stability.

These citations illustrate the variety of work which has been done on the problem of winter hardiness and show how little the various workers are in agreement on the nature of winter injury and the cause of cold resistance.

MATERIALS AND METHODS

MATERIALS

The plant material used in this experiment for the different cutting treatments consisted of 2-year-old, field-grown, certified Grimm alfalfa. Grimm was selected because of its availability and because of its adaptation to this section so far as cold resistance, yield and quality are concerned.

In the different cutting treatments the following legend is used: "Uncut" refers to plants uncut after July 26; "Cut late" refers to plants cut July 26 and again Oct. 8; "Cut early" means plants cut July 26 and Aug. 29 but not cut Oct. 8; "Continuously cut" is used to designate plants that were cut at approximately 1-month intervals on July 26, Aug. 29 and Oct. 8.

In a study of varietal resistance to cold it was necessary to use varieties that exhibit widely different responses to cold. For this purpose six varieties which have shown striking differences in field tests were chosen. Ladak and Grimm were used as hardy varieties. Utah Common has exhibited responses to cold which placed it in the intermediate group. California Common, Arizona Common, and New Mexico Common were used as representatives of the cold susceptible varieties.
SAMPLING AND PRESERVING

The material for chemical analyses of root reserves was washed free of soil and the small fibrous side roots and crowns were cut off and discarded. The water on the roots was removed with blotting paper and duplicate 75 to 100-gram samples of the upper 3 inches were preserved separately from the same size sample of the lower 7 inches of the roots.

The roots were handled as rapidly as possible in order to avoid enzymatic changes in the material. The samples were weighed, cut into 2 to 3-mm. sections and dropped into mason jars containing 500 cc. of boiling 95 percent ethyl alcohol. The jars containing the samples were placed on a boiling water bath and allowed to simmer for 30 minutes. At the termination of this period the jars were sealed tightly and set aside until extractions were made.

The material was extracted 20 times by decantation with 80 percent redistilled ethyl alcohol. Further extractions showed the process to be complete. The combined extracts were made to volume (1000 or 2000 cc.) at 20°C. The insoluble residues were dried and weighed, after which they were ground in a Wiley mill and then in a ball mill until the material passed a 200-mesh sieve. The residues were stored in tightly sealed bottles for polysaccharide and insoluble nitrogen determinations. The extracts were used for determinations of sugars and soluble or non-colloidal nitrogen fractions.

METHODS FOR THE ANALYSES OF ROOT RESERVES

One-tenth aliquots of the alcoholic extract were transferred to water, cleared with neutral lead acetate, delead with anhydrous sodium oxalate, and reducing sugars determined by a modification of the Munson-Walker and Bertrand methods. Sucrose was hydrolyzed with invertase and determined as invert sugar (20). The alcohol-extracted residue, ground to 200-mesh, was extracted with cold 10 percent alcohol to remove dextrins. The extract was cleared, made to volume, filtered, delead and 200-ml. aliquots autoclaved with 1 + 20 HCl at 15 lbs. pressure for 1 hour to hydrolyze dextrin. The hydrolysate was neutralized, made to volume and its reducing power determined.

The residues from the dextrin extraction were gelatinized, digested with saliva and the digest filtered off, cleared, hydrolyzed and reducing sugars run as above. The reducing power of this extract, calculated as glucose and multiplied by 0.90, is considered to be starch. The residue from the starch extraction was autoclaved with 1 + 20 HCl and the reducing power of the extract calculated as glucose and reported as acid hydrolyzable material.
The total nitrogen of the alcoholic extract was determined by the unmodified Kjeldahl method and reported as non-colloidal or soluble nitrogen. Total nitrogen of the alcohol insoluble residue is reported as colloidal nitrogen and considered to be a measure of the protein content of the tissues.

The method used for pectin determinations was that recommended by Carré and Haynes (4) in which pectin was determined as impure calcium pectate. Duplicate 2-gram samples of the finely ground residue were extracted with cold water, and the cold water extracts were made to a volume of 300 cc. One hundred cc. of tenth-normal sodium hydroxide were added to hydrolyze the pectin to the soluble sodium salt of pectic acid. The hydrolysis was allowed to continue overnight at room temperature. Then 50 cc. of normal acetic acid were added to decompose the sodium salt and 50 cc. of molar calcium chloride to form calcium pectate.

The mixture was allowed to stand 1 hour with occasional stirring. It was then brought to a boil, filtered and washed until all chlorides were removed. The precipitate was transferred to tared weighing bottles, dried in the oven at 95° C. for 16 hours and weighed. The pectin was calculated directly as the impure calcium pectate.

Protopectin was determined by hydrolyzing the residue from the pectin extraction with n/20 hydrochloric acid in the autoclave at 7 pounds pressure for 30 minutes. The hydrolyzed solution was filtered into large beakers, nearly neutralized, and the protopectin was determined by the method used for pectin.

**EXPERIMENTAL RESULTS**

**EFFECT OF FALL CUTTING UPON GRIMM ALFALFA**

**THE EFFECT OF FALL CUTTING UPON THE GROWTH OF GRIMM ALFALFA**

Fifty representative plants were dug from plots that had been subjected to different cutting treatments, and the diameter of the roots was determined by measuring immediately below the crown with a vernier caliper. The results of the diameter measurements are shown in table 1 and are the averages of measurements on 50 or more roots.

Differences among the less frequently cut plants were not significant, but there was a suppression of root growth in plants having their tops removed "continuously." It should be noted that the observed root diameter differences between the uncut and continuously cut plants represent cross sectional area reductions of 38 percent in October and 57 percent in November.
TABLE 1. DIAMETER OF THE ROOTS OF GRIMM ALFALFA.

(Diameters are expressed in millimeters.)

<table>
<thead>
<tr>
<th>Date</th>
<th>Uncut</th>
<th>Cut early</th>
<th>Cut late</th>
<th>Cut continuously</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/15/34</td>
<td>10.79</td>
<td>9.93</td>
<td>10.48</td>
<td>8.47</td>
</tr>
<tr>
<td>11/11/34</td>
<td>11.75</td>
<td>10.28</td>
<td>10.00</td>
<td>7.72</td>
</tr>
</tbody>
</table>

Measurements of the weight of the upper 3 inches of the roots from the plots agreed with the diameter measurements in showing a sharp reduction in size as the result of continuous cutting. Later tests showed that the early-cut roots, although smaller, were better filled with reserves and harder than the late-cut.

The dry matter in the roots of the plants from the different cutting treatments was determined during early fall, late fall and spring. Duplicate 100-gram samples, representing 20 or more of the fresh roots, were dried in an electric oven maintained at 100° to 105° C., for 24 hours. The results are shown in table 2.

TABLE 2. DRY MATTER IN THE ROOTS OF GRIMM ALFALFA.

(Expressed as percentage of fresh weight.)

<table>
<thead>
<tr>
<th>Date</th>
<th>Uncut</th>
<th>Cut early</th>
<th>Cut late</th>
<th>Cut continuously</th>
</tr>
</thead>
<tbody>
<tr>
<td>8/30/34</td>
<td>38.2</td>
<td>39.0</td>
<td>38.2</td>
<td>34.2</td>
</tr>
<tr>
<td>10/8/34</td>
<td>39.0</td>
<td>40.0</td>
<td>38.8</td>
<td>32.2</td>
</tr>
<tr>
<td>6/19/35</td>
<td>30.1</td>
<td>30.3</td>
<td>29.6</td>
<td>27.6</td>
</tr>
</tbody>
</table>

Though there is no test of significance, these data indicate that continuous cutting reduced the dry matter percentage of the roots. The percentage of dry matter in the roots of uncut and early cut plants remained fairly constant during the fall. The spring determinations indicated an over-winter reduction of about 25 percent in the dry matter of the normal roots. The continuously cut samples showed less reduction, but the roots were dead in the spring.

Frequent observations were made upon the character and amount of top development of the test plants. During the month of October the weather was very mild and all plots showed good development. However, the height attained by the continuously cut plants was only about 2 inches. In contrast, the plants given a single late cutting on Oct. 8 showed a new top growth of 12 inches on Nov. 1. The plants on the uncut and early cut plots, already having sufficient top development for a good crop of hay, made practically no new top growth during October.
The amount of top growth in the spring was determined by harvesting four, 1-meter quadrats on each of the plots. The dry matter content of the foliage was determined by drying 100-gram samples at 95°C for 24 hours. The results appear in table 3 and are predominantly affected by stands (table 5). Weeds invaded the plots in which the stands were reduced by winterkilling.

**TABLE 3. YIELD AND PERCENTAGE OF DRY MATTER ON JUNE 19, 1935, IN ALFALFA GIVEN DIFFERENT FALL CUTTING TREATMENTS.**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Average yield of meter quadrats in pounds</th>
<th>Percentage of dry matter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncut</td>
<td>5.45</td>
<td>24.6</td>
</tr>
<tr>
<td>Cut early</td>
<td>5.24</td>
<td>23.5</td>
</tr>
<tr>
<td>Cut late</td>
<td>2.36</td>
<td>22.5</td>
</tr>
<tr>
<td>Cut continuously</td>
<td>0.0</td>
<td>0</td>
</tr>
</tbody>
</table>

**EFFECT OF FALL CUTTING ON COLD RESISTANCE OF GRIMM ALFALFA**

Freezing tests were run in November, 1934, to determine the comparative resistance to cold of the plants from the plots that had been given different cutting treatments. Duplicate samples of 10 plants each were dug from the field and frozen at various temperatures in 1/2-gallon jars, but without other protection. After the freezing periods were terminated the roots were held at 5°C for 2 hours and allowed to thaw out. Ten of the roots from each plot were then potted in soil and held in the greenhouse. Daily notes were taken on the survival and general condition of the plants. The results of the artificial freezing tests are presented in table 4.

**TABLE 4. SURVIVAL OF GRIMM ALFALFA WHEN ARTIFICIALLY FROZEN.**

(Dug and frozen Nov. 11, 1934.)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Period of freezing at -18°C</th>
<th>Percentage survival</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncut</td>
<td>1 hr.</td>
<td>100</td>
</tr>
<tr>
<td>Cut early</td>
<td>1 hr.</td>
<td>100</td>
</tr>
<tr>
<td>Cut late</td>
<td>1 hr.</td>
<td>100</td>
</tr>
<tr>
<td>Cut continuously</td>
<td>1 hr.</td>
<td>100</td>
</tr>
<tr>
<td>Uncut</td>
<td>2 hr.</td>
<td>100</td>
</tr>
<tr>
<td>Cut early</td>
<td>2 hr.</td>
<td>100</td>
</tr>
<tr>
<td>Cut late</td>
<td>2 hr.</td>
<td>100</td>
</tr>
<tr>
<td>Cut continuously</td>
<td>2 hr.</td>
<td>80</td>
</tr>
<tr>
<td>Uncut</td>
<td>4 hr.</td>
<td>100</td>
</tr>
<tr>
<td>Cut early</td>
<td>4 hr.</td>
<td>70</td>
</tr>
<tr>
<td>Cut late</td>
<td>4 hr.</td>
<td>50</td>
</tr>
<tr>
<td>Cut continuously</td>
<td>4 hr.</td>
<td>0</td>
</tr>
<tr>
<td>Uncut</td>
<td>5 hr.</td>
<td>0</td>
</tr>
<tr>
<td>Cut early</td>
<td>5 hr.</td>
<td>0</td>
</tr>
<tr>
<td>Cut late</td>
<td>5 hr.</td>
<td>0</td>
</tr>
<tr>
<td>Cut continuously</td>
<td>5 hr.</td>
<td>0</td>
</tr>
</tbody>
</table>
It may be observed that all plants survived freezing for 1 hour at \(-18^\circ C\), but as the period of freezing was extended to 4 hours, the percentage of plants surviving decreased with the lateness and severity of the cutting treatment. A striking phase of this experiment was the inability of the exposed roots from the check plots to withstand 5 hours of freezing even though they withstood 4 hours with no mortality.

The subsequent growth of the frozen plants was observed daily and it was noted that the less frequently cut plants recovered from the freezing treatments more rapidly than did the more frequently cut plants. In some cases the frequently cut plants appeared to be dead, but within 2 to 4 weeks sent a few shoots up from the crowns. The injury appeared to be confined to the crown. In no instance was there cracking of the roots. Many of the roots that started growth, apparently were severely injured. This was shown by the continued dying of plants that had been previously recorded as having survived. For this reason the final counts were not made until 2 months after the tests were begun. The development of frozen plants from cut and uncut plots is shown in fig. 1.

The effect of fall cutting upon the cold resistance of Grimm alfalfa in the field was determined by staking off four, 1-meter quadrats in each plot. The plants were counted at the beginning of the experiment and the plants surviving in the spring were again counted. The results of the field tests are shown in table 5.

**TABLE 5. SURVIVAL OF GRIMM ALFALFA IN THE FIELD.**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Dates of cutting</th>
<th>Survival in percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncut</td>
<td>7/36/34</td>
<td>85</td>
</tr>
<tr>
<td>Cut early</td>
<td>7/36/34 and 8/29/34</td>
<td>73</td>
</tr>
<tr>
<td>Cut late</td>
<td>7/26/34 and 10/8/34</td>
<td>37</td>
</tr>
<tr>
<td>Cut continuously</td>
<td>7/26/34, 8/29/34 and 10/8/34</td>
<td>0</td>
</tr>
</tbody>
</table>
The 15 percent reduction in the stand of the uncut plots probably represents normal thinning as the result of competition within the rather close stand. The effect of late cutting upon the ability of a hardy variety to resist cold is shown in a striking manner.

EFFECT OF FALL CUTTING UPON THE ROOT RESERVES OF GRIMM ALFALFA

It is generally assumed that top removal reduces the root reserves of alfalfa. Quantitative data on the subject, however, are rather limited and show conflicting results. In an attempt to determine quantitatively the effect of late fall top removal upon the root reserves of Grimm alfalfa, analyses were made on duplicate 100-gm. samples collected from late summer through December. The results of the late summer analyses are shown in table 6.

<table>
<thead>
<tr>
<th>Fraction</th>
<th>Upper 3 inches</th>
<th>Lower 7 inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reducing sugars</td>
<td>1.04</td>
<td>1.68</td>
</tr>
<tr>
<td>Non-reducing sugars</td>
<td>1.90</td>
<td>0.62</td>
</tr>
<tr>
<td>Total sugars</td>
<td>2.94</td>
<td>2.30</td>
</tr>
<tr>
<td>Dextrin</td>
<td>2.73</td>
<td>2.63</td>
</tr>
<tr>
<td>Starch</td>
<td>6.49</td>
<td>5.37</td>
</tr>
<tr>
<td>Acid hydrolyzable materials</td>
<td>2.58</td>
<td>2.55</td>
</tr>
<tr>
<td>Total carbohydrates</td>
<td>14.74</td>
<td>12.85</td>
</tr>
<tr>
<td>Insoluble nitrogen</td>
<td>0.28</td>
<td>0.26</td>
</tr>
<tr>
<td>Soluble nitrogen</td>
<td>0.27</td>
<td>0.28</td>
</tr>
<tr>
<td>Total nitrogen</td>
<td>0.55</td>
<td>0.54</td>
</tr>
</tbody>
</table>

The total sugars in the upper 3 inches of the roots were greater than in the lower 7 inches. This difference may have been due to the closeness of the upper 3 inches to the crown and the active leaves. Total carbohydrates were greater in the upper 3 inches of the roots than in the lower 7 inches. The nitrogen fractions were nearly equal in the two sections studied.

On Aug. 29, half of the 16-square rod experimental area was cut and the other half was left uncut. The effect of this treatment on the root reserves was determined on Oct. 8 and is shown in table 7. It may be seen from these data that, with the exception of non-reducing sugars, every reserve fraction studied was higher in the uncut series than in the cut series.
TABLE 7. ROOT RESERVES ON OCT. 8 IN THE UPPER 3 INCHES AND LOWER 7 INCHES OF THE ROOTS OF CUT AND UNCUT GRIMM ALFALFA.

(Expressed as percentage of fresh weight.)

<table>
<thead>
<tr>
<th>Fraction</th>
<th>Uncut</th>
<th>Cut Aug. 29</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Upper</td>
<td>Lower 3 inches</td>
</tr>
<tr>
<td>Reducing sugars</td>
<td>3.28</td>
<td>3.04</td>
</tr>
<tr>
<td>Non-reducing sugars</td>
<td>1.62</td>
<td>2.67</td>
</tr>
<tr>
<td>Total sugars</td>
<td>4.90</td>
<td>5.71</td>
</tr>
<tr>
<td>Dextrin</td>
<td>6.52</td>
<td>5.58</td>
</tr>
<tr>
<td>Starch</td>
<td>5.34</td>
<td>2.68</td>
</tr>
<tr>
<td>Acid hydrolyzable materials</td>
<td>2.83</td>
<td>2.69</td>
</tr>
<tr>
<td>Total carbohydrates</td>
<td>19.59</td>
<td>16.66</td>
</tr>
<tr>
<td>Insoluble nitrogen</td>
<td>0.52</td>
<td>0.40</td>
</tr>
<tr>
<td>Soluble nitrogen</td>
<td>0.43</td>
<td>0.38</td>
</tr>
<tr>
<td>Total nitrogen</td>
<td>0.95</td>
<td>0.78</td>
</tr>
</tbody>
</table>

The field results, reported earlier, indicated that cutting in early October was very injurious to Grimm alfalfa. Chemical analyses of the roots from plants cut Oct. 8 were made in November. The results of these analyses are shown in table 8.

TABLE 8. ROOT RESERVES IN THE UPPER 3 INCHES OF GRIMM ALFALFA ROOTS ON NOV. 11.

(Expressed as percentage of fresh weight of sample.)

<table>
<thead>
<tr>
<th>Fraction</th>
<th>Uncut*</th>
<th>Cut early</th>
<th>Cut late</th>
<th>Cut continuously</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reducing sugars</td>
<td>3.66</td>
<td>1.39</td>
<td>2.04</td>
<td>1.39</td>
</tr>
<tr>
<td>Non-reducing sugars</td>
<td>5.14</td>
<td>4.62</td>
<td>4.86</td>
<td>4.23</td>
</tr>
<tr>
<td>Total sugars</td>
<td>8.80</td>
<td>6.01</td>
<td>6.91</td>
<td>5.63</td>
</tr>
<tr>
<td>Dextrin</td>
<td>5.97</td>
<td>4.43</td>
<td>3.24</td>
<td>2.37</td>
</tr>
<tr>
<td>Starch</td>
<td>2.43</td>
<td>2.53</td>
<td>1.45</td>
<td>1.17</td>
</tr>
<tr>
<td>Total reserve carbohydrates</td>
<td>17.20</td>
<td>12.97</td>
<td>11.60</td>
<td>9.77</td>
</tr>
<tr>
<td>Acid hydrolyzable materials</td>
<td>4.60</td>
<td>3.57</td>
<td>3.16</td>
<td>2.79</td>
</tr>
<tr>
<td>Soluble nitrogen</td>
<td>0.45</td>
<td>0.38</td>
<td>0.32</td>
<td>0.31</td>
</tr>
<tr>
<td>Insoluble nitrogen</td>
<td>0.66</td>
<td>0.53</td>
<td>0.53</td>
<td>0.40</td>
</tr>
<tr>
<td>Total nitrogen</td>
<td>1.11</td>
<td>0.91</td>
<td>0.85</td>
<td>0.71</td>
</tr>
</tbody>
</table>

*Uncut, not mowed after 7/26; cut early, mowed on 7/26 and 8/29; cut late, mowed on 10/8; cut continuously, mowed on 7/26, 8/29, and 10/8.

These data show that the uncut plants were higher than the cut plants in all the fractions. The insoluble carbohydrate fraction shows that frequent cutting interferes with the accumulation of starch, dextrins and acid hydrolyzable carbohydrates. The differences between uncut and continuously cut samples are very conspicuous in all fractions except non-reducing sugars. This exception may have been due to the open fall weather which favored photosynthesis by the young active leaves that were produced during October on the late cut plants. The nitrogen fractions were higher in the uncut plants than in the cut plants. Probably nitrogen was withdrawn from the roots for the initiation of new top growth.
The effect upon the reserves of removing the tops of Grimm alfalfa is clearly shown by these analyses. The lowering in the reserves corresponds to the severity of the cutting treatment and, in an inverse manner, to the cold resistance and survival of the plants as shown in tables 4 and 5.

The chemical composition of the root reserves of cut and uncut Grimm alfalfa was determined during December after all the plants had become dormant. The results of these analyses are shown in table 9.

TABLE 9. CHEMICAL COMPOSITION OF THE ROOTS OF GRIMM ALFALFA ON DEC. 15, 1934.  
(Expressed as percentage of fresh weight of sample.)

<table>
<thead>
<tr>
<th>Fraction</th>
<th>Uncut</th>
<th>Cut continuously</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reducing sugars</td>
<td>1.29</td>
<td>0.95</td>
</tr>
<tr>
<td>Non-reducing sugars</td>
<td>6.57</td>
<td>5.84</td>
</tr>
<tr>
<td>Total sugars</td>
<td>7.86</td>
<td>6.79</td>
</tr>
<tr>
<td>Dextrins</td>
<td>2.29</td>
<td>1.35</td>
</tr>
<tr>
<td>Starch</td>
<td>0.65</td>
<td>0.61</td>
</tr>
<tr>
<td>Total reserve carbohydrates</td>
<td>10.81</td>
<td>8.75</td>
</tr>
<tr>
<td>Acid hydrolysable materials</td>
<td>4.12</td>
<td>3.35</td>
</tr>
<tr>
<td>Insoluble nitrogen</td>
<td>0.62</td>
<td>0.34</td>
</tr>
<tr>
<td>Soluble nitrogen</td>
<td>0.50</td>
<td>0.23</td>
</tr>
<tr>
<td>Total nitrogen</td>
<td>1.12</td>
<td>0.59</td>
</tr>
</tbody>
</table>

These data indicate that continuous cutting treatments did not induce as great percentage differences in the total carbohydrate levels as were observed in the nitrogen fractions. However, if high carbohydrates are associated with cold resistance the uncut plants still had the advantage. The data also indicate that the uncut plants had built up a larger quantity of protoplasm than the cut plants. Both the insoluble (colloidal) and soluble (non-colloidal) nitrogen fractions in the uncut plants were almost twice as high as in the cut plants. Composition differences had been reduced at this date by the abnormally late fall growth of the cut plants. In spite of this, the field tests (table 5) showed that the plants were decidedly different in their ability to resist low temperatures.

SEASONAL CHANGES IN THE ROOT RESERVES OF CUT AND UNCUT GRIMM ALFALFA

Seasonal changes in the distribution of reserves are of the greatest interest from the standpoint of a physiological explanation of cold resistance. In the following figures the seasonal changes in the reserves of the uncut Grimm alfalfa which
showed 15 percent winterkilling are compared with those of the continuously cut plants which were completely killed.

The rapid increase of reducing sugars in the roots of uncut alfalfa until October is shown in fig. 2. The depressive effect of foliage removal upon their accumulation is very striking.

The trends of non-reducing sugar (sucrose) are shown in fig. 3. Sucrose appears to be distinctly a winter reserve in contrast to the reducing sugars which did not accumulate in the winter. High sucrose has been associated with winter hardiness in wheat (18) where it constitutes the principal reserve substance. The curves of fig. 3 do not indicate that sucrose, which is only one of the available reserves of alfalfa, is correlated with winter hardiness in this plant. They do, however, show that it constitutes an important midwinter reserve.

In contrast to sucrose, dextrin was greatly reduced by the late cutting treatment (fig. 4). The dextrin content of the cut plants is on an average 39 percent less than that of the check plants. The earlier drop in the dextrin curve of the uncut treatment is associated with the earlier frost injury to the leaves of these plants and is reflected in fig. 3 in increased sucrose. The slight increase of this fraction in the cut plants was apparently due to photosynthesis and would not have been expected in a less open fall.

It may be observed from the graph of fig. 5 that starch
almost disappeared in both cut and uncut alfalfa during the fall months. However, its decrease in uncut plants was slower than in cut plants. By comparing figs. 3 and 5 it may be seen that when starch was disappearing in the uncut plants, sucrose was increasing. This suggests a relationship between starch and dextrin on the one hand and sucrose and the winter condition on the other. The results reported here, and in connection with the variety tests, indicate that starch is not a winter storage carbohydrate in alfalfa. If, however, starch is the forerunner of an active factor in hardening, as it appears to be, it is shown that the uncut plants had a decided advantage.

Martin (22) has found that the secondary wall substances of sweet clover are removed from the libriform fibers of this plant during the second season and suggests that these non-starchy compounds may serve as reserves. The curves in fig. 6 show a somewhat higher
value for acid hydrolyzable materials (hemicelluloses) in the uncut plants. It is possible, however, that wall differen­tiation and protoplast differentiation are parallel re­actions, both associated with higher sugar levels (19). In this case, protoplast differentiation would be expected to be the factor actually concerned in cold resistance, although cell wall differentiation, as shown by acid hydrolyzable materials, might be an indicator of the more difficultly measured proto­plast differentiation.

The trend of the soluble nitrogen is presented in fig. 7. It is shown that cutting prevented the marked increase in the soluble nitrogen content of the roots which was shown by the uncut plants. The increase in soluble nitrogen after November might have been due to protein hydrolysis. Any advantage in soluble nitrogen was definitely in favor of the uncut plants. Har­vey (16) has suggested that proteins are changed to soluble forms during hardening and thus escape precipitation. A comparison of figs. 7 and 8 will show that most of the soluble nitrogen accumulation found in this material was independent of protein hydrolysis, since protein or insoluble nitrogen increased at the same rate and in the same treatments as the soluble fraction.

If a high content of protein nitrogen is related to cold resis­tance, the trend of the insoluble nitrogen in cut and uncut al­falfa reveals a distinct difference in favor of the uncut plants.

![Fig. 7. Non-protein nitrogen of the roots of uncut and continuously cut alfalfa. Total nitrogen extracted by 80 percent alcohol.](image)

![Fig. 8. Protein nitrogen of the roots of uncut and continuously cut alfalfa. Total nitrogen not extractable with 80 percent alcohol.](image)
STUDIES OF HARDY AND TENDER ALFALFA VARIETIES

In as much as variety has been emphasized in relation to winter hardiness it was deemed advisable to analyze the root reserves in alfalfa varieties that differ widely in their field responses to cold. An attempt was made to include varieties that exhibit three degrees of hardiness. For the hardy varieties Ladak and Grimm were used; for the intermediate variety Utah Common; and for the tender varieties New Mexico, Arizona and California Common. The sampling and analytical procedures were the same as those mentioned in connection with the different cutting treatments of the certified Grimm variety.

Oakley and Westover (32) found that the hardy varieties of alfalfa did not make as much top growth as the tender varieties. The varieties used in this test were checked to determine the amount of late fall growth as a possible index of hardiness. The results of these measurements are presented in table 10.

<table>
<thead>
<tr>
<th>Variety</th>
<th>Class</th>
<th>Fall growth</th>
<th>Percent winterkilled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ladak</td>
<td>Very hardy</td>
<td>3 inches</td>
<td>8</td>
</tr>
<tr>
<td>Grimm</td>
<td>Hardy</td>
<td>5 inches</td>
<td>15</td>
</tr>
<tr>
<td>Utah Common</td>
<td>Medium hardy</td>
<td>6 inches</td>
<td>25</td>
</tr>
<tr>
<td>California Common</td>
<td>Tender</td>
<td>6 inches</td>
<td>75</td>
</tr>
<tr>
<td>New Mexico Common</td>
<td>Tender</td>
<td>6 inches</td>
<td>80</td>
</tr>
<tr>
<td>Arizona Common</td>
<td>Very tender</td>
<td>9 inches</td>
<td>100</td>
</tr>
</tbody>
</table>

The hardy varieties grew very little after Oct. 1, but the tender varieties produced additional top growth. There was a marked relationship between the amount of fall growth and winterkilling. These results are in agreement with field observations; that is, plants that make a late fall growth because of cutting, environmental or heredity factors are more susceptible to cold injury than plants not making a late fall growth.

THE ROOT RESERVES OF HARDY AND NON-HARDY VARIETIES OF ALFALFA

Sugars have been emphasized in connection with recent studies pertaining to cold resistance. Determinations of reducing and non-reducing sugars were made in an attempt to determine whether sugar content is associated with hardiness in the varieties used in these studies. These data are presented in table 11.
The low content of reducing sugars in Ladak and Grimm, particularly on Oct. 8, may be accounted for by low activity of these varieties under the short day and low temperature relationships. The non-reducing sugars show the same trend as the variety hardiness at both dates, but no test of significance is available. The concentrations of total sugars would not serve to classify the varieties in order of hardiness. The data show that there was an increase in the non-colloidal carbohydrates in all varieties during the month of October. There was a doubling of the reducing sugar content, while the non-reducing and total sugars were nearly three times greater than at the preceding sampling date.

**THE INSOLUBLE CARBOHYDRATES**

These insoluble carbohydrate fractions consisted of the dextrin, starch and acid-hydrolyzable materials. The methods of analyses were the same as those mentioned in an earlier paragraph and the results are shown in table 12.

These data show the similarity in composition on Oct. 8 of all varieties except Ladak, irrespective of their field performances. Just why this sample of Ladak was lower in dextrin than the other varieties is not known. There was a tendency toward increase in the dextrins of these samples as fall pro-

### TABLE 11. REDUCING, NON-REDUCING AND TOTAL SUGARS IN THE ROOTS OF ALFALFA VARIETIES ON OCT. 8 AND NOV. 11, 1934.

(Percentage of fresh weight of samples.)

<table>
<thead>
<tr>
<th>Varieties</th>
<th>Reducing sugars</th>
<th>Non-reducing sugars</th>
<th>Total sugars</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>October 8 sampling</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ladak</td>
<td>0.89</td>
<td>1.80</td>
<td>2.79</td>
</tr>
<tr>
<td>Grimm</td>
<td>0.83</td>
<td>1.72</td>
<td>2.55</td>
</tr>
<tr>
<td>Utah Common</td>
<td>1.15</td>
<td>1.54</td>
<td>2.70</td>
</tr>
<tr>
<td>California Common</td>
<td>1.14</td>
<td>1.60</td>
<td>2.74</td>
</tr>
<tr>
<td>New Mexico Common</td>
<td>1.32</td>
<td>1.30</td>
<td>2.61</td>
</tr>
<tr>
<td>Arizona Common</td>
<td>1.30</td>
<td>1.42</td>
<td>2.72</td>
</tr>
<tr>
<td><strong>November 11 sampling</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ladak</td>
<td>1.63</td>
<td>4.82</td>
<td>6.45</td>
</tr>
<tr>
<td>Grimm</td>
<td>2.07</td>
<td>4.50</td>
<td>6.56</td>
</tr>
<tr>
<td>Utah Common</td>
<td>3.10</td>
<td>4.14</td>
<td>7.25</td>
</tr>
<tr>
<td>California Common</td>
<td>2.53</td>
<td>4.18</td>
<td>6.72</td>
</tr>
<tr>
<td>New Mexico Common</td>
<td>2.86</td>
<td>3.32</td>
<td>6.19</td>
</tr>
<tr>
<td>Arizona Common</td>
<td>2.74</td>
<td>3.79</td>
<td>6.53</td>
</tr>
</tbody>
</table>
TABLE 12. THE INSOLUBLE CARBOHYDRATES IN THE ROOTS OF ALFALFA VARIETIES ON OCT. 8 AND NOV. 11, 1934.
(Percentage of fresh weight.)

