1959

Observations on the etiology, prophylaxis and therapy of pasture bloat

Richard Harmon Johnson
Iowa State University

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I. INTRODUCTION

...It is universally known that red clover is a dangerous food for horned cattle; and particularly when under heavy dew or rain, it is a destructive poison. In the last spring I felt the effect of it by an accident having lost a bullock, which I valued very highly for his good qualities in labour, by his eating clover; and when I came to him I felt the loss more, for the ploughman who used to follow him was standing by him, who upon seeing me, with tears in his eyes said 'Ah, Sir! there he lies! the best companion that ever poorman followed.'....

---"An Englishman", 1765 (Beddows, 1959)

Bloat is a non-infectious disease of livestock occurring in many parts of the world and in many species. The term as used, however, generally refers to ruminants, particularly the bovine and ovine species. For the purposes of this study bloat is defined as a non-infectious disease of cattle or sheep in which gas accumulates within the rumen in sufficient quantity that the normal pressure within the rumen is exceeded and distension of the rumen results. The distension of the rumen can be observed exteriorly as a swelling of the abdomen, particularly on the left side. The extent of the distension increases with the severity of the condition. As seen in cattle, the first sign of bloat is generally a slight puffiness in the left paralumbar fossa. With increasing severity the distension of the left paralumbar fossa becomes more marked and eventually the right side of the animal becomes distended also. The skin becomes tight and drum-
like to the touch (the term "tympanites", often used to describe the syndrome, comes from a Greek phrase meaning "drum-like"). Defecation and urination are frequent and incoordination is noted. The animal becomes restless and may become extremely nervous and excited if disturbed. As internal pressure increases still further the anus protrudes and symptoms of respiratory distress appear. In the terminal stages there is extreme abdominal distension, severe respiratory distress, cyanosis, prostration and death unless treated. One factor contributing to the seriousness of the condition is that the amount of time elapsing between the first and last stages described above can be as little as 10 to 15 minutes in severe cases.

Under normal conditions of the farm the husbandman cannot afford a constant watch on the herd of grazing animals, particularly since bloat is often sporadic in nature, not occurring for a considerable time and then striking with no warning. Even when the herd is under constant surveillance it may be difficult to drive animals that are bloating to a place where they can be restrained and treated in time. Where facilities for treatment are readily available and adequate the tendency of otherwise docile animals to become extremely nervous and unmanageable may still make treatment impossible. A further complication is that most of the less drastic treatments (from the standpoint of undesirable side effects on the
animal) are relatively ineffective in severe cases. In fact, the only relatively sure treatment involves an emergency rumenotomy which at the best requires a period of convalescence and at the worst can result in peritonitis and death from secondary causes. There is one saving aspect to all the foregoing, however, which is that the problems described above apply to the relatively few (but these are no less frightening to the farmers affected) extreme cases; effective measures can be applied in most of the less severe cases.

It will be noted that bloat was defined on page one in general terms and the symptoms were described. Nothing was said of underlying causes. This is because the different types of bloat and their various characteristics are difficult to define inasmuch as the syndrome is exceedingly complex. Damage resulting from bloat is not confined to death losses (although these are the usual data reported in statistical studies on the subject); there often occur widespread loss in production and inconvenience to the farmer, both of which are extremely difficult to evaluate objectively.

As a result of all of these maleffects considerable research effort has been devoted to investigating the etiology of bloat and developing methods of prophylaxis and therapy. The literature of agricultural research from many lands has been devoting more and more space to discussions of the con-
dition described by the terms "bloat", "hoven", "tympanites", "tympany", "blown", "meteorism", or others of local use. As in many analogous situations in other fields of scientific investigation, these efforts have all contributed something toward understanding the problem and combatting it, yet none of them has achieved completely the triple goals of finding cause, cure and preventive. Today only hypotheses of etiology exist, and prophylaxis and therapy are still in a rudimentary stage of development.

Iowa State University has participated in an inter-institutional project to investigate the chemistry, physiology and bacteriology of bloat. Studies at this institution have involved field trials with cattle and sheep to test prophylactic and therapeutic agents and to investigate factors affecting occurrence. These last include observations on weather, individual susceptibility, the effect of time of day and experimental production of both pasture and feed-lot bloat. Laboratory investigations coupled with the field trials have dealt with the problems of chemical composition and physical nature of the feed and the chemical, physical and bacteriological characteristics of the rumen contents. Blood studies have been conducted to gain some idea of the changes occurring with bloat, and possibly to determine which of these, if any, lead to death. Investigations on the mode of action and other characteristics (particularly duration of time) of the prophyl-
lactic and therapeutic agents used have received extensive attention.

The particular part of the studies conducted by the author has been most directly concerned with field trials and certain laboratory investigations of the chemical and physical characteristics of the rumen contents. The author has been indirectly and to some extent directly connected with most of the other phases of the bloat work at Iowa State, however, and data from these will be used to supplement the descriptions of the author's own work.
II. REVIEW OF LITERATURE

...You say you do not arrogate any praise to yourselves, as the authors of the Reviews may do, who can publish a monthly pamphlet without any other assistance but their own. Surely, gentlemen, you mistake this affair. What, pray, could they do but for the many publications, both at home and abroad, which every day brings forth? Are they not the very food and foundation of their undertaking? Let the one discontinue, (but that, perhaps you will say is impossible) and the other naturally falls to the ground. I wish the authors of the Reviews all imaginable success, so long as they act with justice and impartiality, but when they deviate from either, it is the duty of every lover of useful knowledge, and friend to his country, to look upon them with an eye of contempt.

"G.B.", 1765 (Beddows, 1959)

A. Reviews

The 1945 review of Cole and his collaborators (Cole et al., 1945) was the principal standard reference in the field of bloat until it was revised in 1956 (Cole et al., 1956). Blake (1955) made a very comprehensive review of the literature up through 1955 in his dissertation which, incidentally, served as the beginning point for the present review. The Louisiana workers (Parham et al., 1956) compiled an extensive review in 1956. Johns of New Zealand, and his co-workers (Johns, 1956a, 1956b, 1958a, 1958b; Johns et al., 1957) have published a series of very interesting review articles in various journals. Dougherty has two reviews dating from 1956. The more comprehensive of the two was his
report (Dougherty, 1956b) presented at the Seventh International Grasslands Conference; the other (Dougherty, 1956a) was more condensed, and was presented in the 1956 Yearbook of Agriculture. Bloat was the subject of a recent review in AgraData (Pfizer, 1958a) and in a more recent paper by Dyer (1959). Brown has prepared an extensive review (Brown, 1959) concurrent with that of the present author and which the reader may find useful as a supplement to this review.

The reviews mentioned above deal with bloat in its general aspects; however, Lindahl et al. (1957) have prepared a valuable review of alfalfa saponins and their relationship to bloat which will also be useful to those interested in the field of bloat research.

B. Definition and Types of Bloat

1. Definition of bloat

The definition of bloat given on page one is actually a composite of the definitions given by several authors (Blake, 1955; Dougherty, 1956a; Parham et al., 1956) all of whom are in substantial agreement. Parham and his collaborators included as part of their definition the statement that the condition arises from eating watery foods and eating too rapidly. The present author feels that these statements are subject to question and Johns (1957, 1958a) makes statements contradictory to those of Parham et al., (1956).
2. **Classification of types of bloat**

All the authors who discuss classification of types of bloat approach the topic from one or more of the following general viewpoints. They classify bloat according to the particular feeding regimen under which it occurs (legume vs. feed-lot bloat), or according to the nature of its symptoms (acute, subacute, chronic). It has also been more or less traditional to classify it according to the presence of free gas in the rumen (non-foamy, gassy) or of foam (frothy, foamy). There are also some other miscellaneous types of bloat worthy of mention.

**a. Classification by feeding regimen**  
Bloat is often differentiated according to the system of feeding as legume or feed-lot bloat. The term "legume bloat" may not be sufficiently inclusive, and "pasture bloat" may be a more appropriate term. It is true that bloat is most often reported in animals grazing legumes; however, at one time or another many grasses have been reported to be tympanogenic (Johns, 1956a; Nicholson, 1955; Reber, 1956). Feed-lot bloat may occur when animals receive rations containing a relatively high proportion of concentrates, although occasionally bloat on dry hay has been observed.

**b. Classification by nature of symptoms**  
Cole *et al.* (1956) suggest that bloat can be classified according to the
nature of its symptoms as acute, subacute and chronic. Chronic bloat is a condition occurring irrespective of the qualitative nature of the diet and is usually considered to arise from some anatomical anomaly, known or unknown (Benson, 1957; Blake, 1955; Cole et al., 1956; Picarelli, 1957; Giacomini, 1957; Jensen, 1955; McGeady, 1958). Barrentine et al. (1956b) do not include chronic bloat as such, but they discuss the same condition under the heading of pathological bloat. Kuykendall et al. (1957) described a case of chronic bloat which may have been caused indirectly by parasite infestation, while Ferrari (1957) and Sapre (1956) mention hair balls as a possible cause. Chronic bloat is further distinguished from the other forms of bloat by the fact that it is persistent or recurrent (Reber, 1956).

Subacute bloat is a condition resulting from a specific dietary regimen—i.e., either pasture or feed-lot—in which visible distension of the paunch is observed but the other more severe symptoms are not present, (Cole et al., 1956; Reber, 1956). Johns (1956a) points out that although subacute bloat may be only an early stage of the acute condition it is possible that conditions causing subacute bloat may be secondary factors leading to acute bloat and he therefore argues in favor of retaining the subacute classification. Barrentine (1959) confines the subacute classification to legume bloat.
Acute bloat and subacute bloat are mainly a matter of degree; the acute classification is applied to pasture or feed-lot bloat in which the condition is further advanced and distressing symptoms appear (Cole et al., 1956). In acute bloat, treatment is required to save the animal (Barrentine, 1959; Reber, 1956). It has been stated that chronic cases may suddenly become acute, making the chronic classification questionable (Pfizer, 1958a).

c. **Classification by presence of gas or foam** As late as 1956, when Johns wrote his first review (Johns, 1956a), bloat was still classified as either foamy bloat or free-gas bloat. In his 1958 reviews (Johns, 1958a, 1958b); however, the same author quotes observations by several scientists leading to the belief that both legume and feed-lot bloat are frothy bloat and that in bloat the ingesta always are frothy but that there is always a free gas pocket above the ingesta, varying in size with the severity of the condition. Other work supports this contention (Barrentine, 1959; Barrentine et al., 1956b; Jacobson, 1956; Jacobson et al., 1957).

d. **Miscellaneous types of bloat** In addition to the generally recognized types of bloat resulting from specific feeding conditions, another type of bloat resulting from choke is described. Barrentine et al. (1956b) mention choke bloat resulting from the swallowing of large, hard objects, such as
green fruit, beets, etc., and Blake (1955) apparently considers some forms of chronic bloat resulting from pressure on the esophagus to be a form of choke bloat. It is not known whether froth is a problem in choke bloat as in feed-lot or legume bloat, or whether choke bloat is associated with the accumulation of free gas.

Barrentine (1959; Barrentine et al., 1956b) also mentions toxic bloat, due to HCN, ammonia, etc. Hiepe (1957) describes a type of bloat associated with tetanus. Irwin (1956) discusses a condition similar to bloat, resulting from over-eating of fruit. Huffman and Cole (Cole et al., 1956) state that bloat may result from feeding toxic levels of several non-protein nitrogen compounds, particularly urea.

C. Symptoms

The description of symptoms, as presented on page one, is taken largely from the author's own observations, and from the evaluation scale of Blake (1955). Boda and his collaborators (Boda, et al., 1956) have described in detail the sequence of events preceding the death of a cow in acute bloat. Although the symptomology of the individual animal is doubtlessly important it is well to remember that the greatest danger comes when some combination of conditions leads to a serious outbreak among many or all animals within a given herd. Then, due to the number of animals involved and the
rapidity and violence with which bloat often strikes, very rapid and drastic measures are required. Time may not permit the veterinarian to be called and the farmer must be able to cope with bloat on this large scale or suffer the loss of valuable animals. Solomon (1957) has published a very vivid description of one such outbreak, which makes one realize what drastic, herd-wide measures may be required at times.

With respect to a method of predicting bloat, Sears and Reid (1955) cite the observation that skim milk from the separator may be more foamy when bloat is impending. Geddes and Johns (Johns, 1956a) observed independently that cattle grazing bloat-provoking pasture tended to become restless and difficult to handle at milking time, whether bloated or not.