<table>
<thead>
<tr>
<th>Variety</th>
<th>Dextrin</th>
<th>Starch</th>
<th>Acid-hydrolyzable materials</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>October 8, 1934</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ladak</td>
<td>3.17</td>
<td>2.50</td>
<td>4.37</td>
</tr>
<tr>
<td>Grimm</td>
<td>6.56</td>
<td>2.58</td>
<td>4.42</td>
</tr>
<tr>
<td>Utah Common</td>
<td>7.15</td>
<td>1.42</td>
<td>4.12</td>
</tr>
<tr>
<td>California Common</td>
<td>6.98</td>
<td>2.19</td>
<td>4.07</td>
</tr>
<tr>
<td>New Mexico Common</td>
<td>6.09</td>
<td>2.22</td>
<td>4.62</td>
</tr>
<tr>
<td>Arizona Common</td>
<td>6.82</td>
<td>2.34</td>
<td>4.26</td>
</tr>
<tr>
<td><strong>November 11, 1934</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ladak</td>
<td>6.27</td>
<td>1.41</td>
<td>4.32</td>
</tr>
<tr>
<td>Grimm</td>
<td>6.26</td>
<td>2.03</td>
<td>4.29</td>
</tr>
<tr>
<td>Utah Common</td>
<td>5.13</td>
<td>2.03</td>
<td>4.71</td>
</tr>
<tr>
<td>California Common</td>
<td>7.87</td>
<td>1.81</td>
<td>4.70</td>
</tr>
<tr>
<td>New Mexico Common</td>
<td>8.10</td>
<td>1.48</td>
<td>4.82</td>
</tr>
<tr>
<td>Arizona Common</td>
<td>9.38</td>
<td>2.53</td>
<td>4.59</td>
</tr>
</tbody>
</table>

progressed, but no test of significance is available. It may be indicative that the more hardy varieties showed less accumulation of dextrin (Grimm none). A tendency to accumulate starch and dextrin, or a delay in the transformation of these fractions to the winter forms, may be associated with low resistance to cold.

The starch fractions from the varieties do not show as great fluctuations as the dextrins. The starch contents of Ladak and Grimm were slightly higher than those of the other varieties on Oct. 8. Starch as a storage carbohydrate, however, apparently is not the determining factor in cold resistance. Analysis of Grimm at an earlier date indicated that starch was declining during October, reaching minimum values in December. The acid-hydrolyzable materials show a great uniformity among varieties.

NITROGEN

In as much as nitrogen is an important constituent of protoplasm, it was thought that the varieties might exhibit sufficient differences in their nitrogen contents to enable them to be placed in their correct order of hardiness. The results of analyses of the nitrogen fractions are shown in table 13.

The data show that the insoluble and soluble nitrogen fractions fluctuate among the varieties irrelative to hardiness. In all varieties the percentage of insoluble nitrogen was greater than the soluble nitrogen. It will be seen that all varieties
TABLE 13. INSOLUBLE, SOLUBLE AND TOTAL NITROGEN CONTENT OF ALFALFA VARIETIES ON OCT. 8 AND NOV. 11, 1934.
(Percentage of fresh weight.)

<table>
<thead>
<tr>
<th>Variety</th>
<th>Insoluble nitrogen</th>
<th>Soluble nitrogen</th>
<th>Total nitrogen</th>
</tr>
</thead>
<tbody>
<tr>
<td>October 8, 1934</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ladak</td>
<td>0.51</td>
<td>0.29</td>
<td>0.80</td>
</tr>
<tr>
<td>Grimm</td>
<td>0.43</td>
<td>0.33</td>
<td>0.76</td>
</tr>
<tr>
<td>Utah Common</td>
<td>0.48</td>
<td>0.29</td>
<td>0.77</td>
</tr>
<tr>
<td>California Common</td>
<td>0.53</td>
<td>0.34</td>
<td>0.87</td>
</tr>
<tr>
<td>New Mexico Common</td>
<td>0.51</td>
<td>0.31</td>
<td>0.82</td>
</tr>
<tr>
<td>Arizona Common</td>
<td>0.49</td>
<td>0.30</td>
<td>0.79</td>
</tr>
<tr>
<td>November 11, 1934</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ladak</td>
<td>0.50</td>
<td>0.49</td>
<td>0.99</td>
</tr>
<tr>
<td>Grimm</td>
<td>0.65</td>
<td>0.43</td>
<td>1.08</td>
</tr>
<tr>
<td>Utah Common</td>
<td>0.61</td>
<td>0.39</td>
<td>1.00</td>
</tr>
<tr>
<td>California Common</td>
<td>0.70</td>
<td>0.38</td>
<td>1.08</td>
</tr>
<tr>
<td>New Mexico Common</td>
<td>0.54</td>
<td>0.38</td>
<td>0.92</td>
</tr>
<tr>
<td>Arizona Common</td>
<td>0.64</td>
<td>0.48</td>
<td>1.12</td>
</tr>
</tbody>
</table>

showed an increase of alcohol soluble nitrogen during October and early November. Ladak showed the greatest increase in this fraction of any of the varieties, but the insoluble nitrogen in Ladak remained constant, while this same fraction increased in the other varieties. The total nitrogen increased in all varieties.

SEASONAL CHANGES IN THE ROOT RESERVES OF A HARDY AND A TENDER ALFALFA VARIETY

The open fall of 1934 made it possible to collect a third set of samples of Ladak, a very hardy variety, and Arizona Common, a tender variety, on Dec. 15. A fourth collection was made on March 26, 1935, just as new spring growth was starting. The seasonal changes indicated by the four collections are plotted in figures 9 to 14. The Nov. 11 and Dec. 15 dates are considered to be the critical ones. The analysis of samples collected on these dates shows that the hardiness of these varieties was not correlated with either total carbohydrates or total nitrogen. Total sugars (fig. 9) showed no striking differences. Dextrin was consistently lower (fig. 10) in the hardy Ladak, as were starch (fig. 11) and total carbohydrates (fig. 12). The lower percentage of the colloidal carbohydrates in Ladak, particularly in midwinter, appears to be the most important and consistent difference between the two varieties, although the lower insoluble nitrogen content of Ladak (fig. 14) is significant.
Within the variety Grimm, hardiness and reserves were correlated. When varietal (genetic) differences which might affect the utilization of reserves were introduced, no correlation was found. These results agree with those of Steinmetz (40) and indicate that reserves do not, of themselves, constitute...
hardiness, but that it is the manner of their utilization, perhaps in protoplasmic differentiation, which enables plant cells to endure freezing. According to this hypothesis, a plant which lacks either the reserve or the genetic factors essential to its proper utilization will be non-hardy.

STUDIES OF PROTOPLASMIC DIFFERENTIATION IN COLD RESISTANCE

Newton and Brown (28) (29) and Newton, Brown and Anderson (30), working with winter wheat, concluded that probably both salting-out and acid precipitation play a part in frost precipitation and that sugar is an important factor in protecting the protoplasmic proteins from disorganization by these agencies. If death from cold is a result of protoplasmic precipitation and if sugars are directly protective, it seems reasonable to expect the more cold resistant plants to have the higher sugar content. Our results and those of others show that this is not always true. Loomis (19) has suggested that cold hardness may be the result of structural differentiation within the protoplast which makes it more resistant to destruction by precipitation, such differentiation being dependent upon and in part initiated by a higher sugar concentration in the tissues. In this case the action of the sugar would be indirect and hardness would be correlated with sugar content but would depend

![Fig. 13. Seasonal changes in the non-protein (alcohol soluble) nitrogen of a hardy (Ladak) and a tender alfalfa variety.](image)

![Fig. 14. Seasonal changes in the protein (alcohol insoluble) nitrogen of a hardy (Ladak) and a tender alfalfa variety.](image)
upon genetic factors which might affect the protoplasmic differentiation processes.

TESTS OF THE STABILITY OF THE PROTEINS OF ALFALFA

The object of this series of experiments was to investigate protein stability by determining the quantity of nitrogen precipitated when the proteins, suspended in water, were subjected to different periods of freezing. It was hoped that these determinations, along with the sugar data on cut and uncut alfalfa, could be correlated with each other and with hardiness.

After the plants to be used were dug from the fields, the roots were washed free of soil and the tops and fibrous roots removed. One hundred-gram samples of roots were cut into small pieces and ground in a food chopper; the material was made up to 500 cc. volume with distilled water and 10 cc. of ether, and ground in a ball mill, extracting the proteins and suspending them in water. After the sample had been ground for 16 hours it was filtered through three layers of cheesecloth. Fifty-cc. aliquots were centrifuged for 15 minutes to remove any solids that might have escaped filtration, then the liquid portions were decanted into small soil cans. These cans were placed in the freezing chambers for given periods of time. At the end of the freezing period the samples were thawed and again centrifuged for 15 minutes, and the precipitate was transferred to Kjeldahl flasks for determination of total nitrogen.

Duplicate samples of the same material were transferred directly to Kjeldahl flasks (without freezing) for total nitrogen determinations. Other samples were transferred to beakers, acidified with acetic acid and brought to a boil. These were centrifuged for 15 minutes and the precipitate was transferred to Kjeldahl flasks for total precipitable nitrogen determinations.

The results of the tests were inconclusive, apparently because of a rapid enzymatic hydrolysis of proteins during the grinding. In some instances the hydrolysis appeared to continue through the freezing and thawing treatment as reported by Newton, Brown and Anderson (30). Soluble nitrogen showed a 5:1 ratio with insoluble nitrogen in the water extracts, in comparison with 1:1 or 1:2 ratio in the alcohol-killed samples. Some of this difference may have been due to incomplete suspension of insoluble nitrogen compounds, but the thoroughness of grinding indicates that hydrolysis was the important factor.
THE RELATION OF CERTAIN WATER SOLUBLE SUBSTANCES TO COLD RESISTANCE IN ALFALFA

SUBSTANCES PRECIPITATED FROM THE DEXTRIN EXTRACT BY NEUTRAL LEAD ACETATE

It was observed during the investigation, that an almost unmanageable precipitate was formed in clearing the dextrin extractions. The clearing of the starch extracts also produced a jelly-like precipitate.

It cannot be stated definitely that this precipitated material is a product of protoplasmic differentiation, but the substance is soluble in cold water and may be hydrolyzed with dilute mineral acids with the formation of reducing substances. It is gum-like in behavior, which suggests that it might be active in holding water by imbibition or in preventing the coagulation of protoplasmic colloids, and that it probably consists of a mixture of pectin, pectin-like substances and other gums. Even a thin coating of a stable carbohydrate colloid over the surface of the dispersed protein particles might prevent them from coalescing during freezing and thus preserve the structure of the protoplasm in a manner analogous to the protection of rubber by talcum.

TABLE 14. WATER SOLUBLE GUMS DETERMINED BY DIFFERENCES IN THE REDUCING VALUES OF CLEARED AND UNCLEARED DEXTRIN EXTRACTS.
(Data are calculated as glucose in percentage of green weight.)

<table>
<thead>
<tr>
<th></th>
<th>Nov. 11, 1934</th>
<th>Dec. 15, 1934</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncut</td>
<td>2.67</td>
<td>0.92</td>
</tr>
<tr>
<td>Cut early</td>
<td>1.76</td>
<td>0.92</td>
</tr>
<tr>
<td>Cut late</td>
<td>1.00</td>
<td>0.92</td>
</tr>
<tr>
<td>Continuously cut</td>
<td>1.05</td>
<td>0.95</td>
</tr>
</tbody>
</table>

It is shown that in November the soluble gum fraction from the uncut plants was greater than from the other plants. This material formed more reducing substances than the starch from the same sample. Analysis of the December collections showed this fraction to be lower than it was during November, thus following the same trend as the dextrin. The Nov. 11 collection showed an excellent agreement between the glucose equivalent of the soluble gums and the hardiness of the samples by freezing tests. The Dec. 15 data suggest, however, that further research is needed to identify the precise factor in cold resistance.

Studies on this gum fraction were extended to include the six varieties of alfalfa used in the hardiness experiments. The results are shown in table 15.
TABLE 15. WATER SOLUBLE GUMS FROM HARDY AND NON-HARDY VARIETIES OF ALFALFA.

(Percent green weight.)

<table>
<thead>
<tr>
<th>Variety</th>
<th>Oct. 8, 1934</th>
<th>Nov. 11, 1934</th>
<th>Dec. 15, 1934</th>
<th>March 26, 1935</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ladak</td>
<td>1.12</td>
<td>1.32</td>
<td>0.34</td>
<td>0.87</td>
</tr>
<tr>
<td>Grimm</td>
<td>1.16</td>
<td>1.63</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Utah Common</td>
<td>0.53</td>
<td>1.44</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>California Common</td>
<td>0.73</td>
<td>1.39</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>New Mexico Common</td>
<td>1.44</td>
<td>1.00</td>
<td>0.49</td>
<td>0.93</td>
</tr>
<tr>
<td>Arizona Common</td>
<td>0.82</td>
<td>0.25</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

These data show fluctuations within varieties. In the variety Ladak there is a tendency for this fraction to follow the trend of the dextrin. The Arizona variety showed a decrease in this fraction during November when the dextrin content was going up. However, in March when dextrin went up, a parallelism was shown between dextrin and gums. There is only a partial, if any, relationship between the total content of soluble gums in the varieties and their hardiness; nevertheless the Nov. 11 soluble gum values give as good correlation with hardiness as any fraction studied.

PECTINS

The pectin-like nature of the clearing precipitate led to a study of the water soluble pectins of the available alfalfa samples. Cold water was used for extraction, and the hydrolyzed pectic acid was precipitated and weighed as impure calcium pectate.

The pectin was determined in the Grimm alfalfa that was used as a check in the experiment on the effect of cutting upon root reserves. The results are expressed as percentage of impure calcium pectate. They show that there was an increase in crude pectin as fall progressed. There was a decrease during winter. Pectin apparently followed somewhat the same trend as dextrin.

TABLE 16. PECTIN CONTENT OF THE ROOTS OF GRIMM ALFALFA COLLECTED ON THREE DIFFERENT DATES.

(Data are percentages of green weight.)

<table>
<thead>
<tr>
<th></th>
<th>July 26, 1934</th>
<th>Oct. 8, 1934</th>
<th>Dec. 15, 1934</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.841</td>
<td>1.29</td>
<td>1.13</td>
</tr>
</tbody>
</table>
Pectin determinations were run also on the roots of hardy and non-hardy varieties of alfalfa. The results are presented in table 17. The data show too much fluctuation among varieties to permit varietal classification upon the basis of the crude pectin fraction. The hardy varieties were lower in pectin during November than the tender varieties. There was an increase in pectin toward spring in both Ladak and Arizona Common, although this may be a sampling variation.

**TABLE 17. PECTIN CONTENT OF HARDY AND NON-HARDY VARIETIES OF ALFALFA.**

(Expressed as percentage impure calcium pectate on a fresh sample weight basis.)

<table>
<thead>
<tr>
<th>Variety</th>
<th>Oct. 8, 1934</th>
<th>Nov. 11, 1934</th>
<th>March 26, 1935</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ladak</td>
<td>1.36</td>
<td>0.95</td>
<td>1.18</td>
</tr>
<tr>
<td>Grimm</td>
<td>1.09</td>
<td>0.89</td>
<td></td>
</tr>
<tr>
<td>Utah Common</td>
<td>1.08</td>
<td>1.15</td>
<td></td>
</tr>
<tr>
<td>California Common</td>
<td>1.13</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>New Mexico Common</td>
<td>1.06</td>
<td>1.04</td>
<td></td>
</tr>
<tr>
<td>Arizona Common</td>
<td></td>
<td>1.04</td>
<td>1.34</td>
</tr>
</tbody>
</table>

Pectin has been assumed to be a cell wall substance, but its water soluble nature suggests that it may be found in the protoplast. In our material, no more than traces of "protopectin" could be recovered, and the "pectin" precipitates were apparently impure, containing gummy materials other than calcium pectate. We feel that the water soluble colloids of the alfalfa plant are worthy of further study in spite of the negative or partially negative results shown in our analyses of both soluble gums (which included pectin) and pectin.

**DISCUSSION OF RESULTS**

The data on the effect of fall cuttings upon root growth in Grimm alfalfa are in agreement with Loomis' (21) results on woody plants which show that lateral enlargement is associated, not with stored food supplies, but with active leaves. Nelson (25) found that frequent cutting in an early stage of top growth retarded root growth in alfalfa. In the present study the cross-sectional area of roots from the frequently cut plots was only 50 percent of normal at the end of the growing season.

The dry matter in the roots was found to be higher in the uncut plants than in the continuously cut plants. Graber and his associates (14) found an increase of approximately 100 percent in the dry matter of roots from plants cut in the mature stage as compared with plants cut in the immature stage. The
dry matter in the roots is represented, for the most part, by carbohydrates or differentiation products of carbohydrates. Frequent top removal not only suppressed dry matter accumulation, but probably resulted in withdrawal of carbohydrates in the form of sugars for the initiation of new top growth.

Frequent top removal not only suppressed dry matter accumulation, but probably resulted in withdrawal of carbohydrates in the form of sugars for the initiation of new top growth.

Fall cutting reduced top growth in the continuously cut plots, but apparently stimulated late fall growth in the late cut plots. The spring (1935) top growth, as shown by the yield of hay, was considerably greater in the uncut and early cut plots. These differences were due to differences in the amount of winterkilling combined with the low vigor of surviving plants in the cut plots.

Artificial freezing tests showed that uncut plants were able to survive more severe freezing than cut plants. All plants survived light freezing treatment, but as the freezing period was lengthened, the cut plants failed to survive. This result is in agreement with Dexter's work (9) in which he found that hardening progresses when conditions are favorable for the photosynthesis but unfavorable for rapid utilization of the synthesized foods. The vegetative condition of the cut plants suggested that hardening had not progressed very far.

Frequent cutting of Grimm alfalfa lowered the root reserves. There was a difference of almost 100 percent in the root reserves on Oct. 8 as the result of a single cutting at the end of August. Every fraction studied showed this difference except the sucrose, which showed a smaller difference in favor of the uncut plants. It is true that at this sampling date there was no decrease over the previous month. This failure to show a decrease in the cut plots was probably due to the functioning of the new leaf growth. However, it is shown that the normal accumulation of root reserves was prevented by the cutting.

Analyses of the root reserves in November of plants given different cutting treatments in October showed continued differences between the uncut and continuously cut plots. The chemical differences between late cut and early cut plots were no doubt obscured in part, however, by the open weather conditions which permitted some accumulation of reserve materials.

The percentage of both soluble and insoluble nitrogen was higher in the uncut plants than in the cut plants throughout the test period. There was no evidence of protein splitting as a factor in cold resistance.

In contrast to the results obtained by cutting Grimm alfalfa, the amounts and trends of the root reserves in varieties of
hardy and non-hardy alfalfa offer no evidence that hardy varieties, as such, are significantly higher than the non-hardy groups in any of the reserve fractions at any time during fall, winter or early spring. On the contrary, the non-hardy varieties were consistently higher in some of the reserve fractions than the hardier sorts.

The reducing sugars constituted a progressively smaller portion of the root reserves as fall advanced. The non-reducing sugars (sucrose) increased during the fall and were quite constant during the winter with a slight increase toward spring. The increase in non-reducing sugars was, for the most part, the result of starch and dextrin hydrolysis.

The starch began disappearing in early fall and constituted a very small portion of the root reserves in any variety after October. Analyses for starch in the spring showed no tendency toward reconversion of sugar to starch. These analyses were made shortly before any leaves were expanded. The rapidity with which starch disappeared suggests increased diastatic activity in response to low temperature, or other conditions. Digestion was more rapid in the hardier varieties.

The dextrins increased rapidly when starch showed its greatest decrease. This may mean that the starch, instead of undergoing more complete hydrolysis, was first converted into dextrin. The dextrin fraction in turn, however, showed a rapid decrease as fall progressed. It is highly probable that dextrin was, at least in part, hydrolyzed to sucrose.

The soluble nitrogen in the varieties showed some fluctuations, but no consistent differences between hardy and non-hardy varieties were found. There was an increase in the soluble nitrogen of all varieties during late fall but no evidence of protein hydrolysis since protein and non-protein nitrogen were accumulated simultaneously.

Greathouse and Stuart (15), working with red clover, were able to place their varieties in the proper hardiness groups upon the basis of their chemical composition. In the present study the analytical data on varieties offer no criteria by which the varieties can be placed in their proper order of hardiness as exhibited in field tests.

Tests on protoplasm stability failed to produce data that indicated a consistent relationship between cut and uncut plants. The same applied to hardy and non-hardy varieties of alfalfa. An improved technique may permit using this property as a measure of hardiness.

The pectin and protopectin fractions, although possibly im-
portant in cold resistance, showed fluctuations among varieties that would not justify the use of these fractions as indexes of the hardiness of varieties at the present time.

The positive correlation between reserves and hardiness within a variety (Grimm) and the lack of correlation when comparing varieties is considered to support the protoplasm differentiation hypothesis of winter hardiness. This hypothesis assumes as prerequisites to the development of winter hardiness, both an available reserve and a genetic ability to use these reserves in the building of a stable protoplasm.
LITERATURE CITED


Economics of Agricultural Land Use Adjustments

I. Methodology in Soil Conservation and Agricultural Adjustment Research

By Rainer Schickele

AGRICULTURAL EXPERIMENT STATION
IOWA STATE COLLEGE OF AGRICULTURE AND MECHANIC ARTS
R. E. Buchanan, Director

RURAL SOCIAL SCIENCE SECTION
AGRICULTURAL ECONOMICS SUBSECTION

Ames, Iowa
<table>
<thead>
<tr>
<th>CONTENTS</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foreword</td>
<td>340</td>
</tr>
<tr>
<td>Conclusions</td>
<td>343</td>
</tr>
<tr>
<td>Need for Planning Fundamental Adjustments in Agricultural Production</td>
<td>345</td>
</tr>
<tr>
<td>The Proper Sphere for Economic Planning in Agriculture</td>
<td>346</td>
</tr>
<tr>
<td>Emergency Character of the AAA Programs</td>
<td>347</td>
</tr>
<tr>
<td>Requirements for a Long-Time Program in the Corn Belt</td>
<td>347</td>
</tr>
<tr>
<td>Research Projects in Agricultural Adjustment</td>
<td>348</td>
</tr>
<tr>
<td>Purpose of This Bulletin</td>
<td>349</td>
</tr>
<tr>
<td>Characteristics of Present Farming Conditions in Iowa</td>
<td>350</td>
</tr>
<tr>
<td>Present Land Use Patterns and Crop Systems</td>
<td>351</td>
</tr>
<tr>
<td>Feed Unit Productivity of Crops and Pastures</td>
<td>353</td>
</tr>
<tr>
<td>Commercial Movements of Feed Grains</td>
<td>357</td>
</tr>
<tr>
<td>Animal Units and Livestock Systems</td>
<td>358</td>
</tr>
<tr>
<td>The Economic Problem of Soil Conservation</td>
<td>362</td>
</tr>
<tr>
<td>Some Characteristics of Soil Erosion and Depletion</td>
<td>363</td>
</tr>
<tr>
<td>Levels of Natural Soil Fertility</td>
<td>364</td>
</tr>
<tr>
<td>The “Breaking Point” of Natural Fertility</td>
<td>365</td>
</tr>
<tr>
<td>Regional Allocation of Emphasis on Conservation</td>
<td>369</td>
</tr>
<tr>
<td>Methods of Soil Conservation</td>
<td>374</td>
</tr>
<tr>
<td>Soil Conservation and Farm Income</td>
<td>376</td>
</tr>
<tr>
<td>Adjustments in Iowa Farming Necessary to Establish a Maintenance Farm</td>
<td>378</td>
</tr>
<tr>
<td>Interdepartmental Cooperation</td>
<td>379</td>
</tr>
<tr>
<td>Adaptation of Crop Rotations to Soil Types</td>
<td>380</td>
</tr>
<tr>
<td>Adjustments in the Crop Systems of the Type-of-Farming Areas in Iowa</td>
<td>387</td>
</tr>
<tr>
<td>Effect of Adjusted Rotations on Crop Yields</td>
<td>390</td>
</tr>
<tr>
<td>Feed Production from the Adjusted Crop System</td>
<td>392</td>
</tr>
<tr>
<td>Changes in Livestock Systems</td>
<td>394</td>
</tr>
<tr>
<td>Economic Evaluation of the Adjustment Problems in the Various Areas</td>
<td>398</td>
</tr>
<tr>
<td>The Regional Agricultural Adjustment Project of 1936</td>
<td>404</td>
</tr>
<tr>
<td>Objectives of the Project</td>
<td>404</td>
</tr>
<tr>
<td>Basic Assumptions</td>
<td>406</td>
</tr>
<tr>
<td>Evaluation of the Results of the Regional Adjustment Project</td>
<td>408</td>
</tr>
<tr>
<td>Appendix</td>
<td>411</td>
</tr>
</tbody>
</table>
FOREWORD

Back of this bulletin lies a unique experiment in research technique. The staff and the storehouse of material of the Experiment Station were effectively mobilized to study the uses to which farm land in Iowa was being put and to determine what adjustments are desirable.

While the idea of the functional interrelationship of the many parts of an experiment station is frequently stressed, in practice it is rare indeed for the several agricultural sciences to make a concerted and balanced approach on a major problem. But this is precisely what was accomplished in this study. In February, 1934, under the chairmanship of Vice Director W. H. Stevenson, a project was organized to determine the crop and livestock systems which are best suited to Iowa. What happened as a result of this co-ordinated approach has been told by Director Buchanan:

"Two years ago we tried the experiment of organizing . . . a project . . . to study production planning in the state. Our purposes were: to bring together into a comprehensive picture what we know about the agricultural resources of Iowa, to evaluate these resources, and to devise plans for their better utilization . . . The personnel that participated in this study were men from the research staff in soils, farm crops, animal husbandry, dairy husbandry, agricultural engineering, forestry, and agricultural economics . . . Out of a year's work of this group there finally emerged some rather fundamental agreements, statements to which all were able to subscribe. This was in itself a noteworthy achievement. Any dean of agriculture knows full well that from the standpoint of a man in soils it is really preposterous to have someone whose primary training is in the social sciences teaching the subject of farm management, for the world must know that this is a misnomer for soil management. Equally it requires a major operation really to convince an animal husbandryman that there can be any justification for grain farming without livestock anywhere in Iowa. But suspicions melt away and are replaced by confidence and understanding as all the factors involved are impartially reviewed. The soils specialist and the economist rather unexpectedly find themselves in agreement on fundamentals . . . ."

The integration of the work took place at a seminar organized for that purpose which met once a week during the winter and spring of 1934. It was at the seminar that the staff which was actively engaged in the project discussed the basic assumptions underlying the work. Out of this interplay of ideas and criti-

1 Project 363 of the Iowa Agricultural Experiment Station, "Determination of a Desirable Crop System and Livestock Program for each Township of Iowa for the Purpose of Developing Land Utilization Policies for the State."
2 From a paper, "AAA Regional Adjustment Project from Experiment Station Standpoint," by Director R. E. Buchanan, read at the Land Grant College Meetings, November, 1935. Italics are mine.
cal examination of assumptions emerged a rather well-defined and balanced concept of the goals in agricultural adjustment in Iowa. A series of three progress reports was prepared; these were mimeographed and issued under the general title, "A Study of Certain Aspects of Corn Belt Agriculture in Order to Determine Suitable Policy for Production Reduction." These reports were widely used in connection with the national agricultural adjustment project of 1935 which the Division of Program Planning of the AAA sponsored and which the several states entered into cooperatively. The supply of the reports, accordingly, was soon exhausted.

The active personnel which was responsible for the work done in connection with the project and seminar was, from the Agronomy Section: P. E. Brown, C. S. Dorchester, B. J. Firkins, F. B. Smith, R. H. Walker; from the Animal Husbandry Section: H. H. Kildee, C. Y. Cannon, C. C. Culbertson; from the Agricultural Economics Section: P. H. Cox, Charles Elkinton, Erling Hole, John A. Hopkins, Donald Keene, Keith Kirkpatrick, Rainer Schickele and T. W. Schultz.

While the specific recommendations for changes in the prevailing crop and livestock systems in Iowa resulting from this study are significant, an important complementary product is the clarification and appraisal of concepts, definitions and objectives, and the contribution to a methodology of procedure. It is essentially this phase of the study which Mr. Schickele presents in this bulletin.

The study, however, did not stop with recommendations. Since these had been developed by a group of specialists, the question naturally arose: Were the results practical? The right solution is both theoretical and practical. Thus, in order to test the practicability of the research results, the following techniques were adopted.

Five selected blocks of farms in each type-of-farming area in the state were carefully surveyed and the recommended crop and livestock systems applied to these farms. Another test was made by adding a representative and experienced group of farmers to the personnel of the project to go over the work. The state was divided into 25 groups of four counties each. Each group selected one farmer whom it thought best qualified for this assignment. These 25 farmers were then specifically appointed to work with the research staff of the college. They came to Ames. They were given all of the factual background,

---

3 The first report appeared April 28, 1934, 29 pages; the second, Sept. 21, 1934, 206 pages; the third, Jan. 10, 1935, 37 pages.

4 Project 452 of the Agricultural Experiment Station, "Test of the Economic and Technical Practicability of the Agricultural Adjustments Recommended for Iowa."
all of the data worked out for each county of the state. The underlying assumptions were discussed in meetings lasting 7 to 8 hours a day. These men examined and evaluated our work of the previous year. After a week they returned to their homes to obtain additional facts from their counties. Then they returned to Ames for an additional week of work at the close of which they had developed a set of recommendations.5

What were the repercussions upon the resident research personnel? The experiment with the 25 farmers had led to the clear understanding of a valuable research aid. The staff gained because it was found necessary to modify previous conclusions on the bases of new data and redefined assumptions. It does not matter whether this technique of study is labeled research or extension; it is an essential step in bridging the gap between what is theoretically sound and that which is, in addition, practical.

Another and more comprehensive test was then made. The Extension Service, working hand in hand with the research staff, obtained from each county an independent estimate of the farm land use adjustment desirable for the county.6 Thus, the project initiated early in 1934 was not only successful in bringing the several sciences to bear upon the problem of land use and its close kin, soil conservation, but in its final stages through the Extension Service it also interrelated the findings of the study with the experience and thought of farm leaders throughout the state.

Theodore W. Schultz,
Head, Rural Social Science Section

---

CONCLUSIONS

It is not the purpose of this bulletin to recommend solutions to the soil conservation and land use problems but rather to clarify objectives, evaluate basic assumptions and interpret such concepts as soil conservation and land use adjustment in the light of public policy.