D. Incidence and Severity

1. Classification of bloat severity

Every research worker who conducts experiments on bloat is faced with the problem of evaluating bloat severity. Several criteria, varying in their objectivity, have been proposed and tried, ranging from simple visual observations (Alder and Davies, 1958) to more elegant procedures such as those designed to measure intraruminal pressures. Of these last, the tympanometer of Kleiber (1945) has been used but reproducibility of measurements made with it are low (Blake,
1955; Pfizer, 1958a). Reid's tympanograph (Reid, 1957a) requires that the animals be kept in stalls. Capsule radio transmitters, like those of Payne (Gates, 1959) or of Farrar and Bernstein (1958) show some promise but work must still be done to ascertain the extent of the correlation of intraruminal pressures with bloat (Pfizer, 1958a). Reber (1956) has reviewed rumen pressure and bloat relationships briefly. Pending perfection of the capsule pressure transmitter or some similar technique, the visual criteria proposed by Blake (1955) still seem to have the most validity under pasture grazing conditions, even though animal conformation, thickness of the body wall, and other factors make it difficult to assess the degree of bloat (Pfizer, 1958a). As it stands now, one is dependent on symptoms rather than objective measurements in ascertaining what degree of bloat is present in a given animal.

2. Incidence and severity in various locales

Most of the reviews mentioned previously (Pfizer, 1958a; Cole et al., 1956; Dyer, 1959; Johns, 1956a; Johns et al., 1957; Parham et al., 1956) present some figures designed to impress the reader with the economic importance of the bloat problem. Some people say bloat is not a serious problem in their locale; Seekles (1959) states that bloat occurs only incidentally on clover in Holland and is not a major problem.
More often, however, bloat is considered to be a serious problem wherever the use of legume pastures is extensive. Perhaps the best way to judge the importance of the problem in a specific locale is to see where intensive research is being done.

Some of the very best work comes from New Zealand where the economy is largely dependent upon livestock enterprises and where it is estimated (Johns, 1956a; 1958a; Johns et al. 1957; N. Z. Dairy Board, 1956) that between ten and fifteen thousand cattle died in each of two years (1953-54 and 54-55). This represented a loss of between 0.5 and 1 per cent of the cattle population and amounted to an actual loss of 300,000 pounds sterling in the 1954-55 season. About 12 percent of the farmers considered bloat a serious problem to them.

Alder and Davies (1958) and Johns (1956a) quote English studies which indicate bloat is not quite such a serious problem in that country; nevertheless, they state that between 2 and 16 per cent of grazing animals bloat and that 15 to 50 per cent of these die. Bloat research programs also exist in Japan and South Africa, and papers have appeared describing various aspects of the problem in many languages—Russian, German, French, Spanish, Rumanian, Bulgarian and Hebrew, to mention a few—so the condition is evidently quite widespread.
Several researchers (Dougherty, 1956a; Dyer, 1959; Johns, 1956a; Parham et al., 1956) presented an estimate of $40,000,000 as the annual loss in the United States due to bloat. This figure accounts for the animal loss alone and not for any losses in production or losses in the feed value of legumes, etc. One survey indicated that bloating occurred on 83 per cent of farms with ladino clover pasture (Cole et al., 1956). In two surveys discussed by Johns (1956a) it was shown that in Wisconsin the mortality among animals affected was about 20 per cent, while in Mississippi studies mortality ranged from 10 to 13 per cent. Later studies by Barrentine et al., (1956b) in Mississippi indicated, however, that less than one per cent of the animals that bloated in their trials died from the condition; most recovered spontaneously. They also indicated that bloat losses among steers were most pronounced in the yearling age group. Parham et al. (1956) quote Oregon studies indicating an annual loss of $5 per acre due to bloat on irrigated pasture. Montana and Minnesota studies (Reber, 1956) present estimates of losses less than one per cent, and Parham et al. (1956) cite another worker who has stated that even though a 10 per cent loss is serious, such a loss may well be offset by increased gains on improved pasture. Several Iowa farmers have told the author that they expect annual losses from bloat of about one per cent, and this seems to agree rather well with
the figures quoted above. These figures possess additional significance when estimating how much farmers will pay for prophylactic and therapeutic measures.

Extensive work has been done on the bloat syndrome at the following experiment stations in the United States: California, New York, Mississippi, Iowa, Wisconsin and Maryland; many other stations have made significant contributions—Minnesota, Michigan, South Dakota and Kansas, to mention a few. All of these efforts suggest the existence of a serious bloat problem in the states concerned, and all are important centers of the livestock industry.

3. Nature of losses

Losses due to death, as discussed above, are the easiest to evaluate, although even this is complicated by the fact that ruminants tend to bloat after death from practically all causes, rendering positive diagnosis of bloat as the casus moriendi difficult (Cole et al., 1956; Pfizer, 1958a). There are, however, other less obvious losses. Nicholson (1955) mentions veterinary fees. Johns (1956a) points out that the losses of milk and meat production are also serious from animals that bloat but do not die as well as those that die. Even mild bloat will cause a reduction in feed intake with a subsequent loss in milk or meat production. Barrentine (1956) mentions the labor and expenses of the stockman in trying to
avoid bloat, and both authors indicate that another loss is that due to the hesitation of farmers to use legume pastures, even though this class of plants is generally conceded to produce the most nutritious forage. Outbreaks of severe bloat can disrupt the normal schedule of farm operations, upset the grazing rotation, and force the farmer to use reserves of hay and silage. The physical and mental strain on the farmer and his family are worthy of mention. One problem arising in breeding herds is the loss of key animals which may drastically reduce the effectiveness of the particular breeding program.

E. History

The first known mention of bloat in the literature was a description about 60 A.D. by a writer in ancient Rome (Pfizer, 1958a). He suggested "pouring vinegar through the left nostril and putting two ounces of grease in the jaws," a treatment which is surprisingly similar to those found beneficial in the course of the present study. Beddows (1952) has published a few extracts from the literature of the 18th and early 19th centuries pertaining to bloat, and the present author is also grateful to him for furnishing more of these extracts (Beddows, 1959); excerpts from some of these serve as introductions to the various chapters in this dissertation. Included are early observations and hypotheses about etiology,
and the methods of prophylaxis and therapy used by the vari­
ous men who encountered bloat in their own herds. It is in­
teresting to read there of the development of the trocar and
cannula and of the use of rumenotomy as the ultimate emergency
measure.

In spite of these early observations on bloat, it has
been since 1930 that interest in the condition has been
sparked by a remarkable increase in bloat incidence (Dougherty,
1956a). This increase in bloat has probably been due to changes
in management and feeding practices and a great increase in
the acreage of legumes. Most pertinent scientific writing on
the subject seems to be dated since 1940.

F. Etiology

1. Foam theory

As mentioned earlier, some people still differentiate
frothy from gassy bloat, but more and more it is believed
that foam formation is the prerequisite of bloat, particularly
of legume and feed-lot bloat (Pfizer, 1958a). In 1956 Phillip­
son and Cuthbertson made the following observations in a very
brief but meaningful passage in their report to the Seventh
International Congress on Animal Husbandry in Madrid (Phillip­
son and Cuthbertson, 1956):

...Modern thought suggests that foam formation is the
cause (of bloat) and that this is aided 1) by the low
surface tension and high bicarbonate content of the saliva, 2) by fermentation products such as fatty acids, C3 and upwards, which reduce surface tension, 3) by the viscosity of the rumen contents which does not allow gas to rise easily, and 4) saponins in the pasture may reduce surface tension and inhibit gastric motility.

This is not to imply that the incrimination of foam is a recent development; in 1764 (Beddows, 1959) the following observation was made:

...This distemper, if I mistake not, is owing to the quantity of air-bubbles taken down with the clover, which, being dilated by the heat of the stomach, swell it so immoderately that it leaves no room either for the lungs to play, or for the heart to expand; so that an absolute stagnation ensues."

Perhaps the source suggested to account for the foam is wrong, but the author of that particular account was certainly familiar with the presence of foam in cases of bloat.

Hungate, in the 1956 review (Cole et al., 1956) noted that in eight separate experiments formation of foam was the only factor observed to correlate with bloat. Huffman and Cole differentiated in the same review two types of bloat depending on the amount of froth present in the rumen. One type occurred when the rumen was filled with froth while the other occurred when both froth and free gas were present. They also discuss the work of a whole series of authors whose results suggest froth as the cause of bloat, and they give Quin of South Africa the credit for the first scientific investigation of frothy bloat in cattle and sheep (in 1943).

As mentioned previously, Johns (1956a) originally believed
that both frothy and free-gas bloat existed, but he later
pointed out (Johns, 1958b) that evidence points to frothing of
the ruminal ingesta as the primary cause of bloat. This
change in view resulted from the work of others and from ob-
servations made during the work done by Johns and co-workers
in New Zealand. The foam theory holds that varying amounts
of gases produced by ruminal fermentation (Brown, 1959) or
derived from swallowed saliva are retained within the mass of
ingesta when ruminants graze legumes, and a froth is formed;
incidence and increasing severity of bloat are merely due to
relative increases in foaming (Johns et al., 1957). Although
some gas is held in the foam, some free gas is evolved also
(depending upon the stability of the foam) which may be eruc-
tated in the normal manner until the eructation mechanism is
inhibited by increasing pressure (Johns, 1956b), by some
failure in the cardia-clearing mechanism (Johns et al., 1958)
or by some other mechanism as yet unexplained. One of Johns' 
co-workers, Reid, has also published experimental evidence
and recommendations (Reid, 1955, 1957a, 1958b) incriminating
froth as the primary cause of bloat, mainly on the basis of
the known action of anti-foamers in preventing and treating
bloat. Considerable work has been done by another New
Zealander, Mangan, in investigating the importance of foam in
relation to bloat and the sources of foam (Mangan, 1958, 1959;
Mangan and Johns, 1957; Mangan et al., 1959).
Blake (1955) found increased foaming in cases of both legume and feedlot bloat, as well as in cases of bloat induced by administering alfalfa extracts. Blake measured in vitro foamability and stability of the ingesta from bloated and non-bloated animals. These qualities changed little in the bloat occurring after administration of extracts, but stability increased markedly in feed-lot and pasture bloat, while, surprisingly, foamability of the ingesta decreased. The latter observation was probably associated with the decreased specific gravity (increased content of gas) of foamy ingesta; a diminished quantity of foam precursors are available per unit volume of foamy ingesta as compared with non-foamy ingesta.

Nichols (1956a, 1956b, 1957b) has stressed the importance of foam formation in feed-lot and legume bloat, although he questions the assertion that every case of bloat is due to frothing of the ingesta. He suggests (Nichols, 1956a), like Johns et al. (1957), that bloating associated with foam formation may be merely an extension of normal fermentative processes. Nichols (1957b) observed bloat in fistulated animals from which the ingesta were quite frothy and he enumerates several factors which may be responsible for frothing.

Jacobson, Brown et al. (1957) cite several pieces of evidence from their own work supporting the thesis that bloat
on pasture is due to excessive stable froth formation. This evidence included: 1) the occurrence of bloat in fistulated steers following the escape of free gas through loosely fitting fistula plugs, and the subsequent rapid escape of large quantities of froth upon removal of the plugs; 2) relief of the bloat by administration of oil (anti-foaming agent); 3) normal ruminal-reticular motility during bloat; and 4) excessive stable foam formation in vitro from ingesta samples.

California workers in two separate studies suggested that foaming may be responsible for bloat. Boda (1958) studied intraruminal pressure changes occurring with cases of bloat and after observing that pressure decreased markedly following administration of an anti-foamer (Wesson oil) he concluded that the bloat observed was due to the formation of a stable intraruminal foam. Colvin, Cupps and Cole (1958) studied eructation and related ruminal phenomena and concluded that bloat was at least partly due to the formation of a stable foam which partially or completely blocked the cardia to prevent eructation. They observed that excessive gas formation per se, is probably not responsible for foam formation, but that rapid gas formation may contribute.

a. General aspects of foam formation Berkman and Egloff (1934) have discussed the physical chemistry of foams; Adam (1941) presents another interesting discussion of foam
formation. Reid and Johns (1957), however, present what is probably a more pertinent theory of foam formation with respect to bloat. They state that there are two broad groups of foaming materials; a) solutions of soaps and detergents in which the surface tension is lower than water and in which the foams formed are non-viscous and not particularly stable; and, b) solutions exhibiting a strong surface viscosity and fairly high surface tension, yielding foams of great stability. These latter include solutions of saponins and proteins in the presence of suitable metallic salts. In foams of the first type, foam stability is related to surface tension, but there is little correlation of surface tension with stability of foams of the second type. The surface viscous and non-viscous types are mutually incompatible, so that if soap and saponins are mixed, the soap, having the lower surface tension causes displacement of the saponin from the surface layer. This reduces the surface viscosity of the system and gives a more unstable foam, thus accounting for the effectiveness of detergents as foam breakers. Apparently, Ross and Butler (1956) do not agree with Johns' theory, since they hold that proteins, saponins, soaps and detergents all impart surface plasticity when in solution and thereby produce stable and plastic foams.