The conclusions, therefore, cannot be presented in terms of statement of facts, nor of specific recommendations for changes in land use, but in terms of definitions of concepts, appraisal of objectives and suggestions for methodological procedure which may lead to the development of an effective agricultural conservation policy.

In the past, research in agricultural economics has been focused on the individual farm organization and on the prices of farm products as the major determinants. The relatively depressed conditions in agriculture since the World War, in conjunction with a rapid deterioration of land resources in large parts of major agricultural regions, gave rise to new sets of problems which cannot be handled adequately by traditional research procedure. Regional land use patterns and livestock systems, the forces that determine them and the effect they have on the land as a natural resource constitute a relatively new field for scientific inquiry. From this field any sound and well-rounded land use policy must be developed.

The primary emphasis in the adjustment studies discussed in these pages lies on the determination of land use patterns and crop systems which would conserve the soil resources as fully as it seems economically feasible, assuming no drastic changes in price relationships and in the intensity of farming. Before effective policies accomplishing this objective can be outlined, the concept of soil conservation and its economic implications must be clarified.

Soil conservation aims at the elimination of two types of soil deterioration: erosion and depletion. From the viewpoint of public policy, soil losses from erosion are more serious and require remedial action more urgently than fertility losses from depletion through crop removal. Erosion losses are irreplaceable, occur at a progressive rate, and cause increased flood hazards and silting of streams and reservoirs. The effects of fertility depletion remain localized and can be more easily corrected by application of organic matter and fertilizer. Erosion control, in contrast, usually implies substantial changes in the land use pattern and crop system with all their subsequent
effects on livestock systems, farm size and organization, and land tenure conditions.

One of the most difficult problems of a soil conservation policy is, therefore, to accomplish an adequate regional allocation of emphasis on conservation in terms of public funds and human efforts employed. Soil conservation as an objective of public policy is of a relative rather than absolute character. Instead of diffusing available funds over wide regions regardless of the various land classes and their relative need for conservation, such funds should be concentrated upon those land classes where conservation is most urgent in the interest of the public welfare. The problem is not one of complete preservation of all plant nutrients and soil characteristics on all land classes, but rather one of achieving an adequate degree of conservation on the various land classes according to the present supply of resources left and the present and prospective rate of deterioration.

A carefully balanced policy of soil conservation must evaluate the probable effect of certain desirable changes in land use patterns and crop systems on livestock systems, on the general farm organization, on the adequacy of the prevailing farm size pattern and land tenure conditions, and on the aggregate volume of agricultural production. The present adjustment studies, however, confined the estimates of probable effects of certain land use changes to livestock systems. This phase of research in agricultural adjustment is necessarily speculative in character and involves a highly intricate method of procedure. Different solutions should be developed for different sets of clearly defined assumptions, as there is no unique solution to the disposal of the products obtained from any given crop system. Price relationships, consumers' purchasing power, interregional competition, international trade and land tenure conditions are but a few of the more important factors to be considered in evaluating the long-time effect of a comprehensive policy of soil conservation.

Research activities in this field must necessarily transgress the lines of specific research departments. Workers in agronomy, animal husbandry and economics, particularly, have closely cooperated in the present studies. The development of a technique of effective interdepartmental cooperation is essential to progress in developing a rational land use and soil conservation policy.
Economics of Agricultural Land Use Adjustments

I. Methodology in Soil Conservation and Agricultural Adjustment Research

BY RAINER SCHICKELE

NEED FOR PLANNING FUNDAMENTAL ADJUSTMENTS IN AGRICULTURAL PRODUCTION

The ultimate goal of agricultural policy is to provide a secure foundation for the sound development of farm life. If the farmer is to attain "equality" of opportunity and satisfaction comparable with that obtained by his fellow citizens in urban occupations, the economic returns in farming must be made more secure and the cultural environment of the farm home more attractive than they have been in the recent past.

It is generally held that agriculture has not been able to keep pace with industry and commerce in the advance of living conditions and cultural opportunities. Evidences of the wide acceptance of this view are the Report of the Country Life Commission to President Theodore Roosevelt (1909), the reports of the National Industrial Conference Board (1926) and the Business Men’s Commission on Agriculture (1927), and the persistent drive for "equality for agriculture" throughout the twenties.

The recent depression drastically revealed the vulnerable economic position of domestic agriculture. It produced the gigantic attempt of the government to restore the balance of agriculture—the Agricultural Adjustment Act.

The legislation creating the "AAA" was not strictly an emergency measure. As the farm program entered its second year of operation, the administration, the agriculturists and farm leaders were turning away from emergency objectives

1 Projects 363 and 452 of the Iowa Agricultural Experiment Station.
2 The writer is greatly indebted to Dr. T. W. Schultz, head of the Rural Social Science Section, for the stimulating assistance and constructive criticism received. The writer also wishes to acknowledge the many valuable suggestions offered by John A. Hopkins, Agricultural Economics Subsection, B. J. Firkins, Soils Subsection, and A. J. Engelhorn, Land Utilization Division of the Resettlement Administration, which were very helpful in preparing the manuscript. Since the research work discussed in this bulletin was carried on in a unique manner of interdepartmental cooperation, the staff members of the Soils, Crops, Animal Husbandry and Agricultural Economics sections have all actively contributed to this study.
toward more permanent long-time policies of fundamental agricultural adjustment. These latter policies were intended to prevent disproportionate burdens being thrown upon agriculture, to afford farmers the opportunity of adjusting their production to current and prospective demand, and to facilitate the conservation of soil resources.  

Farmers have not produced the quantities and kinds of products that would yield them, as a group, the highest and most secure income over a long period of time. Nor have they given sufficient heed to the maintenance of soil fertility. Agriculture, throughout wide sections of the country, has the character of an extractive rather than a permanently sustained industry which, indeed, is not conducive to the progressive development of farm life and rural institutions.

This is to say that two crucial problems of agricultural adjustments have come to the fore: (1) unbalanced production relative to the demand situation, and (2) soil wastage.

THE PROPER SPHERE FOR ECONOMIC PLANNING IN AGRICULTURE

It seems that the economic adjustments arising out of unaided individual competitive behavior cannot be depended upon automatically to establish and perpetuate a satisfactory economic balance. Agriculture, in fact, shows an imperfect and often inverse response to price changes and is induced or even compelled by the prevailing forms of competition to exploit and misuse its soil resources. This fact alone would appear to make agriculture a field wherein organized group action potentially promises genuine gains for the farmer as well as for society.

Unfortunately economic planning has become a fad. Injudicious proponents indulge in ambitious and often self-righteous ideas that everything should be planned, from the production of all individual crops to the pattern of racial geneties. It would be equally fantastic, however, to advocate abolition of government on the pretext of making competition really “free.” The determination of the proper economic spheres susceptible to effective guidance and regulation constitutes one of the most urgent problems of modern society. Economic planning in agriculture, therefore, implies by no means the collec-

---

4 There are many causes of exploitive farming, such as adverse pressure of low prices and high fixed charges, traditional farming practices, land tenure systems and inadequate farm sizes, which shall be mentioned later.

5 It should be mentioned that similar conditions of destructive competition are prevailing in other industries. Lumber companies, under the whip of unregulated competition, have ruthlessly exploited vast areas of virgin forest and have left denuded mountainsides, pauperized cut-over lands and dilapidated towns in their wake. Destructive competition in the oil industry is engendering tremendous wastage of natural resources to the ultimate detriment of society. The nation has a vital interest in the conduct of all industries involving the utilization of natural resources.
tive control of all agricultural activities, but rather a technique of adjusting a few key levers—the fewer the better—in order to attain basic and socially desirable ends. Orderly production gauged to the long-time demand outlook and soil conservation may safely be recognized as ends that are both basic and socially desirable.

EMERGENCY CHARACTER OF THE AAA PROGRAMS

The AAA production control programs dealt exclusively with adjusting the production of specific commodities to the short-time demand outlook. The flat percentage reduction from historical base acreages was fairly adequate from the viewpoint of a short-time emergency program of production curtailment, but truly inadequate from the viewpoint of a long-time program for soil conservation. Parity prices, even in their broadest interpretation, are unsatisfactory guide posts for long-time production adjustments, and are absolutely useless for determining adjustments in soil conservation. Character and size of benefit payments under the AAA programs must be considered equally untenable for a long-time policy. All these phases clearly demonstrate the emergency character of the AAA production control schemes.

REQUIREMENTS FOR A LONG-TIME PROGRAM IN THE CORN BELT

The major issues involved in the development of a long-time program of fundamental agricultural land use adjustments in the Corn Belt in contrast to the AAA emergency programs are:

1. Introduction of soil conservation as a major objective of agricultural policy and the correlation of this objective with orderly production.

2. Establishment of suitable standards of land use and soil management adapted to regional and local conditions. Historical bases for acreages of specific crops should be avoided as they tend to "freeze" acreages and production according to a pattern incidental to a few base years and are wholly inadequate for a great number of farms.

3. Differentiation of adjustments between regions as well as between individual farms within each region on the basis of land types. This differentiation should be determined largely by the requirements of soil conservation and such factors as alternative opportunities for various products in a given region, and comparative advantage of various regions for a given product.

All these issues are organically interdependent. Much thought and research are needed before we can hope to solve
adequately these complex problems and clear the way for the shift from a crude and uniform emergency program to a refined agricultural land use adjustment policy.

RESEARCH PROJECTS IN AGRICULTURAL ADJUSTMENT

A start, however, has been made. Herein are presented certain observations and developments in adjustment research which it is hoped may lay the foundation for a more rational agricultural land use policy.

In March, 1934, the Iowa Agricultural Experiment Station invited the Production Planning Section of the AAA to enter into cooperative research in agricultural adjustment. A project entitled, "A Study of Certain Aspects of Corn Belt Agriculture in Order to Determine Suitable Policy for Production Reduction," was initiated. The basic objective of this study was to suggest desirable crop systems for Iowa that would economically maintain soil fertility and be consistent with sound farm management practices.

In March, 1935, the Production Planning Section of the AAA and the Bureau of Agricultural Economics of the U.S.D.A. invited all 48 states to carry on a "Regional Agricultural Adjustment" project following closely the lines of the Iowa study of the preceding year. Two series of regional conferences were held in order to secure a uniform approach and comparable results. The Production Planning Section in Washington summarized and combined the 48 state reports on desirable agricultural production adjustments by main agricultural regions and for the country as a whole. This nationwide research project represents the first systematic attempt ever made to carry on research on a regional and national scale for the purpose of securing a scientific basis for agricultural policies.

In the following, a brief review of other research activities complementing the basic regional adjustment project is presented. During the summer of 1935 the Agricultural Economics Section went one step further and initiated a project entitled, "Test of the Economic and Technical Practicability of the Agricultural Adjustments Recommended for Iowa," in cooperation with the AAA and the Bureau of Agricultural Economics. This study comprised a survey of 413 individual farms in carefully chosen localities representing the various soil types and type-of-farming areas of Iowa. Data obtained from these farms were analyzed and used as a basis for testing out the probable effect of certain recommended crop acreage adjustments on livestock systems and farm income.

In July, 1935, the "Iowa Farm Adjustment Study Group," consisting of 25 farmers selected by county corn-hog production control associations, and each representing four counties, met in Ames and discussed

---

6 Three mimeographed reports on this project have been prepared. Their contents are incorporated in the following pages of this bulletin.

7 See H. R. Tolley, Regional Adjustment and Democratic Planning. Address delivered before the meeting of the Association of Land Grant Colleges at Washington, D. C., Nov. 20, 1935.
with soil experts and economists the results and suggestions that had grown out of the adjustment studies. There was no intention on the part of the experts to propagate their views or any specific program. After the first 2 days of mutual orientation the atmosphere became cleared from embarrassment and suspicion and a free interchange of observations, ideas and judgments among the farmers themselves as well as between the experts and the farmers took place. After one full week of intensive work, the farmer representatives went back to their counties for a week and discussed the tentative crop adjustments recommended with neighbors, corn-hog committee members and county agents, checked up on figures from corn-hog contracts and returned to Ames for another week of intensive study. These men then formulated proposals for the 1936 corn-hog program which they presented to a meeting of all 100 county corn-hog committee chairmen for approval. These proposals were submitted to Washington and received serious consideration in the process of developing the 1936 corn-hog program. This procedure appears to be a very promising approach to bringing research down to reality, to test the adequacy of results derived from research as well as to articulate the ideas and judgments of practical farmers on important matters concerning agricultural adjustments.

In the fall of 1935, a "County Agricultural Planning Project" was initiated on a nation-wide scale. Under this project, jointly sponsored by the Extension Service and the AAA in Washington, and the state extension services and agricultural experiment stations, the counties set up county agricultural planning committees consisting of farmers and leaders in rural communities. Federal and state agencies furnished statistical data on crops, livestock, soil types, tenancy and other relevant factors. The county planning committees, on the basis of this statistical background information and of their experiences as farmers and observers of local conditions, formed their own judgment and submitted their proposals with respect to adjustments they, as representative groups, deemed desirable and necessary in order to fundamentally improve the agricultural conditions in their counties from a long-time point of view. There can be little doubt that such an approach to determining some basic uses of our natural and human resources in the country has vast potentialities and constitutes a most challenging experiment in economic democracy.

PURPOSE OF THIS BULLETIN

It is the purpose of this study to record the procedure and preliminary findings of the research project on agricultural land use adjustment. The problems, methods and results of this project as they affect agricultural production adjustments of the Corn Belt in general and Iowa in particular will be presented.

The emphasis lies on the methodology of indicating and analyzing factual material rather than on the descriptive presentation of the facts themselves. We are in serious need of adequate and effective conceptual tools in the research field of agricultural adjustment. In the past the attention of research workers in agricultural economics has been focused largely on the individual farm organization and on the price and distribu-
tive problems of farm products. Regional land use patterns and livestock systems, the forces that determine them, and the effects they have on the land and its human attributes constitute a relatively new field for scientific inquiry.

The work under these adjustment studies has been confined largely to the problem of production adjustments physically desirable for the establishment of a maintenance agriculture, with the primary emphasis on land use patterns and crop systems which would conserve soil resources as fully as it seems economically feasible under the general conditions of past price relationships and intensity of farming. This does not mean, however, that the importance of the many other phases of agriculture involved in shaping a sound and effective land use policy has been ignored. We know, for instance, that the Corn Belt faces serious problems in land tenure and farm credit which necessarily will have to be considered carefully in a well-rounded program of agricultural adjustment. The Resettlement Administration and the Farm Credit Administration are conducting research work in these and related fields in close cooperation with other federal and state agencies. As a first approximation, however, we must determine what a rational use of our land means in terms of crop systems, acreages and production before we can determine adequately and in detail the desirable policies in credit, taxation, tenancy, marketing and other important fields of agricultural activity.

Although the crop adjustments proposed represent the best judgment of experts concerning practicable soil conservation requirements, it should be clearly understood that methods and results of these studies are not final. They are still changing, are gradually being refined, and improved. Most figures and assumptions must be conceived as preliminary and subject to revision. All figures indicating desirable changes in crop and livestock systems are presented mainly to illustrate methods of procedure and suggest lines of approach. They are not intended to be accepted as final recommendations but rather to invite criticism and to stimulate thinking and further research.

CHARACTERISTICS OF PRESENT FARMING CONDITIONS IN IOWA

Obviously, a clear understanding of present farming conditions is prerequisite to the development of a fundamental adjustment policy. We know much about past movements in acreages, production and prices of farm products, but we know comparatively little about the underlying structure of farm en-
terprises and their institutional ramifications. The type-of-farming studies furnish valuable basic material, but in general they are as yet too much confined to pure description to be of maximum usefulness. The changes in crop and livestock enterprises, their interrelationships and the factors determining their combinations and relative intensities are highly important issues in formulating long-time adjustment programs.

The first step undertaken in the economic phase of the study was, therefore, an attempt to develop sets of criteria and other conceptual tools which would effectively indicate and measure fundamental relationships in the farm enterprises in different parts of the state.

**PRESENT LAND USE PATTERNS AND CROP SYSTEMS**

Long-time adjustments in agricultural production on the basis of farming systems and type-of-farming areas require a concise knowledge of present land use patterns and crop systems. There are three major classes of land uses within the category of arable farming: crop land, pasture and timber. These land use classes are indicated in terms of percentage of the total farm land for all counties in Iowa. To illustrate, the "land use patterns" of two extreme counties and of the state as a whole for 1932 are as follows:

<table>
<thead>
<tr>
<th>Percent of all land in farms*</th>
<th>Allamakee County</th>
<th>Pocahontas County</th>
<th>State</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop land**</td>
<td>40</td>
<td>80</td>
<td>64</td>
</tr>
<tr>
<td>Pasture</td>
<td>40</td>
<td>13</td>
<td>29</td>
</tr>
<tr>
<td>Timber</td>
<td>7</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Waste land, buildings</td>
<td>13</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>roads, etc.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

*Based on statistics from the Iowa Yearbook for 1932 (assessors' reports).

**Land used for harvested crop. Does not include rotation pasture and wild hay.

The land used for timber in Iowa is relatively insignificant inasmuch as only 0.8 percent of the total Iowa farm land is in timber and wood lots. There is, in general, very little variation in waste land, buildings, roads, etc., between counties as almost all counties have between 5 and 7 percent of the farm land in such uses. The analysis of present land uses in Iowa, therefore, can be focused largely on crop land and pasture. This does not
imply, however, that in some sections of Iowa timber should not be expanded or some farm land retired.

In order to depict the detailed use of the crop land, the major crops are expressed in terms of percentage of the total crop land. This, then, represents the crop system prevailing in a given district.

The crop systems of two extreme counties and of the state as a whole, indicate the range within which the crop patterns vary in Iowa (1932):

<table>
<thead>
<tr>
<th>Percent of crop land in:</th>
<th>Allamakee County</th>
<th>Fremont County</th>
<th>State</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>32</td>
<td>77</td>
<td>54</td>
</tr>
<tr>
<td>Small grain</td>
<td>37</td>
<td>13</td>
<td>32</td>
</tr>
<tr>
<td>Hay*</td>
<td>30</td>
<td>9</td>
<td>13</td>
</tr>
<tr>
<td>Other crops</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

| Percent of farm land in: | | |
|-------------------------| | |
| Crop land               | 40 | 71 | 64 |
| Pasture                 | 40 | 18 | 29 |

*Excluding wild hay land, which is usually too poorly drained for cultivation.

The last two figures put the crop system proper into its proportion to the utilization of the total farm land as a whole.

This classification is based on the area used for harvested crops. For the purpose of indicating the potential use of land for crops and rotation pastures, which is a major consideration in adapting crop systems to soil types, the above classification is modified so as to segregate tillable land. Plowable pasture certainly is potential crop land. In evaluating crop rotations from the viewpoint of their effect upon the soil, hay and rotation pasture may well be put into one class since the rotation is not affected by whether the grass is used as hay or as pasture. On the other hand, perennial legumes have a distinctly beneficial effect on soil productivity which other kinds of hay do not have. Hence, legume hay is segregated from other hay and includes in this category all perennial legumes whether cut for hay or used for pasture. Soybeans, an annual legume, are chiefly an intertilled crop and are highly conducive to erosion on rolling land whether they are used for grain or hay. Corn and soybeans, therefore, may be grouped together in one class. The crop system for Iowa (1929) modified from the viewpoint of adapting crop systems to soil conditions is shown below (the crop
systems for the Iowa type-of-farming areas are presented in fig. 6 of the appendix):

<table>
<thead>
<tr>
<th>Crop Type</th>
<th>Percentage of Tillable Land</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn and soybeans</td>
<td>40%</td>
</tr>
<tr>
<td>Small grain</td>
<td>26%</td>
</tr>
<tr>
<td>Legume hay</td>
<td>4%</td>
</tr>
<tr>
<td>Other hay and plowable pasture</td>
<td>26%</td>
</tr>
<tr>
<td>Other crops**</td>
<td>4%</td>
</tr>
</tbody>
</table>

* Crop land plus plowable pasture.
** Includes idle crop land and crop failure.

No statistics on temporary rotation pasture as distinct from permanent plowable pasture are available. Although plowable pasture represents potential crop land, only part of it is actually under rotation, which should be borne in mind in interpreting present crop systems. Unfortunately data on plowable pasture are available only for census years. It should be clearly understood that tillable land as derived from census reports represents by no means land suitable for cultivation from the viewpoint of soil conservation.

It will be seen later that the establishment of an adequate expression of the crop system is of great practical significance, since a regionalized adjustment program depends on present crop systems as a guide for working out detailed adjustment provisions.

**FEED UNIT PRODUCTIVITY OF CROPS AND PASTURE**

For evaluating changes in crop systems, the establishment of a unit of measurement which reduces all crops to a common basis is highly serviceable.

In Iowa this is a relatively simple task, since practically all crops are fed to livestock. The logical unit, therefore, is the *feed unit*. By converting all feeds produced into feed units, it is possible to estimate the effect of a proposed change in the crop system on the aggregate physical crop output of a given farm or area.

The *feed value* of the conventional quantity-unit of the specific crops (bushels for grains, tons for hays) is estimated and expressed in terms of *feed units*. One feed unit represents the feed equivalent of one bushel of corn. These feed equivalents are estimated on the basis of digestible nutrients, allowing for the average quality of the specific feed crops as produced on farms throughout the state, and assuming they are fed in proper combinations to the proper kinds of livestock.

---

8 The Iowa Weather and Crop Bureau is subdividing for the first time the pasture column in the annual assessors' reports into plowable, woodland and other non-plowable pasture in its annual census of 1935.
The following feed equivalents (conversion factors) are used:

1 bushel of corn equivalent to 1.00 feed units
1 " oats " 0.43 "
1 " barley " 0.73 "
1 " wheat " 1.07 "
1 " rye " 0.75 "
1 " soybeans " 1.34 "
1 ton of legume hay " 18.00 "
1 " mixed hay " 15.00 "
1 " timothy hay " 13.00 "
1 " silage " 6.70 "
1 pasture season (6 months)
for a mature cow* 38.70 "
1 acre of cornstalks and ears left on the field** 4.00-5.00 "

* The feed equivalent of the intake of grass by a cow during a pasture season of 6 months is estimated at 2.15 tons of legume hay, or 2.58 tons of mixed hay, or 38.70 bushels of corn (feed units).

** On acres yielding under 35 bu. 4.00 feed units
35-45 bu. 4.50 feed units
over 45 bu. 5.00 feed units

These conversion factors must be used with a great deal of discretion. The realized feed value of any individual kind of feed varies widely according to quality, combination with other feeds, kind of livestock to which it is fed and general efficiency in feeding operations.

The concept of the feed unit implies that one feed unit of corn, for example, can be substituted by one feed unit of oats or hay or any other feed without affecting the performance of a given animal.

It is obvious that this holds only within rather narrow limits of substitution, and that these limits are different for various feeds as well as various kinds of livestock. The limits of substitution for corn and barley are much wider than for corn and hay; hay can substitute for corn within much wider limits in

* These conversion factors are subject to revision and refinement. They will vary as between regions according to quality of the respective crop and prevailing feeding methods. Account should be taken of the fact that the digestible nutrients of feeds as quoted by standard sources are derived from feed samples of a markedly better quality than are generally available on the average farm. Moreover, waste involved in the every-day feeding practices on the farm is apt to be considerably greater than under laboratory conditions. As far as possible, these factors have been considered in establishing the feed unit conversion factors for Iowa. The following Index of feed values, used by the Wisconsin Agricultural Extension Department, has been used as a point of departure:

Relative feeding values when used in proper combinations:
(Base 100%) 100 lbs. of corn = 100
" oats = 85
" barley = 95
" wheat = 100
" rye = 95
" legume hay = 65-70
" mixed hay = 55
" timothy hay = 50
the cattle ration than in the hog ration. In general it can be said that the range of substitution of one feed for another is rather wide within the group of feed grains or within the group of roughages, but is limited regarding the substitution of roughages for concentrates. Each kind of feed, moreover, has specific physiological effects that are not measurable in terms of digestible nutrients; e.g., the physiological values of pasture and oats for growing stock are not adequately expressed by their nutritive values. One feed unit of corn in combination with a protein supplement produces more pork than it does without protein supplement. The bulkiness of hay limits its substitution for concentrates.

Strictly speaking, one bushel or ton of a specific feed stuff would call for as many different conversion factors as there are different qualities and different combinations in feed rations and different kinds of livestock. No such refinement of conversion factors has as yet been attempted. The factors indicated above assume average quality of farm-grown feed stuffs in Iowa and are valid only within narrow limits of substitution of the specific feeds in the feed rations. They apply only to average Iowa conditions. For more fundamental research covering larger regions, the "Total Digestible Nutrients" is probably a more satisfactory unit, as it is independent of any specific crop of specific quality.

Based on these feed equivalents and the average 1928-1932 yields, the feed unit productivity per acre of the various crops for Iowa is estimated to be as follows:

<table>
<thead>
<tr>
<th>Crop</th>
<th>Feed Units per Acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn*</td>
<td>43.0</td>
</tr>
<tr>
<td>Oats**</td>
<td>15.2</td>
</tr>
<tr>
<td>Barley**</td>
<td>20.7</td>
</tr>
<tr>
<td>Wheat**</td>
<td>20.0</td>
</tr>
<tr>
<td>Rye**</td>
<td>10.6</td>
</tr>
<tr>
<td>Soybeans**</td>
<td>20.5</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>47.9</td>
</tr>
<tr>
<td>Clover</td>
<td>28.3</td>
</tr>
<tr>
<td>Mixed clover and timothy</td>
<td>20.1</td>
</tr>
<tr>
<td>Soybean hay†</td>
<td>34.2</td>
</tr>
<tr>
<td>Permanent pasture</td>
<td>14.7</td>
</tr>
<tr>
<td>Rotation pasture</td>
<td>20.4</td>
</tr>
</tbody>
</table>

* Includes stalks and ears left on the field: 38.0 average grain yield plus 5.0 as allowance for stalks and ears left on the field. See footnote to preceding table.
** Does not include feed value of straw. An estimate of the degree of utilization of straw for feed on the average farm by type-of-farming areas would be necessary.
† Includes beans.

This comparison of the feed productivity of the various crops in Iowa is helpful in evaluating proposed changes in the crop system. With the exception of alfalfa, the alternative crops which could replace corn produce from one-third to three-fourths of what corn produces in terms of feed units.
The data on feed unit productivity of crops and pasture are computed for all 99 counties of Iowa. Figures 7 and 8 in the appendix show the average yields of crops and pasture.

The estimates of pasture productivity are tentative. Rotation pasture is evaluated on the basis of the mixed hay yield of the respective county, making allowance for the higher productivity of sweet clover pasture as compared to mixed clover and timothy pasture. Permanent pasture is appraised by its average carrying capacity (acres per mature cow), roughly estimated for each county. (See fig. 8, appendix.) The feed value of pasturage consumed by a cow is assumed as being equivalent to 2.15 tons of legume hay, or 38.7 feed units. The number of acres necessary to carry a cow through a pasture season of 6 months (=carrying capacity) divided into 38.7, then, is the feed unit production of one acre of permanent pasture.

The feed unit production from each crop and from pasture is computed for all counties and townships, based on 1932 acreages and 1928-1932 average yields. For the pasture production of townships, the respective county yields are used, because data on pasture productivity by townships are not available. The following analytical tools were constructed on the basis of feed units.

The "feed supply structure" represents the percentage distribution of the total feed units by crops and pasture available for feed in each county, after allowances for in- or out-shipments of corn and oats were made. This feed supply structure influences the livestock system prevailing in each county (see p. 360). It is, therefore, a valuable guide for estimating changes in the livestock system resulting from a proposed change in the crop system and the corresponding feed supply structure. The feed supply structures of two extreme counties and of the state as a whole are as follows (see fig. 13 in appendix):

<table>
<thead>
<tr>
<th>Feed Units in Percent of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appanoose County</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>Corn</td>
</tr>
<tr>
<td>Small grain</td>
</tr>
<tr>
<td>Hay</td>
</tr>
<tr>
<td>Pasture</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>100</td>
</tr>
</tbody>
</table>

To obtain the total feed unit production of a county, the proportion of rotation pasture to the total pasture has been estimated, because no statistics are available on rotation pasture. These rotation pasture estimates are also subject to revision. Unfortunately the data on pasture yields are exceedingly scant.
Total feed unit production per farm, obtained by dividing the number of farms into the total feed units produced in a county or township, is a useful indicator of the aggregate output per farm. In developing a differentiated adjustment program, regional differences in the level of productivity per farm must be taken into account, since a shift from a high-productive crop in terms of feed units per acre (e.g. corn) to a lower productive crop (e.g. hay) has different implications on a farm producing 5,000 feed units than on one producing only 2,000. Extensification of the crop system on farms already low in aggregate feed unit production suggests farm consolidation or other major readjustments in the farm organization (e.g. definite change in type from corn-hog to dairy), while farms high in feed unit production may more easily absorb a shift of some land from a high-productive crop to a lower one.

Feed unit production per acre is an adequate measure of the general level of soil productivity of a given area. It represents a composite yield, including all crops and pasture. It is obtained by dividing the total feed unit production of a county or township by the number of farm acres. On a county basis, it ranges from 13.3 in Davis County to 31.2 in Pottawattamie County, the average for the state being 24.4. (See fig. 10, appendix.)

Intra-regional differences in the level of soil productivity should be recognized in developing a program, since, by and large, alternative opportunities available to the farmers in a given area tend to decrease with decreasing soil productivity.

Feed unit production is not a comprehensive measure of farm or acre output, where food products for direct human consumption occupy a significant acreage. Where wheat and rye are grown for milling, they should not be expressed as feed units. Here, the physical output per farm or per acre can hardly be measured by a single term. Crop value per acre data for cash crops may supplement the feed unit data for feed crops. This renders the analysis of the effect of proposed crop changes on aggregate output more difficult and complicated. Obviously, this holds true also for areas where substantial amounts of commercial fertilizers are generally applied.

COMMERCIAL MOVEMENTS OF FEED GRAINS

In order to estimate the net amount of feed supporting the livestock system of a county, allowance must be made for the inter-county movements of feed grains. Statistics on the in- and out-shipments of corn and oats during 1929-1932 for all

11 On a county basis average feed unit production per farm ranges from 1,823 in Appanoose County to 5,325 in Humboldt County. The average for the State is 3,923. See fig. 11, appendix.
Iowa counties are available in two recent publications of the Iowa Agricultural Experiment Station.\textsuperscript{12}

The average net in- or out-shipments of corn and oats are expressed in percentage of the production. This percentage shipment figure serves as a valuable measure of feed grain surplus or deficit in a given county. It also indicates the relative prevalence of cash-grain farming. (See fig. 12, appendix.) The shipments of corn and oats vary between a surplus of 54 percent and 69 percent of the production, respectively, in Calhoun County and a deficit of 6 percent of corn and 2 percent of oats in Jackson County.

In arriving at the feed supply structure, these normal percentages of net in- or out-shipments have been applied to the production of corn and oats. Shipments of other feed grains and hay have been disregarded because they are of minor significance in Iowa.