Nichols (1957b) and the AgraData review (Pfizer, 1958a) present the following view of foam formation in bloat. Gas is formed in countless small bubbles which then contact each
other. The monomolecular membranes separating them rupture and they coalesce. The process continues until the bubbles become large enough to rise to the top of the ingesta mass or are broken by the mechanical action of the rumen and reticulum. During periods of excessive frothing accompanied by bloat, nearly all of the free fluid of the rumen is used to make the skins of the bubbles constituting the froth. The ingesta eventually become the foamy, sticky mass observed in cases of bloat. During excessive frothing the breaking rate of the bubbles at the surface of the rumen ingesta mass and the coalescing rate of bubbles within the ingesta are slower than the rate of bubble formation. After the "peak" of foam formation has been reached, the breaking and coalescing rates begin to exceed the rate of bubble formation and the froth becomes unstable and breaks down. As the mass of froth recedes, more and more free fluid can be obtained from the ventral regions of the rumen.

Density of the feed may also have a bearing on the problem (Parham et al., 1956). The lighter feeds, such as hays, tend to remain near the top of the liquid in the rumen and are fermented there, the gases evolved forming one large "bubble" in the dome of the rumen. Heavier feeds, such as fresh legumes or ground grains, tend to sink to the bottom of the rumen so that it is necessary for the gaseous micro-bubbles formed during fermentation to overcome considerable resistance in
passing upwards through the ingesta and in coalescing to form larger bubbles.

**b. Foam measurement**  Various methods have been used to study the physical characteristics of foams (Johns, 1956a). That of Mangan (1958) seems to hold the most promise at present for bloat research. Gas is bubbled through the sample to be tested in a calibrated cylinder at body temperature, and foam volume is plotted versus time to give a measure of dynamic foam stability. The rate of fall of a perforated weight through the foam is indicative of the foam strength. The absolute amount of foam obtainable from a standard volume of rumen ingesta can also be determined for use as an estimator of foamability.

Other methods of studying foaming characteristics include the foam volume and foam half life measurements of Blake (1955) and Blake et al., (1957), the manometric procedures of Hungate et al., (1955), ingesta volume increase, as measured by Jacobson, Lindahl et al. (1957) the foam stability measurements carried out by Lienert and Kienel (1957a) in an apparatus similar to that of Mangan (1958), and some cruder foam measurements, such as that of Kolb (1957).

**c. Physico-chemical characteristics of foams from bloated animals—surface tension, viscosity and pH**  Foam formation and stability seem to depend principally upon three physico-
chemical characteristics of the solutions from which they are formed—surface tension, viscosity and pH. Adam (1941) and Berkman and Egloff (1934) have discussed the first two at length, dwelling upon the definitive and theoretical aspects of foaming. They present no evidence pertaining directly to the frothing associated with bloat.

Dougherty (1956a) indicated the part that surface tension may play in the bloat syndrome:

...The surface tension theory holds that bloat is caused by any material that will alter surface tension so that the gas of fermentation will be entrapped in countless bubbles throughout the feed mass in the rumen....

Blake and his co-workers (Blake, 1955; Blake, Allen and Jacobson, 1956, 1957; Blake, Jacobson and Allen, 1957) found that the surface tension and viscosity of rumen ingesta increased when the animals from which the samples were taken bloated. Defoaming of the samples resulted in decreases in surface tension, and surface tension and viscosity were observed to be higher in foamy samples than in watery samples. No correlations between the phenomenon of frothing and pH values were readily discernible since the pH was higher in feed-lot bloat and lower in pasture bloat.

While Blake tended to stress surface tension measurements, Nichols (1956b) stressed the fact that viscosity of the ingesta increased during frothing. He suggested caution, however, in
attributing frothing solely to changes in viscosity (or to any single factor) because of the observation that some effective defoamers reduced surface tension without changing viscosity. In other trials he found that surface tension and viscosity of the ingesta increased on bloat-provoking diets (Nichols et al., 1956), and that frothing was associated with increases in surface tension and viscosity (Nichols, Penn and Schreiber, 1957). Although the importance of pH measurements in detecting unfavorable changes in ruminal ingesta has been recognized by Nichols and Penn (1958), Nichols apparently has not published any data on pH in relation to bloat.

Bartley (1958) has stressed the importance of increased viscosity as a cause of foaming, while Ross and Butler (1956) have attributed stable foam formation to increased surface viscosity compared to that of the underlying liquid. Reid and Huffman (1949) mentioned the role of surface tension in the physico-chemical interrelationships of the rumen bacteria and their environment.

Johns (1956a) at first tended to attribute foam stability to increased viscosity, conceding however, that surface tension and other factors are involved. By the time of his 1958 review (Johns, 1958b) he concluded that surface tension measurements of foaming agents are not relevant to the foaming
properties of rumen fluid, and his group has placed more emphasis on the importance of pH. Mangan and Johns (1957) felt that lowered pH, brought about by the production of volatile fatty acids from the supply of readily fermentable substrate present in legumes, contributed to bloat by stabilizing foam formation and by releasing extra gas from saliva in the form of carbon dioxide. Mangan (1958) suggested that the action of pH upon foam stability might be due to an indirect effect upon surface tension. The foaming agents tested have ionizable groups attached to their molecules, the state of ionization of which is concerned in the surface activity of the agent and is affected in turn by pH. Such ionizable groups are possessed both by alfalfa saponin (carboxyl groups) and by proteins in general. Mangan (1959) later investigated the dependence of foam strength upon pH in four systems possibly concerned with bloat—red-clover saponin, red-clover cytoplasmic protein, salivary muco-protein and rumen liquor. The normal pH values found in the rumen liquor were in the range 6.0 to 7.0 and these, together with the pH-foam strength curves obtained led him to believe that the foaming agent might be the cytoplasmic protein. The pH optima shifted upward with higher protein and salt concentrations, suggesting the importance of physico-chemical properties other than surface tension, viscosity and pH. Mangan's investigations pointed to several conditions necessary for foam formation:
a) the active foaming agents must be present in solution in the rumen in the required concentration for a sufficient time for foam to be formed; b) pH values, salt concentration and perhaps other factors must be suitable within the rumen for stable foam formation; c) sufficient gas must be generated by fermentation or by release from salivary bicarbonate (at low pH) for genesis of the foam; and, d) anti-foaming agents from the forage consumed must be sufficiently inactivated or diluted to permit the foam to persist.

Shinozaki and Sugawara (1957) also found that the pH of a system containing fresh forage, rumen liquor and artificial saliva decreased during in vitro fermentation. The decreases appeared to be greater in the case of ladino or red clover than where orchard grass or birdsfoot trefoil was the forage used. These decreases in pH were associated with increased volatile fatty acid production. In a later study (Shinozaki et al., 1958) there was little difference in the pH of rumen liquor from sheep receiving hay and wheat bran or grazing pasture (plant species not identified) in spite of greatly increased volatile fatty acid production on the latter feeding regimen.

Phelps et al. (1958) found that increased amounts of magnesium-ammonium phosphate were formed in the rumen from rations which formed froth, and that the quantity of magnesium-ammonium phosphate formed was inversely proportionate
to pH, i.e., as the pH decreased (more acid) magnesium-ammonium phosphate increased and froth production increased. Kleiber (Cole et al., 1956) presents an interesting and detailed discussion of the tendency of salivary bicarbonate to give off carbon dioxide when the pH of the rumen ingesta decreases during feeding. At a ruminal pH of 5.7, for instance, and with an estimated daily secretion of 60 liters of saliva, some 119 liters of carbon dioxide (about equal to half the normal daily methane production) would be derived from salivary bicarbonate. On the other hand, Lindahl and Davis (Lindahl et al., 1957) found that when saponins were administered to cattle, pH values of ingesta samples were not correlated with foam stability, suggesting that foam production and bicarbonate content of the ruminal contents were not related and that foam production was not caused directly by a difference in ruminal pH. Blake et al. (1957) suggested that pH may not be a major factor in causing bloat although it may have an indirect effect through possible interrelations with the microbiota and with other physical characteristics of the ingesta.

d. Animal factors Attempts have been made from time to time to relate a number of animal factors to bloat. Among these are mentioned eructation, absorption of gases by the blood stream, the effect of saliva, chemical composition of rumen fluid and of the blood and variations in individual sus-
ceptibility to bloat including variations in feed consumption.

1) **Eructation** Brown (1959) has recently discussed the role of eructation— one mechanism by which the gases of fermentation are normally removed from the rumen in order to avoid the build-up of pressure associated with bloat. The anatomical and physiological aspects of eructation are reviewed, with particular emphasis being placed on the neurological factors involved. Although eructation may continue through sub-acute bloat, investigations cited suggest that eructation is prevented in acute bloat physiologically by interruptions in normal nervous responses, or mechanically by flooding of the opening from the esophagus into the rumen.

2) **Diffusion of gases through the rumen wall** Although eructation probably accounts for the removal of the greater part of the gases of fermentation from the rumen (Pfizer, 1958a), Kleiber (Cole et al., 1956) has discussed the part that diffusion of gases to and from the rumen and blood may play. The permeability of the rumen wall to passage of gases even though it is composed of several layers of cornified cells has been well established. Definite and reliable data for the diffusion rates of gases through the rumen wall are still lacking but this pathway has been assigned an important role in gas elimination, particularly of carbon dioxide. The blood, however, may be the source of some gases
in the rumen (by diffusion), particularly oxygen and nitrogen. The third escape route of ruminal gases is through the feces.

3) **Saliva** Brown (1959) has stated that saliva is probably the most important animal factor involved in foam formation during bloat. The studies of Reid and Huffman (1949) indicate that saliva, with its average surface tension of 47.1 dynes per centimeter and pH of 8.53 is capable of exerting profound effects upon the physico-chemical characteristics of the ruminal contents. Phillipson and Reid (1958) reviewed hypotheses suggesting that saliva may be related to bloat in two diametrically opposed ways: a) the lack of (or decrease in) salivary secretion resulting from the ingestion of lush, non-fibrous legumes may permit the rumen contents to become more viscous and thereby aid in the formation of a stable froth; i.e., saliva is necessary to prevent foam formation; or b) the presence of saliva, itself a foaming agent, may permit the formation of a stable foam.

In agreement with the latter hypothesis Kleiber (Cole *et al.*, 1956) has pointed out the part that saliva may play in promoting foam formation when the pH of the rumen becomes more acidic. Under these conditions carbon dioxide is released from salivary bicarbonate to add to the volume of gas present which must be removed by eructation or the other pathways discussed previously. Phillipson and Reid (1958) found that
secretion of saliva increased as intraruminal pressure increased, and Johns (1958b) found that the amount of carbon dioxide necessary to raise the intraruminal pressure still further decreased as pressure increased, suggesting a possible "multiplier" effect. That is, as saliva is secreted and enters the rumen the pH drops to that of the rumen; carbon dioxide is released, leading to the formation of foam when other conditions are right. Foam formation leads to increased pressure and eventually depresses eructation. As pressure increases, saliva is secreted at an ever increasing rate, more carbon dioxide is thus formed and pressure then increases at a faster rate since less carbon dioxide is required to raise the pressure a given amount. After this cycle is repeated several times the rates of foaming and pressure increase presumably become so much accelerated that normal mechanisms of relief fail and bloating results.

Bartley (1958) takes the opposite view and concurs with the first hypothesis stated above. He found with in vitro trials that both saliva and the component which accounts for its viscosity, mucin, permitted greater amounts of gas to escape from foamy ingesta than when they were not added. Linseed meal, high in mucin, was then fed to cattle and a substantial reduction in bloat was obtained, lending support to Bartley's hypothesis. Johns and his co-workers (1958) stated that saliva may help prevent bloat by buffering a fall
in pH to levels optimal for stable foam formation. Either
or both phenomena may account for the success of Bartley's
work.

4) Chemical composition of rumen fluid Brown
(1959) has reviewed the writings concerning the importance of
the chemical characteristics of rumen fluid in bloat. At
times different workers have implicated rumen ammonia, vola­
tile fatty acids, proteins, histamine and tyramine, and mag­
nesium-ammonium phosphate, to mention a few.

5) Chemical composition of the blood Brown
(1959) has stated that a relatively small amount of work has
been done on changes in blood composition during bloat. Com­
ponents of the blood whose relationship with bloat have been
investigated include cholesterol, ascorbic acid, cholinesterase,
blood sugar, lactic acid, blood ketones, non-protein nitrogen,
\( \text{pH} \), calcium, sodium, potassium, urea, ammonia and methemo­
globin and related compounds.