ANIMAL UNITS AND LIVESTOCK SYSTEMS

An approach analogous to the feed unit and feed supply structure is made with regard to livestock. A significant change in the crop system entails changes in the livestock system, and in order to evaluate the directions and probable degrees of such shifts, a common denominator for all kinds of livestock seems serviceable.

The number of animals with a feed requirement equal to that of a mature cow (of average weight and average productivity) constitutes one animal unit. The conversion factors used are:\textsuperscript{13}

\[
\begin{array}{l}
1.0 \text{ head of cattle 2 years and older equals 1 animal unit} \\
2.0 \text{ head of cattle 1 to 2 years old} \\
4.0 \text{ calves under 1 year old} \\
1.5 \text{ beef steers} \\
1.0 \text{ horse 2 years and older} \\
2.0 \text{ colts 1 to 2 years old} \\
4.0 \text{ colts under 1 year old} \\
3.5 \text{ sows} \\
7.5 \text{ pigs} \\
7.0 \text{ sheep (ewes and rams)} \\
14.0 \text{ lambs} \\
100.0 \text{ hens}
\end{array}
\]

No standard animal unit conversion factors can be applied throughout the nation. They must be adapted to regional conditions. They are based on feed requirements, not only for maintenance, but also for production at the level prevailing in the region. The animal units used in this study have been established in cooperation with animal husbandry specialists, taking into consideration the relevant factors in the average feed-


\textsuperscript{13} These animal units correspond only partly to the conventional units quoted in “Farm Management” by G. F. Warren, p. 210.
ing operations on Iowa farms and the average feed requirements of Iowa livestock of average productivity. One animal unit, therefore, represents an amount of livestock whose feed intake at an average level of productivity equals that of an average mature cow (around 120 feed units), assuming the feed is fed in proper combinations to the proper kinds of livestock under conditions of prevailing feeding efficiency.

The establishment of animal units involves difficulties analogous to those encountered in establishing feed units. The concept of an animal unit implies the same feed consumption in terms of feed units (or T.D.N.'s) regardless of the kind of livestock. One hog animal unit consumes the same amount of feed equivalents as one cattle or sheep or poultry animal unit.

Obviously, the various kinds of livestock utilize the various kinds of feed with varying degrees of efficiency. A given feed supply structure can be utilized only by a limited number of different combinations of livestock enterprises. Here, again, the limits of substitution of one kind of livestock for another are much wider within the group of concentrate-consuming livestock (chiefly hogs and poultry) or within the group of roughage-consuming livestock (chiefly cattle, sheep and horses) than they are for the substitution between these two groups. Hogs are poor utilizers of roughage, and beef cattle breeding stock are relatively poor utilizers of grains. As supplementary feeds, however, they may not only be used in the respective livestock enterprises with great efficiency, but even increase the degree of utilization of the major kinds of feed. All these facts—and there are many more—must be kept fully in mind in working with feed and animal units.

Strictly speaking, then, different conversion factors should be applied to cows of different weight, different milk production and different breeds, to grass fed steers and to steers fed in dry lot, to grass fed lambs and to grain fattened lambs, to various classes of hogs, etc. In the present study, the animal unit conversion factors have been differentiated only by age classes, as indicated above.

A graphical correlation between total available feed units (after allowances for in- and out-shipments of grains) and total animal units for the 99 Iowa counties shown in fig. 1 suggests, however, a reasonable accuracy of the estimates of feed units and animal units. If we divide the total available feed units by the total animal units of each county, 90 percent of all counties fall within the range of 100 to 140 feed units per animal unit, representing a variation of plus or minus 16.7 percent from the mode 120. Many of the more extreme variations can be explained by special known circumstances, such as skimmilk fed to hogs, differences in the degree of utilization of pasture, comparative efficiency in feeding practices, etc.
The number of animals in each kind of livestock in each county has been converted into animal units.\textsuperscript{14} By expressing the animal units in each kind of livestock in percentage of the total animal units, the \textit{"livestock system"} prevailing in each county is obtained. Again, to illustrate the range within which the livestock systems vary in Iowa, the systems for the extreme counties and for the state as a whole are: (See fig. 14, appendix.)

<table>
<thead>
<tr>
<th>Animal Units in Percent of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Appanoose County</td>
</tr>
<tr>
<td>Hogs</td>
</tr>
<tr>
<td>Cattle</td>
</tr>
<tr>
<td>Sheep</td>
</tr>
<tr>
<td>Horses</td>
</tr>
<tr>
<td>Poultry</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

The correspondence between feed supply structure and livestock system is apparent. Appanoose County is highest in hay

\textsuperscript{14} All livestock data on a county basis are taken from the 1930 census, except the data on hogs which come from the semi-annual Iowa pig survey (1929-33). The census data on hogs are quite inadequate.
and pasture and cattle and sheep. Washington County is high in corn and hogs. These two patterns, the feed supply structure and the livestock system, are useful criteria in evaluating the possible consequences of certain changes in the crop system with regard to the livestock system. (See p. 397.) Assuming a fairly efficient adaptation of livestock to feeds in the past, possible changes in the livestock system resulting from a certain substantial change in the feed structure can be estimated by analogy. Graphical correlations carried out between feed structures and livestock systems seem to confirm the feasibility of this approach. If, however, the change in the feed structure is only moderate, the livestock system may not change materially, due to the substitutability among kinds of feed as well as kinds of livestock.

This method of visualizing the livestock system as a whole in its adaptation to the feed supply structure as a whole is likely to contribute much to the understanding and constructive analysis of many problems related to type of farming and comparative advantages of enterprises; besides it may furnish a useful tool in agricultural land use adjustment research.

A number of other criteria based on this concept of animal unit are developed and used successfully in the analysis of livestock problems. The density of livestock population, or the relative intensity of livestock enterprises in a given area, is more accurately measured by animal units of hogs, cattle, sheep, etc., per 100 acres of farm land than by livestock numbers.

Hog animal units per 100 acres vary from 2.0 in Appanoose County to 10.4 in Cedar County, the state average being 6.7. Cattle animal units vary from 4.5 in Fremont County to 9.2 in Dubuque County. The state average is 6.8.

Moreover, the use of animal units, instead of heads of livestock, facilitates the direct comparison of relative intensities of the various livestock enterprises within one area. The extent to which the cattle enterprise in an area is used for dairying is more adequately expressed by the "gallons of milk produced per cattle animal unit" than by the "number of cows milked" or the "gallons of milk produced per cow." Milk per cattle animal unit varies from 174 gallons in Wayne County to 445 in Bremer County, the state average being 282 gallons. (See fig. 15)

15 This statement may appear somewhat inconsistent with the concept of animal unit. If one cow of average productivity, producing, let us say, 200 lbs. of butterfat, represents one animal unit, a cow producing 500 lbs. of butterfat represents more than one animal unit, let us say 1.5 animal units. In other words, if variations in the productivity of cows were fully accounted for in the computation of animal units, the variation of milk produced per cow animal unit would be considerably smaller than that per cow. There would still be variation, however, because the part of the feed intake used for body maintenance is roughly the same for a low as it is for a high producing cow. The term "milk produced per cattle animal unit," however, does not refer to cows, but to total cattle including calves and feeders. Even if the cattle animal units were set up with minute correctness, this term still would adequately measure the intensity of dairying within the total cattle enterprise.
Hence, Wayne County has the strongest emphasis on beef of any county in the state, and Bremer on dairying, in their respective cattle enterprises.

Even though the importance of such livestock data on developing an adjustment program may seem somewhat remote, they nevertheless are useful in a real sense. Recommending crop systems without having rather definite notions on what the corresponding livestock systems will be, is likely to engender serious miscalculations and shortcomings. Statistics and research on crops and yields are much more reliable and abundant than those on livestock, and any additional information and analysis concerning livestock systems are needed all the more.

In order to present the existing farming characteristics in a comprehensive way, 16 criteria of prime significance, most of which have been discussed above, are worked out by counties and type-of-farming areas and grouped together on one map. Such a synopsis of criteria is exceedingly helpful in visualizing sectional differences in the agricultural set-up. The criteria are so chosen as to indicate the functional interrelations between the various factors and to depict the farming enterprise in its organic entity. (See fig. 16, appendix.) Even though the map may look, on first glance, somewhat crowded, the advantage of such a synoptical presentation of criteria will soon become evident.

THE ECONOMIC PROBLEM OF SOIL CONSERVATION

Balancing the output of agricultural products by adjusting present production to current demand does not necessarily involve the problem of soil conservation. A production control program of flat percentage decreases or increases from a historical base (acreage or production) may succeed in adjusting supply to demand. The problem of soil conservation, however, would remain largely unsolved, for the present differences in degrees of maladjustments in land use between areas as well as between farms would continue to exist; the flat percentage adjustments are not fitted to the requirements of local soil and erosion conditions. The introduction of the soil conservation objective into a long-time adjustment is, therefore, essential for farming areas where soil deterioration is threatening to undermine the future of farmers and rural communities.

The areas where present farming methods result in serious losses of soil fertility comprise large sections of the three great agricultural regions: the corn, wheat and cotton belts. It is in these sections that a long-time adjustment program may effectively be centered upon soil conservation. In the northern dairy states and the southern fruit and vegetable regions, the
agricultural land use problems are of a decidedly different nature. (See p. 408.)

SOME CHARACTERISTICS OF SOIL EROSION AND DEPLETION

Erosion is the most conspicuous form of soil deterioration and, from an economic viewpoint, also the most dangerous because of its irreversible character. Once the fertile top soil is washed away and the land is dissected by numerous gullies, it is extremely difficult and often impossible to restore a profitable level of productiveness. Even on soil types where erosion occurs predominantly in the form of sheet erosion and where the subsoil still can be farmed, subsoil farming implies a lower level of productivity and leads to a greater proportion of grasses and legumes in the crop system unless the land is to be abandoned. Why not, then, adjust the crop system on the fertile top soil so as to keep it from eroding and thereby safeguard the higher level of soil productivity for years to come? This, the conservationists argue, should certainly result in a net gain to farmers and society in the long run.

The case is somewhat different with respect to depletion of plant nutrients and organic matter through crop removals and leaching, which occurs on rolling as well as on level land. It is true that heavy cropping to grains, particularly corn, causes a relatively rapid depletion of available plant nutrients, accelerates the increase of soil acidity and losses from leaching, and, perhaps most important of all, disturbs the balance of soluble nutrients in the soil.16 None of these losses is, however, irreplaceable. Plant nutrients and organic matter can be restored to the soil through commercial fertilizers and manure, and excessive soil acidity can be corrected by liming. Whether it is economically profitable to do this, of course, depends entirely on the relative prices of inputs and farm products.

It may be said, however, that the general cost level of agricultural production is likely to rise if the natural soil fertility is allowed to fall below a certain plane since additional inputs of capital and labor have to replace what nature once furnished free of charge. In order to maintain the aggregate volume of farm production necessary to support the farm and rural town population, the decline in natural soil productivity must be compensated for by increased application of manure, limestone and fertilizers, by increased expenses for tilling and weed control, by the use of more complicated rotations which require more labor and higher managerial skill. This increase in cost will, of course, be at least partly reflected in higher prices of farm products which mean higher food costs to the consumer with-

16 Depletion on rolling land tends to accelerate erosion. The following statements, therefore, pertain primarily to level land.
out yielding higher net incomes to the farmer, consequently a
net loss to society as a whole.

This line of reasoning, while extremely general, indicates the
ground upon which soil conservation as an objective of national
policy is justified. The problem of the socio-economic implica­
tions of a soil conservation policy and the justification of such a
policy in the light of public welfare not only deserves, but
urgently requires, painstaking scrutiny lest soil conservation
become a subterfuge for monopolistic production control or for
outright subsidies to a specific class of society.

LEVELS OF NATURAL SOIL FERTILITY

Granting the fundamental soundness of a public policy of
soil conservation, highly intricate problems arise if an agricul­
tural program of soil conservation is to be developed. They
center around the question: What is the level of natural soil
fertility which should be stabilized in order to maximize the
economic returns from the land over a long period of time?

Men do not live for the purpose of conserving the soil, or else
it would be best to have the Midwest depopulated and re­
turned to a few thousand Indians and some buffalo herds.

No one could have impressed the pioneer who broke the prai­
rie sod, by pleading soil fertility maintenance and erosion con­
trol. And there are at present sections in the Corn Belt that
have been cropped only a few decades and, therefore, still
possess so high a fertility that the farmers shrug their shoulders
at the word soil conservation.

On the other hand, many communities in the East and South,
burdened with abandoned and run-down farms, with a painful
memory of prosperous days long past, may well deplore their
failure to safeguard the producing power of their land in time
to prevent the decline of which the community is now a victim.

Clearly, between the virgin fertility and the complete ex­
haustion of the soil resources, there is a level of natural fertility
which should be stabilized in order to maximize the usefulness
of the land to society. Just where this level lies is hard to de­
terminate. With respect to erosion, the depth of the surface
soil, and number and size of gullies, are highly important cri­
teria which can readily be ascertained. With respect to soil
depletion, the organic matter content, the degree of acidity,
weeds and plant diseases, and the response of crop yields to cer­
tain fertilizer treatments help to determine where definite soil
conserving practices should be employed. The conscientious
determination of the desirable level of natural soil productivity
is one of the most difficult, yet most important, problems that
must be solved before a fundamentally sound program of soil
conservation can be developed.
Public funds used to induce conservation measures on land whose natural fertility is still so high that there is no need for concern for decades to come are spent unwisely from the public viewpoint of a soil conservation policy. This is certainly true as long as there are lands where such funds could be used to greater advantage. With respect to the Corn Belt, it may be said that erosion on rolling land, due to its irreversible character, its rapid rate of progression and its indirect effects on the lower lands (flood, silting of streams and reservoirs, etc.), demands immediate attention more urgently than does soil depletion on level land.

In view of the present status of American agriculture and its historical development, the public interest requires that the level of natural fertility be stabilized wherever there are indications that the productivity of the farm land in a given area is likely to decline within the next 3 to 5 decades to a point where the area will no longer support the present farm and rural-town population with all its public services and institutions. Given these conditions, an active public policy of soil conservation is desirable, if not imperative. 17

THE "BREAKING POINT" OF NATURAL FERTILITY

The crucial question arises: Is it possible to determine with reasonable accuracy the imminence of the decline of soil fertility in a given area?

Before discussing this question, however, it seems advisable to clarify the concept of "natural soil fertility" and to consider its relation to crop yields and to technological improvements.

"Natural soil fertility" refers to the natural fund of currently available plant nutrients and other chemical, physical and biological conditions in the soil. If, assuming constant climatic conditions, a given piece of land is put into corn of the same variety year after year with a constant minimum application of labor and capital input, the corn yields represent a true measure of the natural fertility of this piece of land. 18 Starting with a virgin tract of rolling erosive prairie soil, corn yields stay fairly high for a number of years—until losses of top soil through erosion, decrease in organic matter content and water-holding capacity reduce the fund of available plant nutrients

17 It is assumed that the rural population is, at present, adequately supported by the returns from the land. In some areas which may be called "submarginal" with reference to their present farming pattern, but not for farming in general, erosion control may imply farm consolidation and emigration of a minor part of the farm population. This, for instance, seems to hold true for several sections of southern Iowa. Soil conservation on truly submarginal farm land, however, involves an entirely different set of problems and has not been considered in the present study. In Iowa there is hardly any tract of land as large as a township which could be adjudged truly submarginal for arable farming.

18 Provided, of course, that soil and climate are adapted to the growth of corn which is used here merely as an illustration.
sufficiently to cause a yield decline. First, the decline will be gradual. But erosion, crop removal and tillage decrease plant nutrient and organic matter content and waterholding capacity of the soil. The decrease in the latter, in turn, accelerates erosion. The rate in the decline in yields increases progressively during a period of years—until yields approach the point where crop residues and decomposition of soil material just balance the soil loss through erosion and the loss of nutrients through crop removal. From that point on the decline will slow down, and the yields may eventually become stabilized at a much lower level. This process is roughly illustrated by curve A in fig. 2. The point, or better section, of the curve where the rate of decline, that is the slope, begins to increase materially, may be referred to as the "breaking point of natural fertility."19

But people learn, and progress forges ahead. In the above example a constant minimum application of labor and capital input under a constant technique has been assumed in order to measure the natural soil productivity. Now, an attempt is made to indicate the character of the effect of technological improvements on yields.

If we imagine the historical progress in the prevailing technique of growing corn being applied to a level piece of land of abundant natural funds of available plant nutrients, the resulting corn yields will fairly closely reflect the effect of these technological improvements (assuming constant climatic conditions.) In the beginning of the era of agricultural science and of commercialization of agriculture, the rate of progress in the prevailing technique was low. Experience in cultural methods gradually accumulated in experiment stations and out on the farms, under the stimulus of commercialization and competition. The yields on our imaginary field begin to rise. Better plows are built, discs, planters, cultivators are perfected so as to improve the timeliness of field operations, drainage tiles are laid, higher yielding varieties are developed and seed testing is more generally adopted, and educational services in conjunction with higher farm incomes and an acute interest on the part of the farmers to increase their crop yields lead to a rather rapid and general adoption of these technological improvements. The rate of increase in the corn yields of our imaginary field is on a strong upgrade. After a period of years, many

19 It should be clearly understood that this diagram is not based on experimental or statistical data, but is purely a schematic illustration of the combined effect of decline in natural fertility and of technological advance on the yield level. If, in a given region where the breaking of virgin soil was soon followed by technological improvements, the technological improvements curve is shifted to the left, an increase in the yield level precedes the yield decline. If, in another region where the land was farmed exploitively long before technological improvements were applied, the B-curve is shifted to the right, the yield curve starts declining earlier than is indicated on the above diagram.
Fig. 2. Schematic diagram of combined effect of soil fertility losses and technological improvements on crop yields, under conditions of exploitive farming.

Farmers have taken advantage of these technological improvements, and fewer and fewer farmers are left on the former low level of production efficiency. Education is still going on, implements are constantly being improved, but the rate of progress in the commonly prevailing production technique is slowing down, at least until some new discovery invades the field and revolutionizes the common production technique. The increments in corn yields on our hypothetical field are gradually decreasing, although the total yield per acre is, of course, still definitely on the increase. This process is roughly illustrated by curve B in fig. 2.20

Almost any larger area in the Corn Belt, such as a township or county, comprises bodies of both rolling eroding land and level land, with all degrees of transition and in widely varying proportions. Throughout the Corn Belt both of these processes

20 This is only a crudely simplified picture of the multitudinous phases of technological improvements. Considering the Corn Belt as a whole, many other improvements in technique have tended to support yields; for instance, drainage, expansion of livestock enterprises resulting in manure applications, use of green manure, lime stone, fertilizers, etc. It is, however, the opinion of the writer that the above curve roughly depicts the essential character of the process of technological evolution in specific fields of human endeavor. Any revolutionary discovery, of course, would markedly influence the shape of the curve, provided the discovery is followed by its general adoption in the production field. This adoption is governed by the relative cost entailed and the input-output relationships obtained. This fact is constantly limiting the general application of scientific findings to the production process, and does so especially in agriculture which is particularly subject to the law of diminishing returns.
—decrease in natural fertility and increase in technological improvements—have been in progress simultaneously, although at various degrees of intensity in the various sections of the region. The summation of the two theoretical curves A and B, therefore, represents the effect of these two types of processes upon the actual average crop yields in the area, as illustrated by curve C in fig. 2. Needless to say, this curve is as theoretical and over-simplified as are those from which it is derived.

This line of reasoning, however, as it is illustrated by the diagram in fig. 2, brings out several things which may have considerable import on framing a policy of soil conservation.

First, it becomes evident that natural soil fertility cannot directly be measured by crop yields. Hence, the “breaking point” of natural fertility does not necessarily coincide with the point where yields start seriously to decline. In concrete terms: the fact that in a given area the trend of crop yields is not declining is no proof that soil fertility is being maintained. Technological progress may still offset the losses in natural soil fertility; that is, the area may be in a state corresponding to the period between the time units 6 and 8 in fig. 2.

Where yields are definitely declining, technological improvements no longer offset the progressive losses in natural fertility. The area is in a state corresponding to the period between the time units 8 and 10 in fig. 2. The cost of restoring the former yield level which may be essential to supporting the present farm population is likely to be higher than would have been the cost of maintaining the former yield level by conserving the natural soil fertility. Soil conservation, in essence, is a form of technological improvement gauged to equalize the inevitable decline in natural fertility, that is, to compensate the decrements in fertility by increments in technological progress. The greater the fertility decrements, the more costly the increments in technique necessary to maintain yields are likely to be. Therefore, the most effective and socially most profitable point to induce the adoption of conservation measures is probably the breaking point of natural fertility rather than the point where yields definitely begin to decline.

To summarize: the progress in production technique (technological improvement) cannot offset indefinitely and at all times the effect of the decline in natural soil fertility on yields under exploitive farming. This holds particularly for erosive lands where the progressive character of fertility decline is especially pronounced. That is, once a fairly high plane of commercialization and production technique has been reached, the rate of further technological advance is likely to slow down, at least for some time, while erosion and fertility losses continue at a progressive rate. The periodic slowing down of tech-
nological advance is partly due to the fact that technological improvement, which often implies higher inputs of capital, labor and managerial skill, is subject to the law of diminishing returns.

This line of reasoning seems to be substantiated by the experience of the Corn Belt. The general level of corn yields in the Corn Belt has been fairly stable for the last few decades. This apparent paradox of sustained yields in face of progressive soil deterioration\(^1\) is partly explained by the fact that the decline in natural fertility has been offset by technological improvements, such as better field practices, higher yielding varieties, seed testing, drainage, etc. If there had been no soil deterioration yields would have shown a definite increase.\(^2\)

Considering a great agricultural region like the Corn Belt as a whole, the ultimate effect of exploitive farming would be a serious decline in the aggregate farm production of the region. Such a decline may lead to shifts in consumption toward non-Corn Belt products and thus fail to raise the prices of Corn Belt products sufficiently to make it profitable to apply the high inputs of capital and labor (intensive fertilization, terracing, complicated crop rotations, etc.) necessary to maintain the volume of production at a level which would support the farm and rural town population of the region. This, again, seems to justify public action toward soil conservation in those areas where the breaking point of natural soil fertility has been reached or is likely to be reached soon.

**REGIONAL ALLOCATION OF EMPHASIS ON CONSERVATION**

Soil conservation as an objective of public policy is of a relative rather than absolute character. It is not a matter of complete preservation (and replacement) of all plant nutrients and soil characteristics on all land classes regardless of its economic and social implications, but rather a matter of inducing an economically adequate degree of conservation on the various land classes feasible under present and prospective economic and social conditions.

\(^1\) It has been estimated that over half of the Iowa soils have lost up to 50 percent of their original surface soil through erosion. See "Soil Erosion in Iowa," by Walker and Brown, Special Report No. 2, Ames, Iowa, 1936.

\(^2\) Furthermore, the inference could be drawn from the preceding discussion that on the level land yields may have increased due to the greater net effect of technological improvements relative to the slower rate of fertility decline, while on the rolling land yields may have tended to decrease due to the greater net effect of the higher rate of soil deterioration relative to the effect of technological improvements. Unfortunately, no systematic analysis of this rather complex problem has come to the attention of the writer. A simple comparison of yield data from various sections of the state is rather inconclusive as the identity of the land to which the yield data refer is not retained. There are indications of considerable "swapping" of land from bluegrass pasture into crops and back to bluegrass pasture which tends to keep up the average yield for the area for a considerable period, although fertility is not maintained, nor erosion prevented under such a practice. Changes in prevailing crop rotations and in the distribution of crops over the soil types of the area are other factors to be considered.
What, then, are the indications that the natural soil fertility in a given area is reaching its breaking point? How can the likelihood of serious decline in soil productivity within the next few decades be ascertained? Should land whose productivity has been on the decline for many years be restored to a higher level of fertility at relatively high public cost? Should public action be confined to erosion control in recognition of the irreversible character and indirect detrimental effects of this form of soil deterioration, leaving the problem of soil depletion on level land up to the individual farmer and to the slow-working action of strictly educational policies? It is, of course, impossible to give a clear-cut answer to these queries. They will continue to challenge our best thinkers in the field of agricultural land use policy for many years to come.

The regional allocation of public funds under a conservation policy is an issue of utmost importance. In the Corn Belt there are lands so badly eroded that they are not worth saving for cultivation. They should be withdrawn from arable farming and put into grazing land or timber. Conversely, there are areas which still have such a deep layer of surface soil and such a large fund of nutrients and organic matter that it may be economically justified to continue cropping them rather intensively for another decade. Between these extremes, however, there is much farm land whose natural fertility is rapidly approaching or has reached the breaking point, and the decline of its productivity can be expected to progress at an accelerated speed. These are the farm lands upon which an agricultural soil conservation policy should be focused.

There is little doubt but that soil conservation on rolling farm land subject to erosion is more urgent and of more immediate public concern than is soil conservation on level land not subject to erosion. The basis for determining the areas that need public attention shall be considered first.

The relative urgency for erosion control on the farm land of a given area depends principally upon two sets of factors: (1) present rate and character of erosion; and (2) the present depth of surface soil and character of subsoil.

Where gully and sheet erosion are progressing rapidly, and only a shallow layer of topsoil (e.g. A-horizon) is left on an unproductive subsoil, need for a vigorous erosion control program supported by adequate amounts of public funds is most urgent, provided what is left is still worth saving for agricultural use. Here the breaking point of natural soil fertility in all probability reached years ago. The social cost necessary to con-
trol erosion effectively is likely to be relatively high, because a greater departure from present farming practices is necessary to prevent further erosion. Far-reaching adjustments in crop systems imply shifts in livestock enterprises and types of farming, and may even necessitate major changes in the prevailing farm size pattern and the customary landlord-tenant arrangements. In addition, special erosion control practices, such as the building of numerous check-dams in gullies, terracing, contour-farming, etc., are required to supplement the changes in land use. All these changes imply a substantial immediate sacrifice in current income of the individual farmer, a sacrifice which, in most cases, he will not be able to bear individually. Public assistance in the form of conditional grants or other strong inducements for the necessary changes in farming methods may be fully justified. In Iowa, for example, a large part of the southern Iowa Loess Area would fall under this general land class.

Where gully and sheet erosion are moderate, the surface soil slightly deeper and the subsoil more friable the immediate urgency for public assistance in erosion control may be somewhat smaller. But, from a long-time viewpoint, the net social gain from public funds spent for erosion control is apt to be as great or greater than in the preceding land class. The present level of fertility is considerably higher and the per acre cost of erosion control is likely to be lower since the necessary changes in farming methods are relatively less drastic and can be adopted more easily by individual farmers, considering the higher plane of farm income. In this land class the breaking point of natural fertility presumably has just been reached or will be reached soon, and it is conceivable that the stabilization of the present fertility level could be attained with little cost and sacrifice. In Iowa large parts of the Mississippi Loess Area and the Missouri Loess Area would fall into this land class.

Where gully and sheet erosion are slight to moderate and the surface soil deep or the subsoil potentially productive, the problem of erosion control can hardly be considered of grave public concern for the time being. The present natural soil fertility is, with respect to erosion, likely to be still far from its breaking point since a deep layer of fertile topsoil assures ample funds of available plant nutrients. If erosion occurs as sheet erosion at a moderate rate instead of forming gullies which dissect the fields and hamper machine operations, then relatively less emphasis on conservation is needed. An effective but relatively inexpensive educational program and adjustments in the institutional arrangements of land tenure and rural credit may be all that are justified in the public interest. In Iowa undulating to gently rolling parts of the Missouri and Mississippi Loess areas would fall into this land class.
It should be noted that the present rate of erosion which is used as a criterion in the preceding discussion is not directly obtainable from the erosion reconnaissance map prepared in 1934 by the Agricultural Experiment Station and the Soil Conservation Service. (See fig. 5.) This map shows the estimated degree of erosion in terms of percentage of the original depth of the A-horizon eroded. 24

Although the data from the Erosion Reconnaissance Survey furnish valuable guidance in determining the relative seriousness of the erosion problem in the various areas, the actual depth of the surface soil, the character of the subsoil, the erosiveness of the soil types under the respective topographic and climatic conditions and the indications of present apparent erosion such as frequencies and depth of gullies and subsoil outcappings, must be carefully considered.

The relative urgency for public action regarding soil conservation on level land from an economic viewpoint is in general quite minor. To the extent to which soil acidity, poor tilth, weed growth and disease infection are caused by soil depletion under prevailing exploitive farming and are threatening to reduce the productivity of the land sufficiently to render communities or areas economically submarginal for the present pattern of land use, the interest of the public may become more directly involved. The social cost of a conservation program in such areas may be considerably less than the social cost of rehabilitating or depopulating the area after it has dropped below the economic margin of production.

In Iowa, for example, the larger part of the Wisconsin and Iowan Drift areas consists of fairly level land where the nitrogen, phosphorus and organic matter supply in the soil is not being maintained because of heavy cropping to grains. Here, as on gently rolling to level land with moderate erosion and deep surface soils, an educational program and adjustments in the institutional arrangements of land tenure and rural credit seem to be all that could be justified as conservation policy from the viewpoint of the public welfare, since no significant portions of these soil areas begin to approach exhaustion and

24 The determination of the original depth of the A-horizon is inevitably quite arbitrary. This should not be lost sight of in interpreting the erosion map, as even a small error in estimating the inches of original cover results numerically in a larger error in terms of percentage of loss. Moreover, no information is given regarding the time periods during which the indicated soil losses have occurred. Whether it takes 2 years or 100 years to wash away 1 inch of topsoil is of great significance in determining conservation policies for specific areas and land classes. In some areas the erosion losses as indicated on the erosion maps may have occurred long ago, while during more recent years erosion may have been adequately controlled by the prevailing farming methods. This, for example, seems to be the case in most of northeastern Iowa, which shows heavy erosion losses on the erosion reconnaissance map, yet relatively little erosion is occurring at present because of the general use of well balanced rotations and of considerable amounts of barnyard manure supplied by the strongly developed dairy enterprise.
submarginality for farm production. In fact, they belong to the most fertile land areas of the world.

To summarize: If Iowa should be divided into “soil conservation districts” according to the relative urgency for public assistance in conservation measures, strictly from the viewpoint of the social interest in conservation of land resources, three principal districts could be tentatively outlined as follows (see fig. 3):


2. Conservation District of Second Order: moderate gully and sheet erosion, medium depth of surface soil, subsoil of low to medium potential productivity. Adjustment through educational and some subsidiary measures, with reforms in tenure and credit systems. Mississippi Loess Area: soils of the Tama, Clinton, Fayette series. Missouri Loess Area: the shallower and steeper phases of Marshall soils, mainly in the southern half and the western fringe of the area.