6) Individual susceptibility Variations in in­
dividual susceptibility to bloating have been discussed by
several authors. Johns (1956a) observed that pasture bloat
seemed to be more common in cattle than in sheep in the
United Kingdom, the United States, and New Zealand. In gen­
eral, it appears that approximately one-third of the cattle
in a herd bloat fairly regularly, one-third rarely and one-
third not at all. The difference is probably one of degree, however, since all animals in a herd have been known to bloat if the forage is sufficiently potent. Payn (Johns, 1958b) found 80 per cent of his animals were non-susceptible, 15 per cent susceptible and 5 per cent extremely susceptible. Animals also vary in their susceptibility from time to time. Johns (1956b) suggested that differences in bloating susceptibility may be due to differences in contribution to the foaming medium by the saliva, a difference in bacterial flora, or perhaps a difference in the efficiency of the cardia-clearing mechanism regulating eructation. Barrentine et al. (1956b) found a much higher incidence of bloat in yearling steers than in older animals.

The importance of heredity in accounting for variations in individual susceptibility has been reported in papers reviewed by Huffman (Cole et al., 1956), in identical twin studies conducted by Hancock (1954) and by Johns (1954) and other studies reviewed by Johns (1956a). Some mechanisms probably affected by heredity and related to bloat are differences in composition of the saliva (Johns et al., 1958), differences in the efficiency of eructation (Huffman, in Cole et al., 1956), differences in consistency of the rumen ingesta (Bartley, 1958) and differences in ability to metabolize calcium and phosphorus (Cooper, 1957b).
The amount of feed consumed and the rate of consumption have reputedly been responsible for variations in susceptibility. Barrentine et al. (1956b), Johns (1954), and Hancock (1954) all found that such was definitely not the case, and Huffman and Cole (Cole et al., 1956) review several papers in which bloat incidence and severity were reported to be independent of total intake or rate of intake. Troughton (1955), however, suggests that intake may be correlated with bloat.

Psychological condition of cattle has been mentioned as a source of variation in susceptibility (Johns, 1958b).

e. **Microbiological factors** It seems logical to suspect that microbiological factors may influence the incidence and severity of foaming and of bloat. Brown (1959) points out that although much work has been done on quantitative and qualitative aspects of rumen microbiology little is known yet about the effect of the microbios upon bloat. From time to time the production of bacterial slimes (polysaccharides) has been suggested as a factor in the etiology of foam formation and bloat (Hungate et al., 1955) but the recent work of Bailey (1959) and Mangan (1959; Mangan et al., 1959) seem to rule out this possibility. Other aspects of rumen microbiology in relation to bloat have been recently reviewed (Blake, 1955; Brown, 1959; Cole et al., 1956; Parham et al., 1956; Pfizer, 1958b).

f. **Extrinsic factors** If the animal and microbiologi-
cal factors discussed above are considered to be intrinsic to the animal there are also a number of factors extrinsic to the animal which have been implicated in bloat from time to time. These include such things as the chemical and physical composition of the forage consumed and the direct effect of climatic conditions.

1) The chemical composition of plants

Johns (1958b) suggests that the components of plants are important in bloat in three ways: a) they are the source of the substrate for fermentation leading to gas production; b) they add foaming and antifoaming agents to the rumen fluid; and c) they may be the source of toxic compounds.

a) Fermentation substrates

Among the fermentation substrates mentioned in connection with foamy bloat are various carbohydrate fractions and organic acids. Dry matter content may be important.

With respect to dry matter content, Johns (1954) reported that bloat increased as the dry matter content of the forage decreased. In later work Mangan and Johns (1957) confirmed the previous observations, but noted a between-animal difference in the relationship of dry matter intake to bloat as well as a difference in the same animal at different periods. Barrentine et al. (1956b) found no differences in bloat from forages of different moisture content. Boda (1958) found that
dehydration decreased the tendency of alfalfa to cause bloat but observed mild bloat even on dehydrated alfalfa. The decrease in bloat may have been due to denaturation of foam precursors rather than to an increase in dry matter. In studies reviewed by Maclay and Thompson (Cole et al., 1956) the water content of alfalfa was found to have a large effect on the ratio of starch and sugars present in the leaves and stems.

Rosen et al. (1956) utilized a Warburg technique to study the rapid evolution of gas from an aqueous extract of alfalfa. Since the fraction examined contained organic acids (malic, malonic and citric) in relative abundance they suggested that the bloat-provoking power of alfalfa may result from the relative abundance of these substrates available for microbial decarboxylation. The carbon dioxide thus formed would then serve as a source of additional gas for foam formation. Mangan and Johns (1957) found that although there were generally higher concentrations of organic acids in bloat-provoking clover, it was not invariably so and the levels found in their studies were low when compared to values found in other studies mentioned. They concluded that the presence of readily available organic acids may be important in bloat when the complication of foaming is already present. Gould (1957) has reviewed the role of plant organic acids in bloat.

Conclusions of Mangan and Johns (1957) regarding the
presence of sugars in red clover were similar to their conclusions regarding the presence of the organic acids—high levels may be important when the ingesta are already frothing. In studies on rumen ingesta Mangan et al. (1959) found that the mixture of sugars detected bore no clear relationship to the mixture of sugars found in red clover extracts by Bailey (1958c). Bailey (1958b) also studied the starch content of clovers and rye grass and found that the leaves of clover were higher in starch than those of rye grass. Another interesting finding was that the clovers lost most of their starch during 12 to 14 hours of darkness. Blake (1955) added glucose to alfalfa extracts administered to cattle and observed increases in bloat incidence and severity. Glucose administered in water was fatal at high levels. Conrad et al. (1958) found that galacturonic acid, a hydrolysis-product of alfalfa pectin, was a precursor of rumen gas. Carbohydrate content of the forage was correlated with bloat in some of the studies reviewed by Maclay and Thompson (Cole et al., 1956) and not in others.