3. Conservation District of Third Order: moderate to slight sheet erosion, deep surface soil and level lands not subject to erosion but farmed exploitively. Adjustment through educational measures only, with reforms in tenure and credit systems. Missouri Loess Area: the gently rolling and deep phases of the Marshall soils, mainly in the northern half and the eastern fringe of the area. Wisconsin and Iowan Drift areas: the soils of the Webster, Clarion and Carrington series.
The importance of the time element, that is the rate of soil deterioration on the one hand, and the anticipated rate of adoption and probable effectiveness of conservation practices on the other, should be fully recognized in developing a long-time conservation policy. In the “conservation districts” of the first and second order, for instance, a strictly educational program without any financial inducement and assistance is likely to constitute too slow a process of adjustment; that is, the soil will deteriorate faster than the conservation measures will be adopted. In the “conservation district of the Third Order,” educational activities of public and private agencies may be adequate to meet the problem of soil conservation.

The forces of resistance encountered by soil conservation will greatly affect the rate of adoption and the effectiveness of conservation measures. Some of the most vigorous forces of resistance in Iowa are the tenancy system, the farm size pattern and the credit structure. A conservation policy must specifically attempt to overcome these broad resistances lest the program be doomed to inefficiency or failure.

It must be recognized, of course, that formulating a workable policy is not purely an economic matter. Policies must be put into practice by group actions. Their ultimate execution rests with the people. Unless the policies are adapted to the social and political experiences of the groups to which they are to be applied they cannot be effective. Nevertheless, the stronger the scientific and objective element prevails in the spirit and outline of the policy the more constructive it is apt to be in furthering the cause of general public welfare.

METHODS OF SOIL CONSERVATION

There are three main types of soil conservation methods under public sponsorship and subsidy applicable to farm land: (1) Withdrawal of land from cultivation, (2) changing the crop system in the direction of less intertilled crops and more grasses and legumes, and (3) mechanical devices such as terracing, strip cropping, contour farming, check dams in gullies, etc. The present study deals primarily with the second method of soil conservation, namely, the adaptation of crop systems to soil conditions so as to reduce erosion and depletion to a minimum feasible under prevailing economic conditions.

In most sections of the Corn Belt corn possesses such an outstanding comparative advantage over alternative crops that for decades the general tendency of farmers has been to grow the maximum corn acreage on their farms. There is very little specific and direct responsiveness of corn acreage to corn prices in the Corn Belt proper. If there is any, it is an inverse response, that is, more acres rather than less, are planted
to corn after low corn prices, as was the case during 1930-1933. One of the reasons for this phenomenon is that no matter what corn prices are corn usually produces the highest value per acre of average land among all alternative staple crops adapted to the region. In Iowa the corn acreage (11 million) is almost twice as large as the acreage of the next important crop, which is oats (6 million).

Corn is also the most exploitive grain crop from the viewpoint of soil fertility. As an intertilled crop it greatly fosters erosion. An average crop of corn removes more nitrogen and phosphorus from one acre than does any other major crop. It exhausts the organic matter content of the soil more quickly than any other crop (see tables 1, 2 and 3).

Adding these facts together, it appears inevitable that most of the Corn Belt will sooner or later face a serious problem of soil conservation. In large sections of the region the problem has unmistakably become serious already.

The task, then, is to devise systems of rotations which are adapted to specific conditions of soil type, slope, climate and the relative danger of erosion determined by these three basic factors, rotations which will effectively protect erosive soil from washing and approximately maintain the nitrogen and organic matter content of the soil. The method of adjusting crop systems to soil conditions will be discussed in detail later. Here, suffice it to say, that soil conservation on the farm land of the Corn Belt implies a reduction of corn acreage and an increase in acreages of grasses and legumes. The desirable extent of such a shift in the crop system, of course, varies between areas as well as between farms.

**TABLE 1. SOIL LOSSES FROM EROSION UNDER VARIOUS PLANT COVERS.**

<table>
<thead>
<tr>
<th></th>
<th>Tons of soil lost annually per acre</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Continuous corn</td>
</tr>
<tr>
<td>Columbia, Mo., 1919-21, average*</td>
<td>19.7</td>
</tr>
<tr>
<td>Shelby Loam; 3.7 percent slope.</td>
<td></td>
</tr>
<tr>
<td>Bethany, Mo., 1931-35, average**</td>
<td>60.8</td>
</tr>
<tr>
<td>Shelby Silt Loam; 8 percent slope.</td>
<td></td>
</tr>
<tr>
<td>Clarinda, Ia., Aug. 1932-Dec. 1934, average†</td>
<td>21.6</td>
</tr>
<tr>
<td>Marshall Silt Loam</td>
<td></td>
</tr>
<tr>
<td>LaCrosse, Wis., July 1932-Jan. 1935, average‡</td>
<td>56.6</td>
</tr>
<tr>
<td>Clinton Silt Loam; 16 percent slope</td>
<td></td>
</tr>
</tbody>
</table>

*Data taken from Soil Erosion Experiment Farm, Clarinda, Iowa.†Continuous barley instead of wheat.‡Barley replaced wheat in this case.
TABLE 2. PLANT NUTRIENTS REMOVED PER ACRE BY MAJOR CROPS.*

Based on 1928-32 average yields for Iowa.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Nitrogen pounds</th>
<th>Phosphorus pounds</th>
<th>Potassium pounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn (grain, 38 bushels)</td>
<td>35.0</td>
<td>6.5</td>
<td>6.8</td>
</tr>
<tr>
<td>Corn (silage, 8.4 tons)</td>
<td>50.3</td>
<td>8.4</td>
<td>50.4</td>
</tr>
<tr>
<td>Oats (grain, 35 bushels)</td>
<td>22.4</td>
<td>3.8</td>
<td>5.6</td>
</tr>
<tr>
<td>Wheat (grain, 19 bushels)</td>
<td>22.8</td>
<td>4.2</td>
<td>4.8</td>
</tr>
<tr>
<td>Soybeans (grain, 13 bushels)</td>
<td>41.3</td>
<td>6.2</td>
<td>12.9</td>
</tr>
<tr>
<td>Soybeans (hay, 1.5 tons)</td>
<td>69.0</td>
<td>9.3</td>
<td>27.0</td>
</tr>
<tr>
<td>Alfalfa (hay, 2.7 tons)</td>
<td>132.3</td>
<td>11.9</td>
<td>94.0</td>
</tr>
<tr>
<td>Red Clover (hay, 1.6 tons)</td>
<td>67.2</td>
<td>7.0</td>
<td>62.8</td>
</tr>
<tr>
<td>Timothy (hay, 1.0 tons)</td>
<td>26.0</td>
<td>4.8</td>
<td>17.6</td>
</tr>
</tbody>
</table>

*Based on Van Slyke, "Fertilizers and Crop Production."

SOIL CONSERVATION AND FARM INCOME

It is sometimes claimed that the soil conservation practice of keeping corn acreage low and grass and legumes high in proportion to the tillable land, results in higher farm incomes, than the prevailing emphasis on corn, and that, therefore, crop adjustments in the direction of less corn do not involve sacrifices in farm income, but actually result in more income to farmers. This claim is not necessarily valid as it confuses immediate income with aggregate income over a long period of years. As long as ample resources are available, the annual income from exploitive farming is boosted by an insidious liquidation of soil assets. As the resources become more and more exhausted, the income drops lower and lower. Conservational farming, on the other hand, produces "true" income under conditions of sustained productive capacity of the land assets. The annual income under the conservational system may in the beginning be somewhat lower than the income under the exploitive system, but it is being maintained indefinitely, while that under the exploitive system is doomed to decline.

The fact that corn, for example, is such a highly exploitive crop must be expected to lead, for a limited period of years, to a particularly high per-acre output, obtained with a relatively low per-acre input, just as the timber output per acre of virgin forest is much higher under the exploitive system of ruthless logging than under a conservational system of silviculture providing for current reproduction of the forest cover and for proper thinning and cutting practices. Considering the average output per acre in agriculture as well as in forestry during a long period of time, say three generations and more, however, the situation is reversed. The acre output under the exploitive system of management drops rapidly after the original resources have been depleted, while under the conservational
management the output is being maintained permanently and possibly increased.

Consequently, wherever in the Corn Belt there is still a considerable fund of natural soil resources available, a reduction in corn acreage may often imply a sacrifice of immediate income for the benefit of a maintained future income.25

This generalization, however, is subject to an important qualification. It assumes that the prices of corn and the prices of products derived from processing enterprises largely based on corn (e.g. hogs) essentially retain the relationship to prices of other crops and livestock products that prevailed during the past few decades. In other words, if the degree of comparative advantage formerly held by corn should be significantly reduced, for instance through some fundamental changes in the demand situation, a reduction in corn acreage corresponding to the extent of the loss in comparative advantage, would not entail any sacrifice in current income.

Such a loss in comparative advantage of corn occurred, within limits, during the depression years when corn and hog prices fell relatively faster and lower than did cattle and butterfat prices. Corn and hogs lost some of their comparative advantage to cattle. As the cattle enterprise requires roughage, beef and dairy farms with a relatively high grass and legume acreage tended to show higher incomes than corn and hog farms with a relatively high corn acreage. To the extent to which corn and hog prices during the next 10 or 20 years recover their former relationship to other prices, these enterprises will recover their former degree of comparative advantage, assuming the maintenance of the present level of corn yields.

Two principal sets of factors are in prospect that may tend to alter permanently the position of corn in its comparative advantage in the Corn Belt. One is economic in character and may significantly affect the demand situation. If our export

25 This statement holds true despite the fact that a considerable number of farms are now following good soil conservation practices and producing equal or even higher incomes than do farms following exploitive practices. In many cases this is due largely to superior management and can hardly be generalized. But apart from the question of differences in managerial ability between individual farmers, it is entirely possible that a farm under a conservational crop system with little corn and much grass and a relatively low crop value or feed unit output per acre produces as much or more net income than does a similar farm under an exploitive crop system with much corn and a high crop value or feed unit output per acre. This is possible because of the pyramiding of utilities, or the adding of manufactured value through intensive livestock enterprises on the low acre output farm as compared to the sale of feed grain, a raw material, on the high acre output farm. That is, a livestock farmer, in addition to earning a profit by producing feed crops, makes another profit by converting feed into livestock products; while the cash grain farmer produces only a raw material and leaves its manufacture into livestock products up to someone else. Hence, to the extent to which exploitive grain cropping is associated with a cash-grain type of farming, a shift toward the less productive grass crop does not, in the end, involve a reduction of income if the loss in crop value is offset by a corresponding gain in livestock value, i.e., added manufactured value. During the time of shifting from a cash-grain to a livestock system of farming, however, sacrifices in immediate spendable income are probably inevitable in most cases.
markets for pork and lard prove to be permanently lost, and if there should be a definite increase in the purchasing power of the lower income classes of our urban population, the price relationship between hogs and cattle products (dairy products and beef) would probably change in favor of the latter which in turn would tend to reduce the present comparative advantage of corn over grasses and legumes. The fact that lard is likely to be under more adverse economic pressure from other fats (lard substitutes) than are dairy products from their substitutes will tend to work in the same direction. A shift toward less corn and more roughage as a soil conservation measure would, then, involve less sacrifice in immediate income than it would under the past price structure. Such a shift will probably be reflected in lower land values.

The other set of factors is chiefly physical in character and pertains to the productive capacity of the soil resources in the Corn Belt. If a considerable portion of the soils under the present heavy drain from high corn acreages should soon reach the breaking point of their natural fertility, a reduction in the corn acreage would gradually be forced upon the farmer by nature itself, and the reduced productive capacity of the soil would through subsequently lower yields alter the comparative advantage of corn in favor of grasses and legumes. Such a forced “soil conservation,” after the most precious reserves of fertility are lost, involves a drastic “sacrifice” in immediate and future income. To the extent to which this course of events is imminent an early reduction of corn as a soil conservation measure to maintain a relatively high level of fertility must be considered economically profitable in the long run, although it may imply, perhaps not a drastic, but a moderate sacrifice in immediate income to be compensated for by a sustained future income.

ADJUSTMENTS IN IOWA FARMING NECESSARY TO ESTABLISH A MAINTENANCE AGRICULTURE

Soil conservation in the Corn Belt implies a re-allocation, though not necessarily a drastic reduction, of the corn acreage and an increase in the acreage of grasses and legumes. Inasmuch as a reduction of corn acreage is desirable from the supply-demand aspect, it should be the goal of an adjustment program to reduce corn acreage most where corn does the greatest damage to the soil and least where it does the least damage.

26 It is conceivable, however, that under continuance of exploitive farming land values will eventually drop much lower in correspondence with the progressively reduced productive capacity of exploited land. The lower level of land values resulting from conservation practices, on the other hand, represents merely a correction of the present over-capitalization of land values. Present land values are boosted by the current liquidation of the basic asset, the soil.
Soil conservation, therefore, requires differential adjustments between areas as well as between individual farms.

In the following pages, the economic implications of the program of differential crop adjustments outlined in the Iowa Adjustment Study shall be discussed in detail.

**INTERDEPARTMENTAL COOPERATION**

"When the Agricultural Adjustment Administration was organized there was thrown out to the agricultural thinkers of the United States a challenge: Is it possible for agriculture to synthesize from the vast accumulations of factual material a basically sound agricultural program for the nation?"²⁷

In response to this challenge the Iowa Agricultural Experiment Station organized, in the spring of 1934, a "Staff Seminar in Agricultural Planning," consisting of research workers in the fields of agronomy, animal husbandry, forestry, agricultural engineering and agricultural economics. Out of this seminar and the active work carried on by its members emerged a rather well-defined and balanced concept of the goal toward which agriculture in Iowa should be directed, and a set of rather specific recommendations for land use adjustments which in its essential features found the approval of all the staff members concerned.²⁸

This experiment in co-operative research has more than local or ephemeral significance. There is an urgent need for breaking down the walls between the various compartments of knowledge. The modern tendency toward extreme specialization in research threatens to disintegrate our knowledge to a point where we know much about an infinite number of parts but deplorably little about the whole. What we really need is to develop a method of "conscious, premeditated and controlled fusing together of the contributions of a number of minds to secure encyclopedic knowledge and—the end product—synthesis from that knowledge. . . . The value lies in our realization of this process as an instrument that can be consciously applied to the task of seeing, understanding, and bettering situations so complex that single minds cannot fully cope with them."²⁹

Our agriculture at present is in just such a situation, too complex for single minds to handle. The Iowa Adjustment Study and the Regional Adjustment Project constitute the first systematic attempt to create, by co-operation of social scientists and experts in the technical fields, a comprehensive understanding of the problems of agricultural adjustment and to develop coördinated lines of approach to their solution.

²⁷ R. E. Buchanan, AAA Regional Adjustment Project from Experiment Station standpoint; address delivered before the Land-Grant College Association, December, 1935.
²⁸ For details of the procedure, and the active personnel responsible for the work under this project, see the foreword.
²⁹ R. E. Buchanan, op. cit.
ADAPTATION OF CROP ROTATIONS TO SOIL TYPES

It has been pointed out that the adjustments in Iowa farming to requirements of soil conservation center largely around the problem of fitting crop systems to soil conditions. For illustration, table 3 presents estimates of net losses and gains of plant nutrients and organic matter under various crop rotations. It should be emphasized that the losses indicated in the table do not include erosion losses. They refer only to nutrient losses through crop removal and leaching under conditions of level lands and approximately average farming practices in Iowa. Most of these rotations which are commonly used on Iowa farms are rapidly draining the soil of its nitrogen and organic matter supply. On rolling land the rotations causing large losses in nitrogen and organic matter (rotations 1, 2, 3 and 4 particularly) are greatly accelerating erosion as the loss of organic matter reduces the infiltration rate and water-holding capacity of the soil and as a high proportion in clean tilled crops exposes the soil to the impact of rain.

As a general rule, then, the steeper the land, the shallower the top layer of the soil and the lower the present fertility, the more should rotations be used that have the conservational qualities of those on the lower end of table 3.

It can easily be seen that the soil conservation attainable through a judicious use of crop rotations is necessarily limited to the maintenance of the nitrogen and organic matter content of the soil and to the retention of the soil itself. Minerals are inevitably lost from the soil wherever any crops are harvested or livestock is pastured, no matter what rotations are used. Minerals can only be fully replaced by application of commercial fertilizer. This, however, is not implied in the objective of soil conservation under the present study; a complete replacement of all plant nutrients removed by crops is not necessarily economically justified. Mineral plant nutrients are constantly being released by the gradual decomposition of the soil constituents, and nitrogen is being added through rains and bacterial activities. The economically desirable degree of partial replacement of the nutrients removed by crop and livestock depends primarily on three factors: (1) The character and natural fertility of the soil, (2) the rate of plant food removal through the crop systems, and (3) the price relationship between farm products and fertilizers.

30 The data for this table have been prepared and made available through the courtesy of Dr. F. B. Smith of the Soils Department.

31 In European countries the “replacement theory” of fertilization advanced by Justus Liebig and his disciples has dominated the thinking of agronomists for many decades. In modern times it has been largely abandoned in favor of a more economic attitude toward soil management problems on level land. Erosion losses, because of their irreversible character, have relatively more serious economic implications.
TABLE 3. ANNUAL NET LOSSES (−) OR GAINS (+) OF PLANT NUTRIENTS AND ORGANIC MATTER UNDER VARIOUS ROTATIONS, ON LEVEL LAND WITHOUT EROSION.*

<table>
<thead>
<tr>
<th>Rotation</th>
<th>Nitrogen</th>
<th>Phosphorus</th>
<th>Potassium</th>
<th>Organic matter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Corn-corn-oats</td>
<td>-17</td>
<td>-5</td>
<td>-72</td>
<td>-2200</td>
</tr>
<tr>
<td>2. Corn-oats</td>
<td>-15</td>
<td>-5</td>
<td>-72</td>
<td>-2200</td>
</tr>
<tr>
<td>3. Corn-soybeans-oats-red clover</td>
<td>9</td>
<td>8</td>
<td>-82</td>
<td>-1800</td>
</tr>
<tr>
<td>4. Corn-corn-oats-red clover</td>
<td>-6</td>
<td>-5</td>
<td>-82</td>
<td>-1500</td>
</tr>
<tr>
<td>4a. Same with second clover crop plowed under</td>
<td>+4</td>
<td>-5</td>
<td>-78</td>
<td>-1000</td>
</tr>
<tr>
<td>5. Corn-corn-oats-mixed hay-rot. past.</td>
<td>-2</td>
<td>-4</td>
<td>-74</td>
<td>-1000</td>
</tr>
<tr>
<td>6. Corn-oats-red clover</td>
<td>-1</td>
<td>-5</td>
<td>-86</td>
<td>-1300</td>
</tr>
<tr>
<td>7. Corn-oats-mixed hay-rot. past.</td>
<td>+3</td>
<td>-3</td>
<td>-75</td>
<td>-600</td>
</tr>
<tr>
<td>8. Corn-corn-oats+sweet clover (pastured)</td>
<td>-11</td>
<td>-7</td>
<td>-82</td>
<td>-1600</td>
</tr>
<tr>
<td>8a. Same (sweet clover not pastured)</td>
<td>-4</td>
<td>-5</td>
<td>-72</td>
<td>-900</td>
</tr>
<tr>
<td>9. Corn-oats+sweet clover (pastured)</td>
<td>-4</td>
<td>-7</td>
<td>-87</td>
<td>-900</td>
</tr>
<tr>
<td>10. Same (sweet clover not pastured)</td>
<td>+5</td>
<td>-5</td>
<td>-72</td>
<td>+100</td>
</tr>
</tbody>
</table>

*These figures are based on the following assumptions: No erosion losses; yields of corn—40 bu.; oats—35 bu.; soybeans—20 bu.; red clover—2 tons; mixed hay—1.5 ton; cornstalks returned to the soil; no oats straw returned except through manure; 1 ton of manure per acre annually. Rainfall returns 10 lbs. of nitrogen; non-symbiotic bacteria add 15 lbs. of nitrogen annually. Leaching losses 7.3 lbs. of nitrogen and 57 lbs. of potassium annually. These assumptions correspond approximately to the average crop yields and general farming practices in Iowa.

If conditions of intensive livestock farming were assumed, with higher yields (corn—50 bu.; oats—50 bu.; clover 3 tons), with careful preservation and return of manure, and with the second clover crop or all sweet clover plowed under for green manure, the following losses and gains would result (numbers correspond to the above rotations):

<table>
<thead>
<tr>
<th>Rotation</th>
<th>Nitrogen</th>
<th>Phosphorus</th>
<th>Potassium</th>
<th>Organic matter</th>
</tr>
</thead>
<tbody>
<tr>
<td>4b. corn-corn-oats-red clover</td>
<td>+8</td>
<td>-4</td>
<td>-84</td>
<td>-200</td>
</tr>
<tr>
<td>6b. corn-oats-red clover</td>
<td>+20</td>
<td>-4</td>
<td>-85</td>
<td>+200</td>
</tr>
<tr>
<td>8b. corn-oats+sweet clover</td>
<td>+8</td>
<td>-4</td>
<td>-81</td>
<td>+300</td>
</tr>
</tbody>
</table>

Figures 4 and 5 show the major soil types and the extent of erosion as measured by the percentage of the estimated original depth of the surface soil eroded. This should be kept in mind in interpreting the erosion map. (See p. 383.)

For Iowa, the objectives of soil conservation and fertility maintenance are largely confined to erosion control and the maintenance of an adequate nitrogen and organic matter content of the soil. The application of limestone is required on many soil types mainly for correction of excessive acidity. This does not mean that application of phosphorus and even potassium may not be profitable in certain cases. But the use of such fertilizers is largely an economic problem and is not as yet as essential for soil conservation as is the maintenance of the nitrogen and organic matter content of the soil.

The objective of the crops and soils phase of this project has been stated in the summary report prepared by Messrs. F. B. Smith and B. J. Firkins of the Soils Department and C. S. Dorchester of the Farm Crops Department, as follows:

"(a) To recommend cropping systems for each township in the state of Iowa, which are believed to be satisfactory from the standpoint of soil management and conservation of soil fertility."
Fig. 4. Principal soil types of Iowa.
EXTENT AND SERIOUSNESS OF SOIL EROSION IN IOWA

IN PERCENTAGE OF ORIGINAL SURFACE SOIL REMOVED BY EROSION

GULLYING

Fig. 5. Erosion in Iowa.
"This program is to be considered one of fertility maintenance and not one which will have any immediate effect of increasing yields of crops in the various soil areas of Iowa. It is not a program to increase fertility or even to replace fully all nutrients extracted from the soil by crops, since no reference is made to the use of commercial fertilizers to supplement the normal farm resources. However, it has been assumed that it would be possible to lime a certain percentage (10%) of the acid soils in any one year.

"(b) It has been the purpose to keep uppermost in mind the characteristics and needs of the soil types existing in the townships of the state to the end that a long time program might be developed, based upon cropping systems and soil management practices, which will meet the needs of the state as regards soil conservation and land utilization."

The following discussion is intended to outline briefly the methodological procedure used and the economic problems involved in adjusting crop rotations to soil conditions for the purpose of developing a sound and workable land use adjustment program. Figures regarding suggested crop systems for the various soil types and type-of-farming areas are presented merely to illustrate the problems. It should be emphasized that these figures are tentative and subject to refinement. They should, as they now stand, be interpreted in a qualitative sense only, as indicating the direction of desirable adjustment rather than absolute goals.32

The area of each individual soil type as shown on the soil survey maps has been measured by townships with the planimeter.33 To these soil types rotations were applied which would, in the judgment of the agronomists, fulfill the above stated objectives. For illustration, one-fourth of the area in Clinton Silt Loam in a given township was put into permanent pasture, one-fourth into the 5-year rotation of corn - small grain - winter wheat - mixed hay - rotation pasture, and one-half into the 3-year rotation of corn - small grain - legume hay.

Table 4 presents, as an example, the major soil types in the Southern Pasture Area and the major crop rotations assigned to them. Within any one county the same general combinations of rotations adjusted to the general characteristics of the soil type were applied to the same soil type in the various townships.34 It was hoped that later on in refining the process of adapting rotations to soil types, differentiation between townships in rotation patterns on the same soil types could be

32 The details of the agronomic phases of this study will be published by the Agronomy Section of the Experiment Station in the near future.
33 These measurements were made by the Agricultural Engineering Section under the direction of Mr. H. J. Barre. For counties which have not been surveyed the areas in the various soil types have been estimated on a county basis.
34 The procedure is indicated more in detail by the sample worksheets 1-3 in the appendix. The areas measured on the soil maps with the planimeter were equated to the area in farms reported by the 1930 census. The soil reports contain estimates of the proportions of the various soil types in permanent pasture. These estimates, together with the general knowledge of the topography of soil types, were used as a basis for determining the cultivatable area of each soil type to which the standard rotations then were applied.
made on the basis of more detailed information on local

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Proportion of soil type in respective rotation</th>
<th>Rotation</th>
<th>Percent of rotated land in:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Corn &amp; soybeans</td>
<td>Grass &amp; legumes</td>
</tr>
<tr>
<td>Grundy Silt Loam</td>
<td>34% of area; Grade 1</td>
<td>C C SG LH</td>
<td>50 25</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C SB WW MH RP</td>
<td>40 40</td>
</tr>
<tr>
<td>Average for soil type</td>
<td></td>
<td></td>
<td>50 25</td>
</tr>
<tr>
<td>Shelby Silt Loam</td>
<td>27% of area; Grade 6</td>
<td>Permanent pasture</td>
<td>33 33</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>25 50</td>
</tr>
<tr>
<td>Average for soil type</td>
<td></td>
<td></td>
<td>29 41</td>
</tr>
<tr>
<td>Lindley Silt Loam</td>
<td>8% of area; Grade 9</td>
<td>Permanent pasture</td>
<td>25 50</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>25 50</td>
</tr>
<tr>
<td>Average for soil type</td>
<td></td>
<td></td>
<td>25 50</td>
</tr>
</tbody>
</table>

*This table serves as an illustration of the method of procedure used in apportioning crop rotations to soil types. In some counties minor deviations from the above pattern, both as to proportion of soil type in respective rotation and in specific rotations themselves, have been made. The soil types listed in this table are, of course, not complete. The legends used are: C = corn; SB = soybeans; SG = small grain; WW = winter wheat; LH = legume hay; MH = mixed hay; RP = rotation pasture.

There often are several alternative rotations of nearly equal conservational qualities for a given soil type. The decision as to how much of the soil area is to be put into these equivalent rotations affects, of course, the resulting acreages in the specific crops. The choice between these equivalent rotations is a matter of indifference from the agronomists’ viewpoint and rests chiefly upon economic considerations. For instance, the rotation corn - corn - small grain - mixed hay - rotation pasture is with reference to soil conservation on level or gently rolling land practically equivalent to the rotation corn - soybeans - small grain - mixed hay - rotation pasture. Under the first rotation the resulting corn acreage is twice as large as under the second. Hence, how much of that part of the soil type area which can stand 2 intertilled crop years out of 5 shall be put into the soybean rotation depends primarily on the competitive position of soybeans.

The same situation prevails in the determination of the acreages devoted to specific kinds of small grains and to specific kinds of grasses and legumes. For the purposes of soil con-

---

55 During the time the Crops and Soils Section worked out these crop rotations, the recommendations of county after county were discussed in a weekly seminar attended by members of the various departments interested in the study. In several cases the recommendations were revised as a result of these inter-departmental discussions which had a stimulating effect on all the workers in the various fields of research, and secured a well-balanced collective judgment on the problems under consideration.
servation, it is a matter of indifference whether oats or barley or rye or wheat is used as the small grain in the rotation, or whether a clover-timothy mixture or red clover or sweet clover is used for hay or for pasture as grassland in the rotation.

In Iowa, the problem of soil conservation is concerned primarily with rotation patterns of three classes of crops: intertilled crops, small grains, and grasses and legumes. Within these classes there is considerable leeway in apportioning the acreages of individual crops which should be determined essentially on the basis of comparative yields and other economic considerations.96

One might even go one step farther and argue that the agronomists, recognizing the outstanding comparative advantage of corn, tended to maximize the corn acreage on each soil type, but that the distribution of the residual land in rotation into small grains and grassland was relatively less vital to the problems of soil conservation. For instance, a given soil type may stand a rotation of corn, oats, sweet clover (see rotation 9 in table 3) nearly as well as one of corn, oats, mixed hay, rotation pasture (rotation 7 in table 3). There is twice as much grassland relative to small grain in the second rotation as in the first. Again, the proportion in which these two rotations should be used on the respective soil type may partly be decided on economic grounds. Since such economic details have not been considered in the determination of crop systems by soil types, it follows that the adjusted intertilled crop acreage has, within limits, a more absolute character and is of more distinctive significance than either the adjusted small grain or grassland acreage.

The speed with which this study had to be undertaken did not allow the establishment of elaborate standards of crop rotations adapted to clearly defined land classes on the basis of soil type, slope, depth of surface soil, climate and present state of erosion. These factors have entered into the determination of adjusted rotations only to the extent to which they are associated with the general characteristics of the specific soil types. But land of the same soil type differs widely in surface configuration, depth of A-horizon, and present state of erosion, and these differences should, of course, be reflected in the suggested rotations.

Furthermore, these rotations should be more thoroughly test-

96 This may seem to be a sweeping statement. The author realizes the agronomic significance of certain specific crops from the viewpoint of soil conservation. For instance, on less erosive soils soybeans are less soil depleting than corn because they do not draw so heavily, if properly inoculated, upon the nitrogen resources of the soil. Winter wheat protects the soil from erosion during the winter and spring months while the spring grains do not; on erosive land, timothy mixtures are usually preferable to clover alone, because of the dense root systems of the former; alfalfa, aside from developing a deep root system, keeps the plow away from the soil for 3 to 6 years. Nevertheless, the above generalization seems justified by reason of economic feasibility and methodology.
ed with respect to their effect on specific land classes of different soil textures, slope, climate, etc., regarding water-runoff and erosion, balance of plant nutrients in the soil and other important criteria. The effect of given rotations on soil erosion and depletion on a given land class is also affected by such farm practices as application of manure, plowing under the second clover crop, contour farming, etc. Work along these lines is now being carried on by the Soils Section of the Experiment Station.  

The determination of crop systems in the present study, therefore, rested largely upon the general characteristics of the major soil types and the general conservational properties of major rotations regarding their effects on erosion and nitrogen and organic matter content of the soil.

From the viewpoint of practicability of a soil conservation program, it is essential that the established standards of soil conservation provide flexibility in individual farm adjustments, that is, an adequate choice of specific rotations and farm practices so as to allow profitable combinations of enterprises commensurate with the labor and capital resources of the individual farmer.

ADJUSTMENTS IN THE CROP SYSTEMS OF THE TYPE-OF-FARMING AREAS IN IOWA

These facts should be kept in mind in interpreting the adjusted crop systems which shall be briefly summarized in order to indicate directions and relative rather than absolute degrees of suggested adjustments in the various sections of the state.

Table 5 presents a summary of the adjustments in crop systems tentatively proposed by the Crops and Soils Section. The crop systems are expressed in terms of percentage distributions of the tillable land in major crop classes and plowable pasture. (See above, p. 353.) Although not all of the plowable pasture is actually in rotation, it may well be considered as potentially available for cultivation. Hence, tillable land affords a better basis for the percentage distribution of crops than would crop land alone which does not include rotation pasture in the statistics.

For the state as a whole, the crop rotations adjusted to soil types result in an intertilled crop acreage (corn and soybeans) which is 17 percent smaller than the 1929 acreage, and in a small grain acreage 19 percent smaller. Tame hay and plowable pasture increased by 52 and 32 percent, respectively.  The

37 For the first systematic evaluation of the effect of crops and certain practices on the soil, see R. M. Salter, R. D. Lewis and J. A. Slipher: Our Heritage—the Soil. Ohio State University, Extension Bul. 175, April, 1936.

38 The summarization of the recommendations of the County Agricultural Planning Committees shows a decrease of 12 percent from the 1929 acreage in intertilled crops, of 4 percent in small grains, and an increase of 27 percent in hay and 7 percent in plowable pasture.
segregation of hay and rotation pasture from the grassland in rotation is virtually irrelevant from the viewpoint of soil conservation. If economic conditions should definitely prohibit a 19 percent reduction in small grains in addition to a 17 percent decrease in intertilled crops, a more moderate decrease in the small grain acreage and a correspondingly smaller increase in the grassland acreage may not seriously vitiate the general purposes of soil conservation. The adjusted acreages of small grains, hay and plowable pastures, therefore, are more subject to modifications in the light of economic conditions than the adjusted acreage in intertilled crops whose determination rests more predominantly on physical considerations of soil conservation requirements.

Comparing the percentage changes in intertilled crops between type-of-farming areas it becomes evident that the northeastern dairy area (I) in 1929 was more in adjustment than any other area, requiring a reduction of only 3 percent. Next comes the northwestern cash grain and livestock area (II) with 12 percent, followed by the southern pasture area (VII) with 13 percent, the eastern livestock area (V) with 16 percent, the central cash grain area (IV) with 17 percent, the south-central livestock area (VI) with 22 percent, and finally the western livestock area with 26 percent.

It appears that the southern pasture area and the western livestock area, which practically coincide with the Southern Iowa Loess area, and the Missouri Loess area, respectively, are most distinctly out of line with soil conservation practices, and therefore represent the areas of heaviest exploitation of the soil resources relative to the other sections of the state.

Percentage changes from an arbitrary base period do not indicate the true character of the recommended adjustments in crop systems. The same adjusted acreage in intertilled crops implies, as compared with 1932, a reduction of 23 percent, or compared with 1934, a reduction of only 7 percent, instead of 17 percent on the 1929 basis. A more adequate picture of the adjustment is obtained by comparing the percentage distributions of tillable land in the major crops by the type-of-farming areas. Again, the western livestock area (III) stands out with an adjustment in the intertilled crop acreage from 47 percent of the tillable land in 1929 to 35 percent, in contrast to the northeastern dairy area (I) which requires only a minor adjustment from 34 percent to 33 percent. (See table 5.)

---

38 Under the 1934 corn-hog program, the corn acreage in Iowa has been reduced by 2.6 million acres or 22.4 percent from the 1932-1933 average of 11.6 million to 9.0 million in 1934. This reduction in corn acreage in 1934, however, is not distributed over the various areas of the state in accordance with the proposed adjustments of the soil specialists, but more nearly according to the flat percentage reduction of 20 percent required by the contract.
TABLE 5. SUMMARY OF EXISTING (1929) AND TENTATIVELY ADJUSTED CROP SYSTEMS FOR THE STATE AND FOR TYPE-OF-FARMING AREAS.

(Subject to revision)

<table>
<thead>
<tr>
<th></th>
<th>State</th>
<th>Area I</th>
<th>Area II</th>
<th>Area III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tillable land* (1000 acres)</td>
<td>27,498</td>
<td>4,534</td>
<td>2,060</td>
<td>6,854</td>
</tr>
<tr>
<td>Percent. distribution</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Inertilled crops‡</td>
<td>40</td>
<td>34</td>
<td>46</td>
<td>47</td>
</tr>
<tr>
<td>Small grains</td>
<td>27</td>
<td>29</td>
<td>37</td>
<td>26</td>
</tr>
<tr>
<td>Tame hay</td>
<td>12</td>
<td>17</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Plowable pasture</td>
<td>18</td>
<td>17</td>
<td>12</td>
<td>16</td>
</tr>
<tr>
<td>Other crops#</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

|                  | Area IV | Area V   | Area VI  | Area VII |
| Tillable land* (1000 acres) | 3,983 | 5,513    | 2,009    | 2,548    |
| Percent. distribution | 100   | 100      | 100      | 100      |
| Inertilled crops‡ | 47    | 38       | 38       | 29       |
| Small grains      | 33    | 22       | 20       | 15       |
| Tame hay          | 6     | 16       | 14       | 20       |
| Plowable pasture  | 12    | 20       | 24       | 30       |
| Other crops#      | 2     | 4        | 4        | 6        |

*Tillable land is total crop land (excl. wild hay) plus plowable pasture.
†Includes idle or fallow land or crop failures.
‡Computed from absolute acreage figures.
§Corn plus soybeans.
EFFECT OF ADJUSTED ROTATIONS ON CROP YIELDS

Even though the crop rotation adjustments are intended to conserve the soil rather than to improve it, crop yields would very likely be affected by the adoption of the recommended rotations, if not immediately, certainly over a period of 10 to 15 years. In some areas crop yields may just hold their own. In others they may have a tendency to increase, in others to decline. The yields of one crop may be affected differently, in direction or degree, from those of another crop. The effect which these suggested crop rotations would have on yields depends on the soil type, on the change in the livestock system they would produce, on the thoroughness with which they would be adopted by farmers, and on many other factors.

The concept of "maintenance of soil fertility" is not amenable to narrow interpretation. On eroded acid land, for instance, applications of lime and manure may be necessary in order to establish legumes and to increase the infiltration rate and water-holding capacity of the soil. These measures may be essential for holding the soil in place. They will, at the same time, increase the productivity of the soil over its present level.

The following estimates of changes in crop yields, which can be reasonably expected in about 10 years from the date of the general adoption of the recommended crop systems, must be considered as rough approximations. They are the result of the combined opinions held by agronomists and farm management experts, all of whom stressed the extremely tentative character of these estimates. It has been the intention of the group not to account for an increase in the general level of management efficiency on the average farm.

Three principal factors have been considered in their influence on crop yields: (a) The position of the respective crop in the adjusted rotations; (b) the application of lime necessary to establish the new rotations; and (c) the relative concentration or dispersion of the respective crop on the better or poorer soils under the new crop system. Besides these factors, several others will exert some influence on yields, of which the most important is likely to be the increased supply of manure provided by an expanded cattle enterprise. The wider use of high yielding varieties and of seed testing is also likely to affect future yields. These two factors, however, have not been considered in the following estimates.

Table 6 shows the yields of corn, legume hay and small grains expected by 1946 if the recommended crop rotations were generally adopted in 1936.

The response of corn yields is smallest in the northeastern dairy area (I), i.e., an increase of 1 bushel or 2.7 percent. The adjustments there provide only for a minor change in the crop
system (see table 5), and, therefore, no substantial increase in yields is expected. In the eastern livestock area (V) with a substantial reduction in corn and increase in legumes, for which liberal lime application is prerequisite, an increase of 5.4 bushels or 12.7 percent is anticipated. In the southern pasture area (VII) the corn acreage reduction implies a distinct concentration of corn on the better soils and an increase in legumes with strong lime applications. There yields are expected to increase by 4.5 bushels or 14.5 percent. The yield increases in the other areas fall between these extremes. For the state as a whole, an increase of 2.8 bushels or 7.4 percent is anticipated.

The small grain yields are likely to be affected in a less specific way. A slight rise of about 2 percent in a given area seems probable. Since the acreage reduction in the higher-yielding north is greater than in the south, an increase of 0.4 bushel or 1.2 percent is expected for the state as a whole.

**TABLE 6. ESTIMATED EFFECT OF ADJUSTED ROTATIONS ON CROP YIELDS.**

*(Crop yields expected by 1946, if adjusted crop rotations are followed.)*

<table>
<thead>
<tr>
<th>Crop</th>
<th>1928-1932 Average (bushels)</th>
<th>Expected by 1946 (bushels)</th>
<th>Change Absolute</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>bushels</td>
<td></td>
</tr>
<tr>
<td>Corn</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>State</td>
<td>37.8</td>
<td>40.6</td>
<td>+2.8</td>
<td>+7.4</td>
</tr>
<tr>
<td>Area I</td>
<td>37.0</td>
<td>38.0</td>
<td>+1.0</td>
<td>+2.1</td>
</tr>
<tr>
<td>II</td>
<td>32.7</td>
<td>33.0</td>
<td>+0.3</td>
<td>+0.9</td>
</tr>
<tr>
<td>III</td>
<td>37.2</td>
<td>40.0</td>
<td>+2.8</td>
<td>+7.5</td>
</tr>
<tr>
<td>IV</td>
<td>39.2</td>
<td>41.0</td>
<td>+1.8</td>
<td>+4.6</td>
</tr>
<tr>
<td>V</td>
<td>42.6</td>
<td>48.0</td>
<td>+5.4</td>
<td>+12.7</td>
</tr>
<tr>
<td>VI</td>
<td>37.3</td>
<td>40.1</td>
<td>+2.8</td>
<td>+7.5</td>
</tr>
<tr>
<td>VII</td>
<td>31.0</td>
<td>35.5</td>
<td>+4.5</td>
<td>+14.5</td>
</tr>
<tr>
<td>Legume hay</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Composite yield)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>State</td>
<td>1.93</td>
<td>1.86</td>
<td>-0.07</td>
<td>-3.6</td>
</tr>
<tr>
<td>Area I</td>
<td>1.77</td>
<td>1.50</td>
<td>-0.27</td>
<td>-15.2</td>
</tr>
<tr>
<td>II</td>
<td>2.18</td>
<td>2.18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>2.12</td>
<td>2.12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td>2.20</td>
<td>2.20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>1.78</td>
<td>1.78</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VI</td>
<td>1.79</td>
<td>1.25</td>
<td>-0.54</td>
<td>-30.2</td>
</tr>
<tr>
<td>VII</td>
<td>1.58</td>
<td>1.08</td>
<td>-0.50</td>
<td>-31.4</td>
</tr>
<tr>
<td>All small grains</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Yields increased by 2%, resulting in the following state averages)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oats</td>
<td>35.3</td>
<td>35.7</td>
<td>+0.4</td>
<td>+1.1</td>
</tr>
<tr>
<td>Barley</td>
<td>28.2</td>
<td>28.6</td>
<td>+0.4</td>
<td>+1.4</td>
</tr>
<tr>
<td>Wheat</td>
<td>18.6</td>
<td>18.5</td>
<td>-0.1</td>
<td>-0.5</td>
</tr>
<tr>
<td>Rye</td>
<td>14.2</td>
<td>14.0</td>
<td>-0.2</td>
<td>-1.4</td>
</tr>
<tr>
<td>Mixed grains</td>
<td>35.4</td>
<td>35.5</td>
<td>+0.1</td>
<td>+0.3</td>
</tr>
<tr>
<td>All small grains</td>
<td></td>
<td></td>
<td>+0.4</td>
<td>+1.2</td>
</tr>
</tbody>
</table>

The yields of legume hay are likely to show no significant change except in the northeast and the south, where decreases of 0.27 ton or 15 percent in Area I, 0.54 ton or 30 percent in...
Area VI, and 0.50 ton or 31 percent in Area VII, are expected due to the dispersion of legumes over less favorable soils than those they occupy now. Although legumes will be pushed onto poorer soils in the other areas, too, the recommended increase in alfalfa will tend to hold the average composite yield of legume hays up.

**FEED PRODUCTION FROM THE ADJUSTED CROP SYSTEM**

Keeping in mind constantly the tentative character of the recommended crop acreage adjustments and their estimated effect on crop yields, it may now be assumed that these proposed adjustments in corn acreages would solve the problem of soil conservation as far as this is possible by adapting properly balanced rotations to soil conditions. The next question is, then, how the new crop system will affect the feed supply produced on the farms.

**TABLE 7. NET CHANGE IN ACREAGE AND PRODUCTION OF FEED GRAINS AND ROUGHAGE RESULTING FROM TENTATIVELY ADJUSTED CROP SYSTEM.**

<table>
<thead>
<tr>
<th>For Iowa</th>
<th>Feed units (Assuming yields expected by 1946)</th>
<th>Feed units (assuming 1928-32 average yields)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acreage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feed grains</td>
<td>-17.6</td>
<td>-14.4</td>
</tr>
<tr>
<td>Roughage (all hay and pasture)</td>
<td>+39.2</td>
<td>+31.8</td>
</tr>
<tr>
<td>Grand total of all feed units produced</td>
<td>- 0.4</td>
<td>- 0.4</td>
</tr>
</tbody>
</table>

Table 7 indicates the net percentage change, from the base year 1929, in total feed grain and total roughage (hay and pasture) acreage and in their corresponding production in terms of feed units. A decrease of nearly 18 percent in the acreage devoted to feed grains results in a reduction of about 14 percent in grain feed units produced, assuming the yields which are expected to be realized under the adjusted crop system. The total acreage used for roughage, including all hay and all pasture, increases 39 percent in excess of 1929, which practically offsets the decrease in feed grains, leaving a net reduction of only 0.4 percent in the total feed units produced. The anticipated increase in corn yields and the great expansion of high-yielding legume acreages largely account for this negligible decline in total feed production after an 18 percent cut in the grain acreage. Assuming no significant changes in yields and applying the 1928-32 average yields to the adjusted crop acreages, the net reduction in total feed production is about 3 percent from a 19 percent decrease in feed grain and a 34 percent increase in roughage feed units.
In either case the effect of the new crop system on the net total feed production is of much smaller significance than its effect on the feed structure, that is, the relative proportions of the various kinds of feed. While in 1929 the ratio of roughages to feed grains was 1:2.3, this ratio under the adjusted crop system (assuming expected yields) is much narrower, namely, 1:1.5. This means that the farmer will have only about two-thirds as many feed units in grain for each feed unit in roughages as he used to have under the old crop system.

In terms of the percentage of total feed units in the various classes of feed, the proportion of corn is changed from 55 to 46 percent, of small grains from 15 to 12 percent, of hay from 10 to 18 percent, and of pasture from 20 to 23 percent of the total amount of feed units produced, as shown in table 8.

This narrowing of the roughage to grain ratio appears even more accentuated if the outshipments of cash grains are considered. It can well be assumed that Iowa will remain a grain surplus area after the crop acreage adjustments have taken place. In this study the assumption was made that each county continues to sell or buy the same net percentage of its production of corn and oats which it sold or bought during the years 1928-1932. The main argument for this assumption is the fact that the annual shipments tend to be more stable in terms of percentage of production than in terms of absolute quantity.

It is, of course, doubtful whether the same percentage of the corn and oats production will be shipped out after the reduction under the new crop system. The main advantage of this assumption is its simplicity. There are, in the main, two antagonistic forces pulling in opposite directions: the higher feed grain prices resulting from a general reduction in supplies will tend to induce cash grain farmers to continue selling grain; and the

<table>
<thead>
<tr>
<th>Total produced under*</th>
<th>Retained on farm under**</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1929</strong></td>
<td><strong>Adjusted</strong></td>
</tr>
<tr>
<td><em>crop system</em></td>
<td><em>crop system</em></td>
</tr>
<tr>
<td>Total feed units (in thousands)</td>
<td>766,583</td>
</tr>
<tr>
<td>Percentage of total feed units in:</td>
<td></td>
</tr>
<tr>
<td>Corn</td>
<td>100.0</td>
</tr>
<tr>
<td>Soybeans</td>
<td>54.5</td>
</tr>
<tr>
<td>Small grains</td>
<td>0.1</td>
</tr>
<tr>
<td>Hay</td>
<td>15.0</td>
</tr>
<tr>
<td>Pasture</td>
<td>10.4</td>
</tr>
<tr>
<td></td>
<td>20.0</td>
</tr>
</tbody>
</table>

*Assuming 1928-32 average yields under the 1929 crop systems and yields expected by 1946 under the adjusted crop system.
**Assuming the same net percentage of corn and oats production shipped out as during the period 1929 to 1932.

40 See p. 358, and R. C. Bentley, op. cit. None of the type-of-farming areas in Iowa are net deficit areas in corn or oats.
greater roughage supply will require more feed grains to be retained on the farm so as to balance the feed rations. Where the resultant will fall depends principally on the price relationship between feed grains and livestock products, and on the ability of farmers to change their farming system in accordance with these price relationships.

Table 8 indicates the feed structures under the old and the new crop systems after allowances for net shipments of feed grains have been made. It should be noted that the total amount of feed units retained on farms is larger under the adjusted than under the old crop system by about 2 percent for the state as a whole. This increase may, of course, be considerably greater for the cash grain areas (IV and II) for which the adjusted crop system may imply an expansion of the livestock enterprises in order to utilize the larger supply of non-marketable roughage.

CHANGES IN LIVESTOCK SYSTEMS

It has been said of the recommended crop adjustments that they must be considered extremely tentative, particularly with reference to the acreages of crops other than corn, as very little consideration of local trends and farm management conditions has entered into the process of their determination. This limitation holds even truer for the recommended adjustments in the livestock system. Fitting crop rotations to soil conditions in Iowa is more distinctly a problem of technical consideration, while fitting livestock systems to given feed supplies is predominantly a problem economic in character. One may assume that the shift from corn to grasses may imply certain shifts in the livestock system, but to what extent, quantitatively, the additional roughage supply is to be absorbed by dairy cows, beef cattle, sheep and horses, and to what extent a reduction in corn acreage will be reflected in the volume of hog production constitutes an economic problem of extreme intricacy.41

Obviously, any one livestock system fitted to the new crop system represents only one alternative out of many to utilize the new feed structure. There is no unique solution to this problem as hay and pasture can be fed to beef as well as dairy cattle, sheep and horses, and the available supply of concentrates can be distributed to the different livestock classes in various proportions, depending largely upon the price relationship between feed grains and livestock products on the one hand and the price relationship between the products of the competing

---

41 Recent studies of crop and livestock systems on sample farms seem to indicate that a reduction in corn acreage may, for Iowa, not reduce hog production. In fact, a reduction in grain production of about 10 percent and a corresponding increase in roughage production may not change the livestock system for Iowa as a whole.
livestock classes on the other hand. This perhaps holds true for Iowa more than for any other state, as the livestock system in Iowa is exceedingly flexible. The many herds of dual purpose cattle facilitate the shifting of the emphasis to dairying or beef production in response to changes in price relationships, and the volume of hog production is easily expanded or contracted because of the short periodicity of the hog enterprise. Moreover, grains can be substituted for roughages within certain limits which increases further the flexibility in adapting livestock systems to feed structures.

The logical approach to the problem of adapting livestock systems to the new feed structure entailed by the adjusted crop system, then, would be to assume several sets of prices, and to work out, for each of them, a corresponding livestock system. The initial price structures which are necessarily hypothetical could then be tested as to their consistency with the supply relationships of livestock products resulting from the respective livestock system. That livestock system which is most nearly in correspondence with its respective set of prices according to its ensuing supply of livestock products would be the one with greatest probability of realization under the new crop system.42

In a qualitative sense, there are two extreme alternatives for absorbing a shift from grain to grasses in the livestock system of Iowa. One is to reduce grain shipments off Iowa farms and to widen the grain to roughage ratio in the feed rations of cattle and horses, thereby economizing on grain consumption in these enterprises and concentrating it in the hog enterprise so as to maintain maximum hog production. The other is to continue out-shipments of grain and to retain or even narrow the grain to roughage ratio in the feed rations of cattle at the expense of the hog enterprise, thereby drastically reducing hog production and expanding dairy or beef production or both. A continuous series of compromises is possible between these two extremes. Present types of farming, farm size and character of land tenure, principally, will decide which compromise is most feasible for any given locality, dependent, of course, upon price relationships.

Time did not allow approaching this complex problem ade-

42 It goes without saying that in setting up the various initial price sets the character of the prospective demand for the various livestock products must be assumed to remain essentially the same for these alternative price sets. In other words, these hypothetical price sets should be determined on the basis of anticipated supply relationships of the livestock products assuming no essential change on the demand side. If such a change in demand, for instance subsequent to a possible revival of foreign trade, is to be considered two groups of price sets should be assumed, such as one for the demand situation under greatly restricted foreign trade, and another for the demand situation under greatly stimulated foreign trade.
An attempt, however, has been made to estimate one possible adjustment of the livestock system to the feed supply provided by the new crop system. While the adjusted crop rotations have the character of recommendations, inasmuch as they should be followed if proper soil conservation is to be achieved, the adjusted livestock system is an estimate of what could be done in utilizing the new feed supply.

The approach of the Animal Husbandry Section was to distribute the "new" feed supply to the various classes of livestock on the basis of feed rations that have proven profitable in the past. Taking out of the total feed available enough to maintain approximately the present horse population and poultry production under the assumption that no significant change would occur in these two livestock enterprises, the remaining hay and pasture were disposed of by providing the number of cattle and sheep units necessary to utilize adequately the roughage, and grain was apportioned to them sufficient to make up a well-balanced feed ration. The residual amount of grain, then, determined the volume of the hog enterprise.

The resulting adjustment in the livestock system strongly inclines toward the second alternative outlined above: a reduction in pork production and an increase in milk and beef cows. The question of the extent to which significant changes in the average efficiency in feeding operations should be assumed in developing agricultural adjustment programs will be discussed later (see page 407).

It should be emphasized again, however, that if the recommended crop adjustments were to be generally adopted, the changes in livestock production imputed by such a rather arbitrary distribution of the "new" feed supply to the various kinds of livestock would not necessarily occur; the suggested changes merely indicate one of the physical possibilities in utilizing the new feed structure. Further study of prospective prices, farm labor distribution and landlord-tenant relationships may show the likelihood of a better maintained volume of hog production and a less grain-intensive cattle enterprise, following more the direction of the first alternative suggested above.

It has been stated previously that a comparison of feed structures in terms of percentage distribution of feed units by kinds of feed, and livestock systems in terms of percentage distribu-

---

43 A recent study of some phases of this problem is being published by the Agricultural Experiment Station. The conclusions of the forthcoming study point in a different direction from those suggested by the Animal Husbandry Section in the present study. Due to partial substitutability of roughage for grain and to the possible reduction in out-shipments of grain, a shift from corn to grass acreage in the contemplated order of magnitude may not materially affect kinds and volumes of livestock production in Iowa.

44 For the detailed set-up of livestock units and the feed rations employed, see appendix, work sheets 4, 5 and 6. The report of the Animal Husbandry Section was prepared by C. Y. Cannon and C. C. Culbertson.
tion of animal units by kinds of livestock between counties reveals their interrelationship fairly well, considering the crudeness of the original data. Hence, if one could find a county which now has a feed structure similar to that resulting from the adjusted crop system, one might be justified in considering the livestock system of that county as one of the possibilities of utilizing the new feed structure.

TABLE 9. POSSIBLE LIVESTOCK ADJUSTMENT BASED ON COMPARISON OF EXISTING (1929) FEED STRUCTURES AND LIVESTOCK SYSTEMS.

<table>
<thead>
<tr>
<th>Classes of feeds</th>
<th>State adjusted feed structure</th>
<th>Jackson County existing feed structure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Percent of total feed units retained on farm</td>
<td></td>
</tr>
<tr>
<td>Corn and soybeans</td>
<td>45</td>
<td>44</td>
</tr>
<tr>
<td>Small grains</td>
<td>11</td>
<td>9</td>
</tr>
<tr>
<td>Hay</td>
<td>19</td>
<td>16</td>
</tr>
<tr>
<td>Pasture</td>
<td>25</td>
<td>32</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Livestock enterprises</th>
<th>State existing livestock systems</th>
<th>Jackson County existing livestock system</th>
<th>State adjusted livestock system derived from Jackson County</th>
<th>Percentage change under adjusted system</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Percent of total animal units)</td>
<td>(Percent of total animal units)</td>
<td>(Percent of total animal units)</td>
<td>(Percent of total animal units)</td>
</tr>
<tr>
<td>Hogs</td>
<td>37</td>
<td>32</td>
<td>44</td>
<td>-14</td>
</tr>
<tr>
<td>Poultry</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>-20</td>
</tr>
<tr>
<td>Cattle</td>
<td>38</td>
<td>48</td>
<td>44</td>
<td>+16</td>
</tr>
<tr>
<td>Sheep</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Horses</td>
<td>17</td>
<td>14</td>
<td>17</td>
<td></td>
</tr>
</tbody>
</table>

It so happens that Jackson County has a feed structure very similar to the adjusted feed supply structure of the state, as table 9 indicates. If, for the state as a whole, no change in horses and sheep is assumed, their proportions in the livestock system of Jackson County may be roughly adapted to those of the state by adding three animal units out of a hundred to horses and one to sheep and reducing those of cattle by four. This implies only a shift within the roughage-consuming class of livestock without affecting the concentrate-consuming classes, hogs and poultry. The comparison of the state to the modified Jackson County livestock system indicates a reduction in the proportion of the hog enterprise from 37 to 32, of the poultry enterprise from 5 to 4, and an increase in the proportion of the cattle enterprise from 38 to 44 percent of the total animal units. Assuming for the state as a whole no significant change in the total feed units retained on the farm under the new crop system and no change in the feed unit consumption per animal unit, the above changes in the livestock system would represent a reduction of about 14 percent in hogs and 20
percent in poultry, and an increase of about 16 percent in cattle.

This last adjustment in the livestock system represents just another of the possibilities in utilizing the new feed structure. This livestock adjustment may, in contrast to the adjustment proposed by the Animal Husbandry Section, come closer to the first extreme alternative stated on page 395, that is, to maximize hog production. It implies that price relationships remain about what they were during 1929 and several preceding years, and that Jackson County is fairly typical for the state as a whole with reference to general farming conditions. Since shifts in crop systems, however, will change relationships between prices of the various kinds of feed, and since changes in the livestock system of a whole state or region necessarily imply changes in relationship between prices of various livestock products, it cannot be concluded that the "new" livestock system for the state will approach the one now found in Jackson County. The great flexibility in adapting livestock systems to any given feed structure renders price relationships and institutional factors rather than the physical composition of the feed structure the chief determinants.

In order to arrive, however, at a rough approximation of what an adjustment in the livestock system may possibly be the procedure just outlined may, after considerable refinement in the line of reasoning as well as in the data used, prove helpful in later studies in this field. The discussion of the procedure, therefore, is intended to suggest a method of approach worthwhile to be tested out rather than to present definite conclusions regarding the best feasible livestock adjustment.

ECONOMIC EVALUATION OF THE ADJUSTMENT PROBLEMS IN THE VARIOUS TYPE-OF-FARMING AREAS OF IOWA

So far, the discussion has centered around the methodology of determining desirable crop adjustments and their possible effects on feed supply, feed structure and livestock production.

It should again be emphasized that soil conservation as an objective of public policy is not an absolute nor a purely physical concept entirely outside the sphere of costs and prices. The tentatively proposed land use adjustments for Iowa, in essence, represent the goal, the highest degree of soil conservation obtainable under generally prevailing farming conditions. As a first approximation it was necessary to omit local economic conditions in determining these adjustments.

A brief discussion of the general economic implications of the land use adjustments proposed for each type-of-farming area follows:
The Northeastern Dairy Area (I) apparently has the best balanced crop systems of any of the major areas of the state. Although several of its principal soil types, particularly the Fayette and Clinton soils and the more rolling phase of the Carrington soils, are susceptible to erosion, the crop rotations used are, in general, fairly well adapted to soil conditions and prevent serious erosion losses rather effectively. Physical and economic conditions have favored the development of the dairy enterprise. Dairying requires much hay and pasture, and more oats than corn for concentrates, and a fairly stable type of farm operators. The percentage of tenancy in northeastern Iowa is the lowest of any area in the state, and the stock-share lease is commonly used, characterizing the close and stable interrelationship between tenant and landlord. Moreover, the dairy enterprise returns a considerable part of the plant foods removed by the crop back to the soil in the form of manure.

All these characteristics of the dairy enterprise facilitate erosion control and adequate soil conservation practices. A small reduction in the intertilled crop acreage (corn) seems necessary (see table 5), although the tentatively proposed adjustments call for reductions in corn of over 20 percent in some counties (Clayton, Buchanan, Floyd), indicating that in some localities major changes seem desirable. For the area as a whole, however, apparently the present crop pattern is already taking care of the soil resources to a fairly satisfactory degree.

The Central Cash Grain and the Northwestern Cash Grain and Livestock areas (IV and II) consist predominantly of fairly level to gently rolling Webster and Clarion soils. Here, the problem of soil conservation arises from nutrient and organic matter depletion rather than from soil erosion. A continuous alternation of 1 or 2 years of corn and 1 year of oats is not uncommon. These two areas have the highest percentage of their tillable land in grains (80 percent) and the lowest in hay and plowable pasture (18 percent).

The desirable crop adjustments lie in the direction of shifting from small grains to grasses and legumes rather than of reducing corn. The small grain acreage under the tentatively proposed adjustments is reduced by 34 percent in the central and 44 percent in the northwestern area, while intertilled crop acreages are cut only by 17 and 12 percent, respectively. This severe reduction in the small grain acreage, however desirable it may be from the viewpoint of fertility maintenance, is likely to be difficult to achieve under present conditions. These areas not only have the highest percentage of tenancy in Iowa,

These two areas are possibly better adapted to a more general use of sweet clover as a green manure crop than other areas in this state. This practice, if it should prove feasible as a general rule, would give farmers an opportunity to keep a fairly high acreage in grains and still maintain a reasonable nitrogen and organic matter balance in the soil.
but also the greatest mobility of tenants. They have the highest oat yields, the cash grain type of farming is predominant, and the average farm size in the northern part runs close to 200 acres. All these factors offer strong resistance to the complete adoption of the proposed crop adjustments.

Since the process of soil depletion, however, is of a much slower and economically less serious nature than that of erosion, the urgency for public action to bring about speedy and far-reaching adjustments is not as great as in other areas. In these two areas particularly, adequate soil conservation may be achieved largely by educational work centered upon the paramount problem of instability of land tenure.

Looking ahead several decades and assuming gradual adjustments in these areas in the directions proposed, it is probable that it is in this section of the state where an increase in farm population and in the number of farms could be absorbed most readily, or even may be necessary in order to effectuate the proposed land-use adjustments. A marked shift from cash grain to dairy farming and beef feeding implies higher labor requirements and consequently fewer acres per family-sized farm.

In the three areas thus far discussed, effective educational activity is probably the most adequate policy from the viewpoint of public interest in soil conservation.

The Western Livestock Area (III) is on the verge of becoming a serious erosion problem area. It comprises the section of the state which is being most heavily exploited. It has the highest percentage of tillable land in corn (47 percent) under conditions of rolling topography and not infrequent intense rainfalls. The originally deep and fertile layer of Marshall silt loam is rapidly being eroded and depleted.

In contrast to the northeastern dairy and the northwestern and central cash grain areas (I, II and IV) it is of extreme importance for this area that an effective land use adjustment be brought about in order to prevent the still highly productive soils from reaching the breaking point of their natural fertility. From the viewpoint of public policy, it seems wise to expend efforts and funds now to keep the productive power of the land intact rather than to attempt to rehabilitate it after the land resources are depleted. Funds for an active program of soil conservation may quite conceivably find a high degree of efficiency in the southern half and the western fringe (except the Missouri bottom) of this area. Large gullies are developing there at a progressive rate, and the depth of the surface soil has been greatly reduced by sheet erosion.

The proposed crop adjustment calls for a 26 percent reduction in intertilled crops, thereby lowering the proportion of tillable land in intertilled crops from 47 to 35 percent (see table
Hay and plowable pasture are increased from 24 to 44 percent of the tillable land, representing a percentage change of 83. The fact that alfalfa is the best hay crop in this area, particularly in the central and northern part, may tend to hamper the large increase proposed in the hay acreage, since this would result in an excessive supply of hay because of the high yields of alfalfa and in an unfavorable seasonal labor distribution on the farm.

The forces of resistance to necessary land use adjustments are strong and, as in the cash grain areas, predominantly economic in character; yet the need for soil conservation is much more urgent. Tenancy is high and mobile, although perhaps not to the same degree as in the cash grain areas. Farmers have not as yet become aware of their soil losses. In addition moisture is more distinctly a limiting factor than in any other area. Permanency as well as rotation pastures, with the exception of sweet clover, often dry out during the summer. This is unfavorable for the expansion of the cattle enterprise, particularly of dairying. A shift from corn to grasses and legumes, if it occurs, is likely to be absorbed largely by increased beef feeding and raising.

The East Central Livestock Area (V) is confronted with erosion problems beginning to attain serious dimensions in several parts of the area, particularly in the central and southeastern sections. The Tama soils, comprising almost one-third of the area, are similar in topography and texture to the Marshall soils of the western area (III), but have generally a shallower surface layer and a somewhat lower infiltration rate and water-holding capacity. The Clinton soils, covering over one-fifth of the area, are steeper and more erodible. That would tend to make this area more subject to erosion than the western area were it not for the fact that it is less heavily cropped and probably receives fewer torrential rainfalls. The proportion of 38 percent of the tillable land in intertilled crops compares with 47 percent in the western area. The fact that the crop systems in the east central area are at present better adapted to soil conditions may be partly attributed to the more conspicuous form of gully erosion, “finger gullies,” on the Tama and Clinton soils, in contrast to the insidious sheet erosion dominant on the Marshall soils. Gullies remind the farmer of his erosion problem every time he crosses them with his plow, while sheet erosion easily escapes his attention.

Substantial adjustments, however, are still necessary in this area for the requirements of soil conservation. Comparing the present 38 percent of tillable land in intertilled crops in this area with the adjusted 38 percent in the northwestern area (II)
and 35 percent in the western area (III), the eastern area seems too high in corn relative to the erosiveness of its land. The proposed adjustments provide for 32 percent of the tillable land in intertilled crops, which puts the crop system of this area relative to soil conditions into a proper relation to those of the other areas. The change represents a reduction of 16 percent in the intertilled crop acreage without affecting small grains and an increase in hay and rotation pasture of 17 percent (see table 5). The fact that this area has the highest corn yields and that application of lime is required in many cases to secure a good stand of legumes may tend to retard the adoption of the adjustments.

In general, the farmers in this area seem to do a relatively good job in adjusting their rotations to soil conditions. Although the hog enterprise is most strongly developed (about 40 hogs per 100 acres of farm land as an average for the area), the cattle enterprise possesses a very appreciable volume and runs second only to the northeastern dairy area in the density of the cattle population (7.1 animal units per 100 acres of farm land). The cattle herds are largely of a dual purpose type and the emphasis can readily be shifted to beef or dairying. About one-third of the average farm is in pasture of fairly high productivity and dependability. Little cash grain farming is practiced. Tenancy is high but seems to be of a more stable character as compared with that of the Northwest.

These are some of the facts which may lead one to the conclusion that the adoption of the moderate adjustments in crop and livestock systems desirable for soil conservation are not likely to face as serious difficulties in this area as in the western and southern areas and may possibly be obtained at relatively moderate social cost. Here, as well as in all other areas, the tenancy situation will probably be the most important single factor, outside of prices, standing in the way of a general adoption of soil conservation practices.

The Southern Pasture Area (VII) constitutes the region of most serious land use maladjustments in Iowa. The breaking point of natural soil fertility has, in all probability, been passed on much of the land in the area. Need for stabilization, if not increase, of soil productivity is extremely urgent, if the land is to be saved from dropping below the margin of agricultural production. Since the area is densely settled and the population has so far been practically able to support its public services and institutions, public funds spent effectively on soil conservation practices.

It is true that the population has declined in many counties of the area, and that some of their institutions and public services are deteriorating. Their schools, roads, hospitals, etc., are the poorest in Iowa. In general, however, the area is not as yet submarginal for arable farming and compares favorably with such truly submarginal areas as the northern cut-over lands or the southeastern Appalachians.
conservation would constitute, in all probability, a good investment. The social cost of subsidizing this area, after it had become truly submarginal for arable farming, would likely be much higher, not to speak of the cost involved in evacuating large sections of the area and retiring it from farming.

Soil types, character of rainfall and topography, farm size and type of farming, land tenure and debt pressure—all these factors contribute to excessive soil losses year after year, and to making desirable adjustments difficult. This area already has the smallest proportion of the tillable land in intertilled crops of any area in the state (29 percent), but this proportion is still too high to prevent progressive erosion. The farmers have been forced by nature to keep their corn crop acreage down. Hence, the proposed adjustment, calling for a 13 percent reduction in intertilled crops from the already low 1929 acreage, presents a difficult problem to the farmers in this area.

In no other section of the state are farmers as conscious of their soil problems as in this area. In several counties they even have organized county soil conservation associations. At the same time, in no other section are adequate adjustments so difficult to bring about as in this area. The average soil productivity is low, alternative opportunities for replacing corn by other profitable crops are lacking, and many farms are too small to allow shifting toward less intensive crops and keep on supporting the family. In addition to these three factors peculiar to this area, the same sets of economic and social forces which impede the establishment of conservational crop rotations and farming practices throughout the Corn Belt are active with maximized intensity. The average farm size is 151 acres, producing about 2,600 feed units as compared with a size of 161 acres and a total feed unit production of 4,000 per farm for the state as a whole. It is obvious that a moderate reduction from this low level of output per farm is much harder to bear, at least for the transitional period of adjustment, than a considerably more drastic reduction would be in any of the regions with a higher output per farm.

Preserving the present pattern of farm sizes and establishing soil conserving rotations can hardly be done without subsidizing a substantial number of farmers for a considerable period of time. Since the proposed crop adjustments in this area are expected to increase corn yields substantially (over 14 percent) after a period of about 10 years, the aggregate feed output of

---

[48] The average farm size would have to be around 230 instead of 151 acres if the southern Iowa farmer were to produce on his farm as much feed as the average Iowa farmer. Under the adjusted crop system, the farm would have to be even larger to reach the state average in feed production.
the area may eventually be even increased after the adjustment has had its full effect.49

This area is not naturally suited to intensive dairying. The pastures are dry in summer, the quality of hay is relatively poor, oats yields are low, the water from the wells is too warm in summer to cool cream, the roads are poor and expensive to improve, and there are no large cities nearby. This area, in general, can hardly compete with northeastern Iowa and Wisconsin and Minnesota in the national market for dairy products.

The type of farming naturally suited to the physical condition of the area is the raising of beef cattle and the fattening of a limited number of steers and hogs, and such a type of farming requires a larger farm unit than 150 acres. If the tenancy problem is the most serious handicap to soil conservation practices in the other areas, it is the under-sized farm unit in combination with the tenancy problem in this area.50

THE REGIONAL AGRICULTURAL ADJUSTMENT PROJECT OF 1935

Long before the Supreme Court in January, 1936, declared the production control programs of the AAA unconstitutional, leaders in the AAA had been working toward the development of a long-time agricultural adjustment program centered around “soil conservation and good farm management practices” as principal goals. Unlike the problem of adjusting supply to demand, which is essentially national in scope, the problems of soil conservation and farm management are inherently regional and local in character.

OBJECTIVES OF THE PROJECT

In March, 1935, the Secretary of Agriculture invited the agricultural experiment stations and extension services of all 48 states to cooperate with the U.S.D.A. Bureau of Agricultural Economics and the Program Planning Division of the AAA in a nation-wide “Regional Agricultural Adjustment Project.” The general objectives of these regional research projects under cooperative agreements between the state experiment stations

Of course, some farmers are exceptional managers who succeed in overcoming all these difficulties, whose managerial skill compensates for physical and economic disadvantages of their environment. In determining regional adjustments, however, it is the managerial ability of the average farmer that counts. For instance, several farmers in southern Iowa support their families at a decent standard of living on 80 acres of rolling Shelby soil under well-balanced extensive crop rotations, by utilizing their family labor through a highly intensive dairy enterprise. Other farmers keep their land in good shape by raising turkeys on purchased feed so as to relieve the pressure upon the soil resources. Others develop different specialties and side-line enterprises to complement their income.

and the U.S.D.A. have been formulated by Dr. H. R. Tolley, then chief of the Program Planning Division, as follows:

1. To determine for the various regions, and type-of-farming areas in each state and region, the nature and extent of desirable adjustments in agriculture, including combination of crops, pasture, and livestock on individual farms, that would (a) maintain or increase real income to producers; (b) conserve the land, and improve soil productivity as far as possible, consistent with rural well being and with national objectives and policy for the conservation of agricultural resources; and (c) contribute to the attainment of national goals in the production of specific crops and classes of livestock consistent with (a) above and within or in addition to the adjustments referred to under (b).

2. To determine criteria and procedure for bringing about the desired adjustments.

More specifically, the task of the research workers in the states was:

1. To differentiate the agriculture of the state into type-of-farming areas or subareas, having similar conditions of soils, crop and livestock systems and farm practices.

2. To assemble, coordinate and interpret existing data and judgment of agricultural specialists, in order to determine the nature and extent of desirable adjustments in farming in the different type-of-farming regions and areas within each state from the standpoint of good farm management practice and conservation of agricultural resources.

3. To estimate the probable change in terms of acreage and volume of crop and livestock production, if the adjustments indicated as desirable were carried into effect, and to determine their probable effect on farm income.

All 48 states responded to the Secretary’s invitation and initiated this project promptly with the understanding that they would submit their state reports by the end of September, 1935.

---

**Footnotes:**

51 H. R. Tolley, Regional Adjustment and Democratic Planning, Address delivered before the meeting of the Association of Land Grant Colleges at Washington, D. C., Nov. 20, 1935.

52 During the end of March and beginning of April, four regional conferences were held by the directors of experiment stations, extension services and representatives of the U.S.D.A. M. L. Wilson, Under-Secretary of Agriculture, H. R. Tolley, Chief of the Program Planning Division, and F. F. Elliott, Chief of the Production Planning Section, conducted the meetings.

The United States Department of Agriculture contributed $200,000. Funds from AAA were allotted to each state and were supplemented by the experiment station funds made available for this project. The staffs of the Farm Management Division of the Bureau of Agricultural Economics and of the Production Planning Section of the AAA assumed the function of coordinating the work in the various states, and every effort was made to secure comparable methods of procedure and results.

At the end of August, a second series of four regional meetings began, each lasting a week. The preliminary results, state by state, were discussed and assumptions, procedures and conclusions between the states included in the region were examined. Here and there, wherever type-of-farming areas crossed state lines, the proposed adjustments of the states involved were subjected to special scrutiny and in some cases modifications in recommendations were agreed upon. The Production Planning Section of the AAA and the Farm Management Division of the Bureau of Agricultural Economics, with the council of regional representatives of the experiment stations, summarized and combined the final state reports into regional and national totals.
It goes without saying that in these 6 months of work, no matter how intensively and conscientiously it was performed, nothing more than a good start has been made in the development of a long-time agricultural adjustment program.

BASIC ASSUMPTIONS

Some of the fundamental difficulties of such an undertaking will be briefly considered—difficulties which have not been adequately met under this project and which deserve most serious attention in future regional land use adjustment research.

First of all, the definition of the two ultimate objectives of soil conservation and good farm management practices is far from being clear-cut. Such vague concepts are suitable only for arriving at a very crude first approximation in determining desirable agricultural adjustments. Let us consider what assumptions these general objectives imply.

"The specific task which the research workers in the 48 states undertook during the summer and fall just past was to recommend systems of farming or ranching for each of the type-of-farming or ranching areas in the United States which would check or prevent soil depletion and soil erosion and tend to encourage the adoption of those practices which lower costs of production. In addition, the effect of the adoption of these systems of farming upon crop and livestock production was estimated.

"Attention was centered primarily upon soil conservation, and the recommendations with respect to systems of farming and methods of production were made without giving full consideration to the other economic factors involved and must be so interpreted. Of course it is impossible, or at least almost impossible, to separate ourselves from the economic environment in which we exist, and as a result it should be recognized that certain tacit assumptions with respect to prices, standards of living, and population were generally accepted. That is, it was generally assumed, as was intended, that the prices of the main agricultural commodities would continue at such a level as to allow the farmers in the major agricultural regions to follow the same general type of farming as in the past. In addition, local price and supply situations with respect to milk production and certain specialty crops were generally recognized and some of the recommendations were modified as a result, especially in the northeast. And, in the south, the recommendations were apparently influenced to some extent by a recognition of the social problem raised by an increasing farm population, industrial depression, and the need for widespread rural rehabilitation."53

This is one of the most concise statements of the concepts and assumptions underlying the work done under this project. It

---

53 Oris V. Wells: The Regional Adjustment Project. Production Planning Section, AAA, Dec., 1935. (Mimeo.) Italics are mine.
was formulated after the completion of the work, and it is safe to say that the issues involved were even less clearly defined in the minds of most of the research workers at the time the project started than they appear in this statement. Yet, all that is said about the concept of soil conservation is to recommend farming systems “which would check or prevent soil depletion and soil erosion,” and about good farm management, it is “to encourage the adoption of those practices which lower costs of production.”

Soil conservation is, in a relative sense, a problem more physical in character than is farm management. Despite the complexity of the conservation problem and its economic implications, it is relatively easier to establish objective standards of soil conservation practice for a given area and from a long-time viewpoint than it is to establish such standards of farm management practices for the average farmer in a given area. The soil can be conserved under many different farming systems, and in any given area a great variety of farm management practices is employed which do not significantly affect the problem of soil conservation. This second objective, good farm management, is, however, essentially of economic character and should be conceived as an objective distinct from that of soil conservation.

The concept of “farm management” comprises two different kinds of activities. The one refers to the proportional combination of enterprises in a given farm unit, that is farm organization, the other to the technical efficiency within each enterprise. The one refers to crop and livestock systems, the other to crop yields per acre, milk produced per cow, bushels of grains fed per 100 pounds of gain, etc. In both phases of farm management, the preference and managerial abilities of the individual farmer are factors of primary importance. These statements, elementary as they are, have a significant bearing on our problems of agricultural adjustments.

If “good farm management” is to be made a primary objective in developing regional adjustment programs, it should be clearly understood which phases of farm management are to be included in the objective. For instance, it could be reasonably argued that the improvement of operating efficiency is an objective for educational policies rather than for programs of subsidiary action designed to correct maladjustments that lie beyond the control of the individual farmer. The fact that not every farmer attains the highest possible level of technical efficiency in his operations can hardly be called a regional maladjustment. The same arguments hold true for organizational efficiency, although to a more limited extent. Here, too, the fact that in a given area not every farmer uses the optimum combi-
nation of enterprises does not constitute a regional maladjustment and, therefore, does not call for an adjustment program, but rather for educational activities.

There may be areas, however, where due to circumstances outside the control of individual farmers the majority of farmers do not follow the farming systems which would be best adapted to the economic and physical conditions of the area. According to the commonly accepted philosophy of economic behavior, the farmers always tend to use their resources so as to realize the maximum aggregate return from them. Yet, there may be counteracting tendencies of a general and long-lasting nature which hinder the individual farmer in adjusting his farming system according to the "law of maximum utilization of resources." To the extent to which these counter tendencies are individualistic in nature, such as lack of knowledge or managerial ability, they constitute legitimate issues for educational policies, but not for adjustment programs. If they are, however, of an institutional character, such as landlord-tenant relationships, lack of adequate credit facilities, traditional prejudices, competitive derangements, etc., they clearly fall within the scope of long-time agricultural adjustment programs.

It can easily be seen that the question of adequately defining the farm management objective in agricultural adjustment is extremely intricate.

EVALUATION OF THE RESULTS OF THE REGIONAL ADJUSTMENT PROJECT

Regarding the results of the Regional Adjustment Project, those recommendations based primarily on the farm management objective are probably less comparable between states, and less dependable in their quantitative aspects than are those based primarily on the soil conservation objective which is of more physical character. These two adjustment objectives apply to the various agricultural regions with very different degrees of emphasis. Soil conservation constitutes a major problem only in areas where the natural soil resources are being unduly tapped under the present farming systems, as is the case in large sections of the corn, wheat and cotton belts and western ranges. It is no accident that the recommendations for these areas are relatively decisive, are clear-cut at least in the directions of the proposed adjustments, and bear the earmarks of considerable confidence of their originators.

In the north central and northeastern dairy states, in the western and southern irrigation areas, truck crops and fruit regions, soil conservation as an agricultural problem is decidedly
of minor importance. Here the recommendations are based primarily on the objective of "good farm management," vaguely defined and in many cases obviously proposing more or less arbitrary increases in operating efficiency as well as organizational efficiency. The major maladjustments in many of these areas may be neither the misuse of land nor inadequate farming systems, but may be caused by defects in the marketing system or in the systems of local government and taxation. All these are problems that have tacitly or explicitly influenced the research workers in drawing up their recommendations as has been stated in the above quotation from Mr. Well's paper (see p. 406). But the time allotted to this project was too short adequately to analyze these problems. Consequently, the recommended production adjustments for these areas are necessarily less decisive, less clear-cut in directions and degrees of adjustments than are those for the areas where soil conservation constituted the principal objective.

Returning to the adjustment problems of the Corn Belt, under relatively homogeneous conditions and with soil conservation as the main issue, differences in basic assumptions between the various states exist. Some states are more optimistic than others regarding the acreage of corn their respective soils can reasonably stand. Some states accounted for increases in average operating efficiency, while others attempted to keep the level of efficiency constant. Some states assumed lime applications to their acid soils every 5 years, others every 10 years. Opinions differ regarding the relative soil-building merits of sweet clover as a catch-crop which can hardly be fully ascribed to differences in rainfall and soil conditions. Economists and specialists in agronomy and animal husbandry from adjoining states should discuss these problems more thoroughly and agree on clearly defined objectives and basic assumptions in undertaking such revisions and refinements.

"On the whole, however, the results of the regional adjustment project should be accepted as the best judgment of the agricultural economists and crop and livestock specialists in the 48 state experiment stations with respect to the changes in systems of farming and in farming practices which are needed to promote efficient farm management and soil conservation, and to the effect of such changes upon the acreage and production of the chief field crops and the number and production of the major classes of livestock. Although some of the recommendations for the 700 type-of-farming areas involved are subject to further revision, the chief recommendations and the production totals for the major areas may be accepted as substantially correct since they will not be materially changed."54

Table 12 offers a general survey of the directions and the order of magnitude of adjustments in the acreages and production of the major Corn Belt crops and livestock products that would result from the proposed crop and livestock systems for the country as a whole, the North Central States comprising the Corn Belt, and Iowa. 55

The various state studies under the Regional Agricultural Adjustment Project of 1935 are necessarily of a very tentative nature. Possibly the most important results of these 6 months' studies are the many crucial questions they have brought to the fore, and the stimulating experience of state, regional and federal co-operation in a unified and vital research problem on the one hand, and of intimate and systematic co-operation of the various branches of natural and social sciences on the other.

### TABLE 10. PROPOSED LONG-TIME ADJUSTMENTS IN ACREAGES AND PRODUCTION OF MAJOR CORN BELT CROPS AND LIVESTOCK PRODUCTS FOR THE U. S., THE NORTH CENTRAL STATES AND IOWA.*

<table>
<thead>
<tr>
<th>Acres of Corn</th>
<th>Oats and barley</th>
<th>Hay</th>
<th>Number of all cattle</th>
<th>Cwt. of beef and veal produced</th>
<th>Number of milk cows</th>
<th>Gallons of milk produced</th>
<th>Cwt. of hogs produced</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>-12</td>
<td>+19</td>
<td>+10</td>
<td>+8</td>
<td>+13</td>
<td>+20</td>
<td>-7</td>
</tr>
<tr>
<td>North Central States</td>
<td>-16</td>
<td>+12</td>
<td>+13</td>
<td>+11</td>
<td>+9</td>
<td>+22</td>
<td>-14</td>
</tr>
<tr>
<td>Iowa</td>
<td>-22</td>
<td>-19</td>
<td>+52</td>
<td>+6</td>
<td>+11</td>
<td>+38</td>
<td>-38</td>
</tr>
</tbody>
</table>

*The changes for the U. S. and the North Central States are based on the data presented in the table "Summary of Changes Proposed in Regional Adjustment Project" of Mr. Wells' paper quoted on p. 409. The North Central States include Ohio, Indiana, Illinois, Missouri, Iowa, Kansas, Nebraska, South Dakota, North Dakota, Minnesota, Wisconsin and Michigan. With the exception of North Dakota, Michigan and Wisconsin, the Corn Belt Region covers a major part of each of these states. Iowa is the only state falling entirely in the Corn Belt Region.

Mention should be made of the great potential significance of the Regional Agricultural Adjustment Project of 1935 for the future course of agricultural policy and legislation. This project has demonstrated a workable method of approach to the scientific determination of agricultural policy. It has proven the possibility of outlining a rational solution of regional and national agricultural problems and has created a precedent which may encourage the removal of antagonistic and self-interested pressure groups from the formulation of agricultural legislation.

55 For a complete compilation of these data, see "Recommended Adjustments in Land Use for the North Central States, A Preliminary Estimate by Type-of-farming Areas." Program Planning Division, AAA, December, 1936. See also "Looking Ahead on Agricultural Policy," U.S.D.A. Bureau of Agricultural Economics, December, 1936.
Fig. 6. Crop systems for type-of-farming areas, 1929. Percentage of tillable land in major crop classes, and percentage of farm land in tillable land.

Fig. 7. Average yield of major crops (1928-1932) for type-of-farming areas.
Fig. 8. Estimated productivity of permanent and rotation pastures, in terms of feed units per acre, by counties. (Last digit represents tenths.)

Fig. 9. Feed unit production index per acre of major crops and pastures, for type-of-farming areas. Based on average crop yields (1928-1932).
Fig. 10. Total feed unit production per acre of all land in farms, by counties. (Based on 1932 acreages and 1928-32 average yields. Last digit represents tenths.)

Fig. 11. Feed unit production per farm, by counties. (Based on 1932 acreages and 1928-32 average yields.)
Fig. 12. Net out and in-shipments of corn and oats, in percentage of total production, 1928/29-1931/32, by counties.

Fig. 13. Feed supply structures for type-of-farming areas. (Corn, small grains, hay and pasture available for feed, in percentage of total feed units supply. Based on 1933 acreages, 1928-32 average yields, and 1929-32 net in or out-shipments of corn and oats.)
Fig. 14. Livestock systems for type-of-farming areas. (Hog, cattle, sheep, horse and poultry animal units in percentage of total animal units, 1929.)

Fig. 15. Milk produced per cattle animal unit and per acre of farm land as measures of intensity of the dairy enterprise, by counties. (Based on 1930 Census data, gallons of milk produced in 1929.)
### Farming System Criteria

#### Farm Type Structure

<table>
<thead>
<tr>
<th>Percent of Farm Land in Type</th>
<th>General</th>
<th>Cash Grain</th>
<th>Dairy</th>
<th>Animal Speciality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>54</td>
<td>52</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>Small Grain</td>
<td>32</td>
<td>12</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Legume Hay</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Other Hay</td>
<td>9</td>
<td>10</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>Crop Land</td>
<td>9</td>
<td>10</td>
<td>2</td>
<td>20</td>
</tr>
</tbody>
</table>

#### Crop System

<table>
<thead>
<tr>
<th>Crops in Percent of Crop Land</th>
<th>Corn</th>
<th>Small Grain</th>
<th>Legume Hay</th>
<th>Other Hay</th>
<th>Crop Land</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent of Farm Land in Crops</td>
<td>54</td>
<td>32</td>
<td>4</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Corn</td>
<td>58</td>
<td>12</td>
<td>10</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Small Grain</td>
<td>12</td>
<td>10</td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Legume Hay</td>
<td>4</td>
<td>10</td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other Hay</td>
<td>9</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crop Land</td>
<td>9</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Feed Unit Supply Structure

<table>
<thead>
<tr>
<th>Available Feed Units</th>
<th>Fremont</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Animal Units 100 Acres</td>
<td>54</td>
<td>13</td>
<td>17</td>
<td>26</td>
<td>32</td>
<td>29.6</td>
<td>4.5</td>
<td>256</td>
<td>172</td>
<td>268</td>
<td>3.4</td>
<td>154</td>
<td>8.0</td>
<td>316</td>
</tr>
<tr>
<td>Hogs Animal Units per 100 Acres</td>
<td>37</td>
<td>30</td>
<td>9</td>
<td>17</td>
<td>32</td>
<td>3</td>
<td>52</td>
<td>26</td>
<td>52</td>
<td>3</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Cattle Animal Units per 100 Acres</td>
<td>37</td>
<td>2</td>
<td>28</td>
<td>39</td>
<td>39</td>
<td>52</td>
<td>52</td>
<td>3</td>
<td>26</td>
<td>3</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Sheep Animal Units per 100 Acres</td>
<td>32</td>
<td>32</td>
<td>6</td>
<td>6</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Milk gallons per 1000 Acres</td>
<td>32</td>
<td>32</td>
<td>6</td>
<td>6</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Hay per Acre</td>
<td>32</td>
<td>32</td>
<td>6</td>
<td>6</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Small Grain per Acre</td>
<td>26</td>
<td>26</td>
<td>6</td>
<td>6</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Fed Units 22.2 per Acre</td>
<td>32</td>
<td>32</td>
<td>6</td>
<td>6</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Amel Animal Units 100 Acres</td>
<td>32</td>
<td>32</td>
<td>6</td>
<td>6</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Milk gallons per 1000 Acres</td>
<td>32</td>
<td>32</td>
<td>6</td>
<td>6</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Hay per Acre</td>
<td>32</td>
<td>32</td>
<td>6</td>
<td>6</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Small Grain per Acre</td>
<td>26</td>
<td>26</td>
<td>6</td>
<td>6</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Fed Units 22.2 per Acre</td>
<td>32</td>
<td>32</td>
<td>6</td>
<td>6</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Amel Animal Units 100 Acres</td>
<td>32</td>
<td>32</td>
<td>6</td>
<td>6</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Milk gallons per 1000 Acres</td>
<td>32</td>
<td>32</td>
<td>6</td>
<td>6</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Hay per Acre</td>
<td>32</td>
<td>32</td>
<td>6</td>
<td>6</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>

**Fig. 16.** Sample fragments of the synoptical map of Iowa farming criteria (criteria for the state and for two extreme counties; see explanatory notes.)

**Commentary to Fig. 16:** Sample Fragments of the Synoptical Map of Iowa Farming Criteria

**Purpose:**

The purpose of this map is to present, in a comprehensive, synoptical way, existing farming characteristics of the various counties and farming areas and to help the student to visualize regional differences in the agricultural set-up of Iowa. The criteria presented are so chosen as to indicate the logical and functional interrelations between the various factors, and to picture the farming enterprise in its organic entity.
Hence, several of the criteria used are rather irrelevant if taken each by itself but are highly indicative if considered in conjunction with other criteria. This is the reason why these criteria are not presented separately on different maps, but grouped together on the map, even though the map may look, for the first moment, somewhat crowded. After some attention is given, the advantage of such a synoptical presentation of the criteria will be realized.

Symbols:

On this map, there are shown 16 farm criteria, arranged in the same order and relative position so as to facilitate the comparing of each single criterion of one county with the same in another county. All figures pertaining to land and crops are placed in square boxes, all those pertaining to livestock are placed in circles. Within the group of land and crop data, a further distinction has been made by tracing the box lines more heavily around the figures referring to feed structure and supply. Within the group of livestock data, those pertaining to the cattle enterprise have been circled by heavier lines. These symbols greatly facilitate the reading and interpreting of the map.

Explanation of criteria:

The figures are explained in the legend of the map, which shows, at the same time, the respective state averages. This enables the student to appraise instantly the deviation of each county from the average of the state as a whole. For the criteria (3) and (7) to (10), all feed stuffs have been converted into “feed units.” One feed unit is the feed equivalent of 1 bushel of corn. For the criteria (4) and (11) to (15), all animals have been converted into “animal units.” One animal unit is the animal equivalent in feed requirements of one mature cow. For more detailed information see page 358 of the text.

Sources of data:

Criterion (1) Percent of Land in Farm Types and the livestock figures except those for hogs, are based on 1929 Census data. Hog figures are based on the Iowa Pig Survey and represent 1928-1931 averages. The acreages and number of farms are, except for criterion (1), taken from the 1932 assessors’ reports. The feed production data are based on the 1932 acreage and 5-year (1928-1932) average yields. The grain shipment data are obtained from a study of corn and oats shipments by Mr. Bentley, Iowa State College, representing 1929-1932 averages.

Some directions for interpreting various supplementary or interrelated criteria:

(a) The last figure in criterion (1) gives the percentage of land in the “Animal Specialty” type of farming and thereby indicates the relative importance of the livestock enterprise in the respective area. It does not reveal, however, what kind of livestock is prevalent in the section. This can be determined by consulting criteria (4), (11) and (12), which show the relative importance of hogs and cattle, the chief livestock enterprises in Iowa. The cattle enterprise, as shown by criteria (4) and (12), is further analyzed by criterion (15) which indicates the degree of intensity of dairying in the cattle enterprise. If, for instance, the amount of milk produced per cattle animal unit (criterion 15) is markedly below 280 gallons (state average = 282), the emphasis in the cattle enterprise is definitely on beef production.

(b) The third figure in criterion (1) showing the percentage of land in the “dairy” type of farming is very significantly supplemented
and augmented in its analytical value by criterion (16), the amount of milk produced per acre, indicating the degree of intensity of dairying in the respective area. For instance, in the north central cash grain area as well as in the south central livestock area, 2 percent of the land is in the dairy type of farm. Dairying, however, is considerably more intensive in the former than in the latter as indicated by criterion (16), showing 19.1 and 14.5 gallons of milk produced per acre, respectively.

(c) Criteria (5), average farm size, and (9), feed units produced per acre, are supplemented by criterion (8), feed units produced per farm. These three criteria reveal that in some sections of the state lower feed unit production per acre tends to be offset by larger farms, thereby tending to keep feed production per farm up, as in the northeastern section, whereas in southern Iowa, poor soil productivity often coincides with smaller farms, thereby increasing the relative disadvantage of poor soil for the individual farmer, and severely depressing his scale of living.

Sample Worksheet 1: General Crop and Soils Information on County.
County: Blackhawk

**CROP LAND**

1. Predominant Topography: Level to gently rolling. Cut by two rivers and their tributaries
2. Erosivity: Slight to medium
3. a. Predominant Types: Tama silt loam
   b. Productivity: High
   Carrington loam
   b. Productivity: High
4. a. Extent of Acidity: 85% b. Degree of Acidity: Strong
5. Remarks: Large areas sandy—good for special crops
6. a. Pasture Types: Clinton, Carrington—Tama, Rolling Phase
   b. Lime? Yes c. Seeding Mixture: Clover and timothy
7. a. Predominant Rotations: 1
   b. Acres: 104,348
   c. Kind of legume: Red clover
   4 38,972 d. Kind of rotation pasture:
   2 36,934 Red clover—timothy, sweet clover

**PERMANENT PASTURE**

1. Predominant Topography: Level to gently rolling
2. Predominant Type of Pasture: Upland
3. Approximate Acreage Woodland Pasture: 16,000

**COMMENTS**

There is a relatively large area of waste land. The need of drainage is evident in many parts of the county. The area of bottomland is small. One of the first needs of the soils of the county is lime. Erosion occurs more extensively in Clinton and Carrington sandy loam. The terrace soils, as O’Neil, Bremer, Waukesha sandy loam and Calhoun, are in need of organic matter. Shorter rotations should be practiced.
Sample Work Sheet 2: Township Data on Crops and Soils Recommendations.

Blackhawk County, Eagle Township

Key No. 7-16

DATA FROM CENSUS, 1930

No. of farms, 109; Acres in farms, 22572; Crop land, 16560; Plowable pasture, 2929; Woodland pasture, 249; Other pasture, 1706; Woodland not pasture, 22; All others, 1106; Area in corn, 8470; Small grain, 2067; Pasture total, 5176; Pasture permanent, X; Hay legume, 416; Hay mixed, 1555; Other hay, X; Green manures, X; Woodland not pasture X; Special crops, 193; All other, X; Total hay 2062.

DATA FROM SOIL MAPS: Source

<table>
<thead>
<tr>
<th>Names of Soil Types</th>
<th>Grade</th>
<th>Area</th>
<th>Distribution of Recommended Rotations* over specific soil types</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tama Silt Loam</td>
<td>1</td>
<td>17009</td>
<td>¼ in (1); ¼ in (6); ¼ in (9)</td>
</tr>
<tr>
<td>Clyde S. Clay Loam</td>
<td>8</td>
<td>2583</td>
<td>¼ in (7); ¼ in (1)</td>
</tr>
<tr>
<td>Carrington Loam</td>
<td>1</td>
<td>826</td>
<td>¼ in (1); ¼ in (2); ¼ in (11c); ¼ in (4)</td>
</tr>
<tr>
<td>Waukesha Silt Loam</td>
<td>1</td>
<td>767</td>
<td>All in (1)</td>
</tr>
<tr>
<td>Meadow</td>
<td>10</td>
<td>193</td>
<td>All in (7)</td>
</tr>
<tr>
<td>Dodgeville Silt L.Sh.Ph.</td>
<td>8</td>
<td>64</td>
<td>All in (7)</td>
</tr>
<tr>
<td>Muck</td>
<td>10</td>
<td>23</td>
<td>All in (8)</td>
</tr>
</tbody>
</table>

*Figures in parentheses refer to the number of the rotations as indicated on work sheet three.

CLASSIFICATION OF SOILS BY GRADES, ROTATIONS AND CROPS

<table>
<thead>
<tr>
<th>Grades</th>
<th>Rotation</th>
<th>Areas in crops under recommended rotation</th>
<th>Woodland not pasture</th>
<th>Special crops</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Net Area</td>
<td>Corn</td>
<td>Small Grain</td>
<td>Pasture</td>
<td>Rotation</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>9478</td>
<td>4720</td>
<td>2370</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>207</td>
<td>69</td>
<td>69</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>206</td>
<td>52</td>
<td>52</td>
<td>51</td>
</tr>
<tr>
<td>1</td>
<td>6</td>
<td>4253</td>
<td>1701</td>
<td>1701</td>
<td>851</td>
</tr>
<tr>
<td>1</td>
<td>9</td>
<td>4252</td>
<td>709</td>
<td>709</td>
<td>1416</td>
</tr>
<tr>
<td>1</td>
<td>1lc</td>
<td>206</td>
<td>52</td>
<td>52</td>
<td>1416</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>1291</td>
<td>646</td>
<td>323</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>7</td>
<td>1356</td>
<td>646</td>
<td>323</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>7</td>
<td>193</td>
<td>709</td>
<td>709</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>8</td>
<td>23</td>
<td>23</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>Totals</td>
<td>Adjusted</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Totals</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Work Sheet 3: Standard Rotations Employed.

<table>
<thead>
<tr>
<th>Rotation No</th>
<th>Crops</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Corn Corn Small Grain Legume Hay</td>
</tr>
<tr>
<td>2</td>
<td>Corn S. G. Legume Hay</td>
</tr>
<tr>
<td>3</td>
<td>Corn Corn Oats Mixed Hay Rot. Pasture</td>
</tr>
<tr>
<td>4</td>
<td>Corn Oats Mixed Hay Rot. Pasture</td>
</tr>
<tr>
<td>5</td>
<td>Corn Corn Small Grain Sw. Clover (Level Marshall-Clarion)</td>
</tr>
<tr>
<td>6</td>
<td>Corn Corn Small Grain W. Wheat Clover</td>
</tr>
<tr>
<td>7</td>
<td>Permanent Pasture</td>
</tr>
<tr>
<td>7x</td>
<td>Woodland Not Pasture</td>
</tr>
<tr>
<td>8</td>
<td>Special Crops</td>
</tr>
<tr>
<td>9</td>
<td>Corn S. B. W. Wheat Mixed Hay Rot. Pasture Rot. Pasture</td>
</tr>
<tr>
<td>10 (a)</td>
<td>½ Corn Corn Small Grain Clover</td>
</tr>
<tr>
<td>10 (b)</td>
<td>½ Corn S. G. W. Wheat Mixed Hay Rot. Pasture</td>
</tr>
<tr>
<td>11 (a)</td>
<td>½ Permanent Pasture</td>
</tr>
<tr>
<td>11 (b)</td>
<td>¼ Corn Oats Alfalfa Alfalfa</td>
</tr>
<tr>
<td>11 (c)</td>
<td>¼ Corn S. B. Oats Clover</td>
</tr>
<tr>
<td>12 (a)</td>
<td>Corn Corn Small Grain W. Wheat Alfalfa</td>
</tr>
<tr>
<td>12 (b)</td>
<td>Corn Corn Oats Alfalfa Alfalfa Alfalfa</td>
</tr>
</tbody>
</table>

**Note:**
- S. G. = Small Grain.
- S. B. = Soy Beans.
- W. Wheat = Winter Wheat.
Work Sheet 4: Livestock Units and Feed Requirements.

<table>
<thead>
<tr>
<th>Class of livestock</th>
<th>Animals Per Unit</th>
<th>Feed Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Hay (legume and mixed)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>tons</td>
</tr>
<tr>
<td>Dairy Cattle</td>
<td>1 Cow</td>
<td>2.8</td>
</tr>
<tr>
<td>One Dairy Unit</td>
<td>1/3 Yearling</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1/3 Calf</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1/20 Bull</td>
<td></td>
</tr>
<tr>
<td>Beef Cattle</td>
<td>1 Cow</td>
<td>1st 2.0</td>
</tr>
<tr>
<td>One Beef Unit</td>
<td>1/20 2-yr-old</td>
<td>2nd 2.7</td>
</tr>
<tr>
<td></td>
<td>1/5 Yearling</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1/5 Calf</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1/20 Bull</td>
<td></td>
</tr>
<tr>
<td>Super Baby Beef</td>
<td>1 Calf</td>
<td>0.33</td>
</tr>
<tr>
<td>Baby Beef</td>
<td>1 Calf</td>
<td>0.60</td>
</tr>
<tr>
<td>Steers, Fattening</td>
<td>1 Steer</td>
<td>1st 0.50</td>
</tr>
<tr>
<td></td>
<td>2nd 0.25</td>
<td>0.75</td>
</tr>
<tr>
<td>Sheep</td>
<td>1 Ewe</td>
<td>0.15</td>
</tr>
<tr>
<td>One Sheep Unit</td>
<td>2/10 Yearling</td>
<td></td>
</tr>
<tr>
<td></td>
<td>replacement</td>
<td>2/10 Lamb replacement</td>
</tr>
<tr>
<td></td>
<td>8/10 Lamb, fattening</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1/50 Ram</td>
<td></td>
</tr>
<tr>
<td>Lamb, Fattening</td>
<td>1 Lamb</td>
<td>0.075</td>
</tr>
<tr>
<td>Swine</td>
<td>1 Sow</td>
<td></td>
</tr>
<tr>
<td>One Swine Unit</td>
<td>6 Spring pigs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 Fall pigs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1/20 Boar</td>
<td></td>
</tr>
<tr>
<td>Horses</td>
<td>1 Mature horse</td>
<td>1.4</td>
</tr>
<tr>
<td>One Horse Unit</td>
<td>1/8 2-year old</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1/8 Yearling</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1/8 Colt</td>
<td></td>
</tr>
</tbody>
</table>
Sample Work Sheet 5: County Feed Supply Resulting from Crop Adjustments

<table>
<thead>
<tr>
<th>COUNTY</th>
<th>BLACKHAWK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Farms (1930)</td>
<td>2384</td>
</tr>
<tr>
<td>Crop Acres</td>
<td>254,118</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Crop</th>
<th>Acres</th>
<th>Bushels per acre</th>
<th>Pounds, total</th>
<th>Corn</th>
<th>Acres</th>
<th>Bushels per acre</th>
<th>Pounds, total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>95,562</td>
<td>41</td>
<td>219,410,352</td>
<td></td>
<td>8114.5</td>
<td>23.63</td>
<td>11,547,272</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Small Grain*</th>
<th>Acres</th>
<th>Bushels per acre</th>
<th>Pounds, total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>59,179.5</td>
<td>32.65</td>
<td>63,376,510</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mixed Hay</th>
<th>Acres used for hay</th>
<th>Tons per acre</th>
<th>Tons, total</th>
<th>Used for rotation pasture</th>
<th>Carrying capacity conversion ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>none</td>
<td></td>
<td></td>
<td></td>
<td>14,159 Acres</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Soybeans</th>
<th>Acres for hay</th>
<th>Tons per acre</th>
<th>Tons, total</th>
<th>Acres for grain</th>
<th>Bushels per acre</th>
<th>Pounds, total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>8,100</td>
<td>1.75</td>
<td>14,175</td>
<td>2,387</td>
<td>16.1</td>
<td>2,305,842</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rotation Pasture</th>
<th>Acres used for hay</th>
<th>Tons per acre</th>
<th>Tons, Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>None</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Replace 4,870 acres of corn with rotation pasture.

* 95 percent oats; 5 percent barley.

† One acre of rotation pasture is equivalent in carrying capacity to 1.15 acres of permanent pasture. All rotation pasture is expressed in terms of permanent pasture acreage. The conversion ratio is obtained from estimates of carrying capacity of permanent and rotation pasture given in figs. 6 and 7.
### Sample Work Sheet 6: Livestock Adjustments.

<table>
<thead>
<tr>
<th>Class of Livestock</th>
<th>Units</th>
<th>Number of Animals</th>
<th>Grain (Lbs.)</th>
<th>Hay (Tons)</th>
<th>Silage Grain equiv. (Lbs.)</th>
<th>Pasture (Acres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horse</td>
<td>9,157</td>
<td>9,157</td>
<td>26,555,300</td>
<td>12,820</td>
<td></td>
<td>14,340</td>
</tr>
<tr>
<td>Mature horses</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Colts</td>
<td>3,433</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poultry</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hens</td>
<td>345,256</td>
<td>690,512</td>
<td>17,262,800</td>
<td>20,715,360</td>
<td></td>
<td>1,197</td>
</tr>
<tr>
<td>Chickens</td>
<td>3,591</td>
<td></td>
<td>179,550</td>
<td></td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>Turkeys</td>
<td>4,309</td>
<td></td>
<td>86,180</td>
<td></td>
<td></td>
<td>86</td>
</tr>
<tr>
<td>Geese</td>
<td>9,815</td>
<td></td>
<td>196,300</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ducks</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dairy Cattle</td>
<td>25,000</td>
<td></td>
<td>*71,250,000</td>
<td>70,000</td>
<td>25,900,000</td>
<td>63,000</td>
</tr>
<tr>
<td>Cows</td>
<td>25,000</td>
<td>16,667</td>
<td>1,250,000</td>
<td>5,000</td>
<td>1,400,000</td>
<td>6,750</td>
</tr>
<tr>
<td>Calves</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bulls</td>
<td>1,250</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beef Cattle</td>
<td>2,500</td>
<td>2,500</td>
<td>1,250,000</td>
<td>5,000</td>
<td>1,400,000</td>
<td>6,750</td>
</tr>
<tr>
<td>Cows</td>
<td>2,500</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Replacement heifers</td>
<td>1,125</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other calves</td>
<td>1,500</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bulls</td>
<td>125</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Super baby beef</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baby beef</td>
<td>1,500</td>
<td>1,500</td>
<td>4,500,000</td>
<td>900</td>
<td></td>
<td>675</td>
</tr>
<tr>
<td>Steers, fattening</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sheep</td>
<td>1,000</td>
<td>1,000</td>
<td>250,000</td>
<td>125</td>
<td>70,000</td>
<td>270</td>
</tr>
<tr>
<td>Ewes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Replacement lambs</td>
<td>400</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other lambs</td>
<td>800</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rams</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lambs, fattening</td>
<td>6,000</td>
<td>6,000</td>
<td>1,050,000</td>
<td>450</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Swine</td>
<td>14,725</td>
<td></td>
<td>103,075,000</td>
<td></td>
<td></td>
<td>13,253</td>
</tr>
<tr>
<td>Sows</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spring pigs</td>
<td>88,350</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fall pigs</td>
<td>29,450</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boars</td>
<td>736</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surplus grain, lbs.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11,717,968</td>
</tr>
</tbody>
</table>

Remarks: Short on pasture. Suggest that 4,870 acres of corn be converted to rotation pasture.
INDEX TO VOL. XVIII, RESEARCH BULLETINS 202-209

A

Acetymethylcarbinol. See "Oxidation of acetymethylcarbinol to diacetyl in butter cultures, the" ........................................... 201
Also "Classification of organisms important in dairy products" .................................................. 217

Acid-proteolytic streptococci.
Action on milk ........................................... 228
Description of ........................................... 229
Biochemical features ..................................... 230
Cultural characteristics .................................. 229
Growth condition ....................................... 230
Morphology ............................................ 229
Isolation from dairy products ......................... 226

Agricultural Economics Subsection, bulletin from .......... 337
Agricultural Engineering Section, bulletin from ........... 253
Agricultural land. See "Economics of agricultural land use adjustments" ........................................ 337

Alfalfa. See "Relation of reserves to cold resistance in alfalfa" 301
Analysis of soils. See "Chemical analyses of Iowa soils" 57
Animal Breeding Subsection, bulletin from ................. 105

Barn design ............................................. 257

Barns. See "Masonry barn design and construction" ......... 253
Barre, H. J. Joint author of "Masonry barn design and construction" ........................................ 253

Botany and Plant Pathology Section, bulletin from ........ 301

Bottomland soils ........................................... 85
Comparison of soils of uniform texture .................... 91
Comparison of upland and terrace and bottomland soils .. 91
Relation of texture to composition ........................ 85
Brown, P. E. Joint author of "Chemical analyses of Iowa soils for phosphorus, nitrogen and carbon: a statistical study" 57
Butter cultures. See "Oxidation of acetymethylcarbinol to diacetyl in butter cultures" .......... 201

Carbon-nitrogen ratio of Iowa soils ....................... 93
Carbon-nitrogen ratio .................................... 93
Discussion ............................................. 100
Factors affecting the phosphorus, nitrogen and carbon content of Iowa soils .............................. 100
Literature cited ......................................... 103
Methods ............................................... 62
Results for the drift soils ................................ 66
Comparison of soils of uniform texture .................. 77
Comparison of surface and subsols........................ 71
The influence of texture ................................ 72
Results for the loess soils ................................ 79
Comparison of loess silt loams ........................... 84
Relation of soil composition to soil color ................ 82
Results for the terrace and bottomland soils .............. 85
Comparison of soils of uniform texture .................. 91
Comparison of upland and terrace and bottomland soils. 91
Relationship of texture to composition 85
Summary 59
“Classification of organisms important in dairy products I. Streptococcus liquefaciens” by H. F. Long and B. W. Hammer 217
Discussion 248
Experimental 226
General action of the organisms on milk 228
General description of the acid-proteolytic streptococci 229
Biochemical features 230
Cultural characteristics 229
Growth conditions 230
Morphology 229
General resistance of the organisms 247
Resistance to heat 248
Viability of the acid-proteolytic streptococci in culture media 247
Identity of the cultures 230
Isolation of the acid-proteolytic streptococci from dairy products 226
Special biochemical features 231
Action on fat 244
Effect of neutralizing cultures on the production of acetylmethylenearbinol in skim milk 242
Examination of skim milk cultures for 2,3-butylene glycol 243
Influence of acetaldehyde on the production of volatile acid and acetylmethylenearbinol in skim milk 238
Acetylmethylenearbinol 238
Volatile acid 238
Influence of added citric acid on the production of volatile acid and acetylmethylenearbinol in skim milk 236
Influence of temperature on the production of volatile acid, carbon dioxide and acetylmethylenearbinol in skim milk 232
Acetylmethylenearbinol 235
Carbon dioxide 234
Volatile acid 232
Isomeric form of lactic acid produced in skim milk 243
Production of volatile acid, carbon dioxide and acetylmethylenearbinol in skim milk 231
Protein breakdown in milk 245
Historical 221
Introduction 221
Literature cited 250
Methods 225
Acetylmethylenearbinol plus diacetyl and diacetyl 225
Acidity 225
Carbon dioxide 225
Detection of proteolytic bacteria on plates 225
Hemolysis 226
Hydrolysis of fat 226
Isomeric form of lactic acid 226
Protein breakdown in skim milk 226
Volatile acidity 225
Statement of problem 221
Summary and conclusions 219
Cold resistance in alfalfa. See “Relation of reserves to cold resistance in alfalfa, the” 301
Dairy Industry Section, bulletin from 201, 217
Danish system of progeny-testing swine. See "Genetic aspects of the Danish system of progeny-testing swine" 105
Davidson, J. B. Joint author of "Masonry barn design and construction" 253
Diacetyl. See "Oxidation of acetylmethycarbinol to diacetyl in butter cultures, the" 201
Also, "Classification of organisms important in dairy products" 217
Drift soils 66
Comparison of soils at uniform texture 77
Comparison of surface and subsoils 71
The influence of texture 72

"Economics of agricultural land use adjustments I. Methodology in soil conservation and agricultural adjustment research," by Rainer Schickele 337
Adjustments in Iowa farming necessary to establish a maintenance agriculture 378
Adaptation of crop rotations to soil types 380
Adjustments in the crop systems of the type-of-farming areas in Iowa 387
Changes in livestock systems 394
Economic evaluation of the adjustment problems in the various type-of-farming areas of Iowa 398
Effect of adjusted rotations on crop yields 390
Feed production from the adjusted crop system 392
Interdepartmental cooperation 379
Appendix 411
Characteristics of present farming conditions in Iowa 350
Animal units and livestock systems 358
Commercial movements of feed grains 357
Feed unit productivity of crops and pastures 353
Present land use patterns and crop systems 351
Conclusions 343
Emergency character of the AAA programs 347
Need for planning fundamental adjustments in agricultural production 345
Purpose of this bulletin 349
Research projects in agricultural adjustment 348
Requirements for a long-time program in the Corn Belt 347
The proper sphere for economic planning in agriculture 346
Economic problem of soil conservation, the 362
Levels of natural soil fertility 364
Methods of soil conservation 374
Regional allocation of emphasis on conservation 369
Soil conservation and farm income 376
Some characteristics of soil erosion and depletion 363
The "breaking point" of natural fertility 365
Regional agricultural adjustment project of 1935, the 404
Basic assumptions 406
Evaluation of the results of the regional adjustment project 408
Objectives of the project 404
Farming conditions in Iowa.................................................. 350
Animal units and livestock systems................................. 358
Commercial movements of feed grains.............................. 357
Feed unit productivity of crops and pastures.................... 355
Present land use patterns and crop systems....................... 351
Farm land use, adjustments of. See "Economics of agricultural
land use adjustments"...................................................... 337

"Genetic aspects of the Danish system of progeny-testing swine,"
b by Jay L. Lush.............................................................. 105
Changes which have occurred in the swine population, 1907
to 1935................................................................. 130
Age and weight at slaughter........................................... 133
Changes in average classification of bacon sides................ 145
Changes in body length.................................................. 139
Changes in dressing percent and in yield of export bacon.... 143
Changes in scores for various characteristics.................... 146
Changes in thickness of back fat and in thickness of
belly........................................................................ 142
Number and representativeness of material....................... 130
Summary of changes in average characteristics of the
swine population......................................................... 156
Trends in daily gain....................................................... 134
Trends in economy of gain............................................. 136
Trends in health......................................................... 132
Visible changes in the conformation of the swine.............. 151
Correlation between full brothers and sisters which were not
litter mates................................................................ 176
Correlation between maternal half-sib litters................... 172
Correlation between progeny test of sire and progeny test
of son........................................................................ 178
Correlation between six characteristics of the same litter... 188
General discussion......................................................... 192
History of the swine breeding and testing system.............. 112
Breeding centers and their supervision......................... 116
Breeds used and breeding policies................................. 114
Feeding plan................................................................. 127
Markets for Danish swine.............................................. 112
Procedure of testing..................................................... 124
Progeny testing stations............................................... 119
Publication and use of data from the testing stations........ 120
Introduction.................................................................. 109
Numerical evidence as to the selection practiced............... 184
References.................................................................... 195
Resemblances and differences between litter mates............ 157
Resemblances between paternal half brothers and sisters... 168
Summary....................................................................... 108
Summary of evidence on heritability................................. 182
Giese, Henry, joint author of "Masonry barn design and construc-
tion"......................................................................... 253

Hammer, B. W., joint author of "Classification of organisms im-
portant in dairy products"............................................... 217
Hammer, B. W., joint author of "Oxidation of acetylmalonyl-
binol to diacetyl in butter cultures"................................. 201
Heritability, summary of evidence on .................................................. 182
Hogs. See "Swine."

I
"Inbreeding in the white leghorn fowl," by N. F. Waters and W. V. Lambert .................................................. 1
Description of families .................................................. 33
The effect of inbreeding on age at first egg in families 1 to 6 .................................................. 44
The effect of inbreeding on egg production in families 1 to 6 .................................................. 47
The effect of inbreeding on egg weight in families 1 to 6 .................................................. 49
The effect of inbreeding on fertility in families 1 to 6 .................................................. 40
The effect of inbreeding on hatchability in families 1 to 6 .................................................. 42
Discussion .................................................. 50
General effects of inbreeding and crossbreeding .................................................. 8
History and purpose .................................................. 10
Inbreeding in mammals and birds .................................................. 5
Literature cited .................................................. 54
Methods .................................................. 11
The effect of inbreeding on days to first egg .................................................. 13
The effect of inbreeding on egg production .................................................. 21
The effect of inbreeding on egg size .................................................. 24
The effect of inbreeding on fertility .................................................. 13
The effect of inbreeding on hatchability .................................................. 15
The effect of inbreeding on rate of growth and on mature body weight .................................................. 27
The effect of inbreeding on viability .................................................. 30
Summary .................................................. 3
The problem .................................................. 10

L
Lactic acid. See "Classification of organisms important in dairy products" .................................................. 217
Lambert W. V., joint author of "Inbreeding in the white leghorn fowl" .................................................. 1
Land use. See "Economics of agricultural land use adjustments" .................................................. 337
Loess soils
Comparison of loess silt loams .................................................. 84
Relation of soil composition to soil color .................................................. 82
Long, H. F., joint author of "Classification of organisms important in dairy products" .................................................. 217
Lush, Jay L., author of "Genetic aspects of the Danish system of progeny-testing swine" .................................................. 105

M
Mark, J. J., author of "Relation of reserves to cold resistance in alfalfa, the" .................................................. 301
"Masonry barn design and construction," by Henry Giese, H. J. Barre and J. B. Davidson .................................................. 253
Barn design .................................................. 257
Preliminary considerations .................................................. 257
Shape of roof .................................................. 260
Size of barn .................................................. 257
Wind loads .................................................. 281
Structural design .................................................. 266
Construction problems .................................................. 279
Experimental barn .................................................. 286
Full sized arch .................................................. 284
<table>
<thead>
<tr>
<th>Subject</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model arch</td>
<td>283</td>
</tr>
<tr>
<td>Roof forms</td>
<td>279</td>
</tr>
<tr>
<td>Cost of materials for the roof</td>
<td>294</td>
</tr>
<tr>
<td>Literature cited</td>
<td>296</td>
</tr>
<tr>
<td>Summary and conclusions</td>
<td>255</td>
</tr>
<tr>
<td>Waterproofing problems</td>
<td>290</td>
</tr>
<tr>
<td>Michaelian, M. B., joint author of “Oxidation of acetylmethylcarbinol to diacetyl in butter cultures, the”</td>
<td>201</td>
</tr>
<tr>
<td>N</td>
<td>57</td>
</tr>
<tr>
<td>Nitrogen. See “Chemical analyses of Iowa soils”</td>
<td></td>
</tr>
<tr>
<td>O</td>
<td></td>
</tr>
<tr>
<td>“Oxidation of acetylmethylcarbinol to diacetyl in butter cultures, the,” by M. B. Michaelian and B. W. Hammer</td>
<td>201</td>
</tr>
<tr>
<td>Conclusions</td>
<td>202</td>
</tr>
<tr>
<td>Discussion of results</td>
<td>213</td>
</tr>
<tr>
<td>Experimental</td>
<td>204</td>
</tr>
<tr>
<td>Introduction</td>
<td>203</td>
</tr>
<tr>
<td>Literature cited</td>
<td>214</td>
</tr>
<tr>
<td>Methods</td>
<td>203</td>
</tr>
<tr>
<td>P</td>
<td>57</td>
</tr>
<tr>
<td>Phosphorus. See “Chemical analyses of Iowa soils”</td>
<td></td>
</tr>
<tr>
<td>Poultry Husbandry Subsection, bulletin from</td>
<td>1</td>
</tr>
<tr>
<td>Poultry, inbreeding</td>
<td>1</td>
</tr>
<tr>
<td>Progeny-testing. See “Genetic aspects of the Danish system of progeny-testing swine”</td>
<td>105</td>
</tr>
<tr>
<td>“Proteins of alfalfa, tests of the stability of”</td>
<td>326</td>
</tr>
<tr>
<td>R</td>
<td></td>
</tr>
<tr>
<td>“Relation of reserves to cold resistance in alfalfa, the,” by J. J. Mark</td>
<td>301</td>
</tr>
<tr>
<td>Discussion of results</td>
<td>329</td>
</tr>
<tr>
<td>Experimental results</td>
<td>310</td>
</tr>
<tr>
<td>Effect of fall cutting upon the growth of Grimm alfalfa</td>
<td>310</td>
</tr>
<tr>
<td>Effect of fall cutting on cold resistance of Grimm alfalfa</td>
<td>312</td>
</tr>
<tr>
<td>Effect of fall cutting upon the growth of Grimm alfalfa</td>
<td>310</td>
</tr>
<tr>
<td>Effect of fall cutting upon the root reserves of Grimm alfalfa</td>
<td>314</td>
</tr>
<tr>
<td>Seasonal changes in the root reserves of cut and uncut Grimm alfalfa</td>
<td>316</td>
</tr>
<tr>
<td>Seasonal changes in the root reserves of a hardy and a tender alfalfa variety</td>
<td>323</td>
</tr>
<tr>
<td>Studies of hardy and tender alfalfa varieties</td>
<td>320</td>
</tr>
<tr>
<td>The root reserves of hardy and non-hardy varieties of alfalfa</td>
<td>320</td>
</tr>
<tr>
<td>Insoluble carbohydrates</td>
<td>321</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>322</td>
</tr>
<tr>
<td>Studies of protoplasmic differentiation in cold resistance</td>
<td>325</td>
</tr>
<tr>
<td>Tests of the stability of the proteins of alfalfa</td>
<td>326</td>
</tr>
<tr>
<td>The relation of certain water soluble substances to cold resistance in alfalfa</td>
<td>327</td>
</tr>
<tr>
<td>Pectins</td>
<td>328</td>
</tr>
<tr>
<td>Substances precipitated from the dextrin extract by neutral lead acetate</td>
<td>327</td>
</tr>
</tbody>
</table>
Literature cited ........................................................................................................... 333
Materials and methods ............................................................................................. 308
Materials ...................................................................................................................... 308
Methods for analyses of root reserves ........................................................................ 309
Sampling and preserving ............................................................................................ 309
Reserves, alfalfa. See “Relation of reserves to cold resistance in alfalfa, the” .......... 301
Root reserves
Analysis ....................................................................................................................... 309
Methods for analysis .................................................................................................. 309
Sampling and preserving ............................................................................................ 309
Effect of fall cutting on root reserves ........................................................................... 316
Seasonal changes in root reserves ............................................................................... 323

S
Schickele, Rainer, author of “Economics of agricultural land use adjustments” .......... 337
Soil conservation and farm income ............................................................................. 376
Soil conservation, economic problems of ..................................................................... 362
Soil conservation, emphasis on .................................................................................. 369
Soil conservation methods .......................................................................................... 374
Soil conservation, regional allocation of ........................................................................ 369
Soil erosion and depletion, characteristics of .............................................................. 363
Soil fertility, levels of .................................................................................................. 364
“Breaking point” of natural fertility ............................................................................ 365
Soils. See “Chemical analyses of Iowa soils” .............................................................. 57
Soils Subsection, bulletin from ................................................................................... 57
Streptococcus liquefaciens. See “Classification of organisms important in dairy products” 217
Swine. See “Genetic aspects of the Danish system of progeny-testing swine” ............ 105

T
Terrace soils ............................................................................................................... 85
Comparison of soils of uniform texture ....................................................................... 91
Comparison of upland and terrace and bottomland soil ............................................ 91
Relation of texture to composition ............................................................................. 85

U
Upland soils, comparison with terrace and bottomland soil ....................................... 91

W
Walker, R. H., joint author of “Chemical analyses of Iowa soils for phosphorus, nitrogen and carbon: a statistical study” 57
Waters, N. F., joint author of “Inbreeding in the white leghorn fowl” ......................... 1
Waterproofing the barn ............................................................................................... 290
White leghorn. See “Inbreeding in the white leghorn fowl” ........................................ 1