Cooper (1957a, 1957b; Cooper and Hall, 1956; Cooper et al., 1958; Cooper and Woodle, 1957) has proposed an interesting theory of bloat without, however, any confirming evidence. He suggests that plant nitrogen to phosphorus ratios much in excess of 11 to 1 and calcium to phosphorus ratios greatly in excess of 1.5 to 1 can lead to bloat. Calcium-
phosphorus ratios may be wider (up to 6 to 1) if vitamin D is available to the animal in sufficient quantities. He suggests several mechanisms to account for the postulated effect, one of which is that with a deficiency of phosphorus or an excess of nitrogen the conditions are favorable for the synthesis of unstable azo, azoxy and diazo organic groups in the plants which may contribute to the production and accumulation of gas in the rumen. Excessively wide calcium-phosphorus ratios may affect the emulsion and surface tension states of the rumen ingesta adversely, leading to bloat. The other effects suggested are mainly indirect and concerned with the formation of toxic compounds due to the imbalance of plant nutrients. These will be discussed in the appropriate place. Troughton (1955) obtained results suggesting an association of low soil phosphorus and potassium with increased bloat. Conversely, Lienert (1950) has suggested that the high phosphatase content of rumen fluid and the relatively large amounts of phosphate normally present in bloat-provoking legumes are responsible for an augmented gas production. Ross (1950) found that certain phosphates in solution tended to show strong surface activity and viscosity effects. They were also foam inhibitors.

b) **Foaming and anti-foaming agents** Johns (1958b) states that saponins and proteins are the only plant constituents considered as contributing to ruminal foaming.
Certainly saponins have received the major emphasis in recent years, but the work of Johns and his collaborators has stressed the importance of plant proteins and anti-foaming agents. Results of Conrad et al. (1958) indicate that the combined effects of the physical structure of green alfalfa fiber, pectic substances of alfalfa plants, galacturonic acid obtained on hydrolysis of pectic substances, and reducing sugars normally present are capable of causing the formation of stable foam.

The effects of saponins seem to be two-fold—as precursors of foam and as strong pharmacological agents. This area has been reviewed by Parham et al. (1956), Cole et al. (1956), Johns (1956a, 1958b) and Lindahl et al. (1957). The latter authors conducted a very exhaustive series of experiments and concluded that while alfalfa saponins may contribute to ruminant bloat they are not the sole cause of naturally occurring bloat. Both the physiological and surface activity of plant saponins can vary considerably and the role of each varies from case to case. In vitro and in vivo experiments indicated that alfalfa saponin can contribute to the formation of stable froth in the rumen but that it was not the only factor causing foam. A possible interaction among saponin, proteins and carbohydrate was postulated. The data presented seem to suggest that the physiological activity of saponins may be more significant than surface activity. Johns (1956a) notes that one of the present limitations in testing the role of saponins is that there are no simple routine tests avail-
able to determine the correlation between saponin level in the herbage and its bloating potential. Mangan (1958) postulated that the dependence of the foaming characteristics of alfalfa saponin upon pH, which he noted in his trials, may be due to the state of ionization of the free carboxyl groups attached to the tri-terpenoid nucleus of the alfalfa saponin molecule. Solutions of yucca saponin, having a steroidal structure devoid of free carboxyl groups, had foaming characteristics which were unchanged by variations in pH. Reber et al. (1957) observed no foam when yucca saponin was fed, yet bloat resulted. These results again suggest the importance of the physiological activity of the saponins. Brune (1956) obtained no bloat symptoms from the oral administration of Gypsophila saponin to sheep in doses ranging up to 20 grams per day. Other pronounced effects of the saponins were observed. Mangan (1959) studied the interrelationships of pH and foaming characteristics in several fractions from red clover and concluded that the foaming characteristics of that plant were probably due more to its content of cytoplasmic protein than saponin. Blake (1955) found that crude saponin was high in alfalfa, intermediate in ladino clover, and low in brome and orchard grasses and birdsfoot trefoil; i.e., higher in plants causing bloat readily and lower in those not causing bloat. Cholesterol precipitated saponin in alfalfa extracts when introduced as an aqueous emulsion, but failed to reduce bloat when administered to cattle concurrently with
alfalfa extract. This suggests that other factors may have been responsible for the bloat. Gutierrez et al., (1958) noted that earlier work in which bloat was produced by administering alfalfa saponins to sheep both orally and intravenously suggested more than one mode of action for the saponin. They present evidence that alfalfa saponins are utilized by certain rumen bacteria with resultant production of acids, gas and large amounts of glycosidic slime. The latter forms stable foam. Boda (1958) felt that the saponin of alfalfa was not the sole cause of frothy bloat since animals bloated on fresh alfalfa and not on dehydrated alfalfa. He assumed that dehydration did not change the saponin content of the forage, but Mangan and Johns (1957) found that oven drying markedly reduced the foaming properties of saponin extracts of red clover.

Johns (1954, 1956a) suggested that conditions in the rumen are suitable for protein to play at least a minor role in stable foam production. He cites unpublished work by Mangan in which a rapid increase of soluble protein nitrogen was observed during grazing and studies in which cytoplasmic protein of red clover was found to produce a stable foam under certain conditions. Mangan (1959) confirms these observations and concludes that cytoplasmic protein appears to be of major importance as a component of the foaming system, depending upon pH, salt concentration and protein concentration.
Boda et al., (1957) produced frothy bloat by feeding fresh egg-whites to cattle, suggesting that proteins are important in the etiology of frothy bloat. Boda (1958) later suggested that the reduction in bloat experienced when dehydrated alfalfa was fed may have been due to the denaturation of soluble protein. This view was contra-indicated by the work of Ferguson and Terry (1955) who subjected alfalfa extracts to several treatments which should have denatured any protein present, yet obtained bloat.

Johns (1956a) first suggested that the plant may be a source of anti-foaming agents as well as foaming agents, and that bloat may be due to a decrease in these natural anti-foaming agents rather than to an increase in foaming agents. Mangan (1959) found that centrifugation of rumen liquor increased its foaming properties, suggesting the presence of some anti-foaming agent in the particulate matter removed by centrifugation. Chloroplasts contain a high concentration of lipids in the form of an envelope around the chloroplast and such a structure was suggested by Mangan to have high anti-foaming properties. He found that fat-free chloroplasts have no anti-foaming properties and actually stabilize foam, so it seems probable that the anti-foaming agent in crude rumen liquor is chloroplasts or chloroplastic fragments. Later studies (Mangan et al., 1959) tended to confirm this belief.

c) Toxic factors

Plant toxic factors which may have some effect upon bloat include saponins, cyanide,
histamine and tyramine, anti-cholinesterases, flavones, nitrates, ammonia, ammonium carbamate and hydrogen sulfide, among others. A number of them are considered to cause bloat by the inhibition of rumen movement, or the eructation mechanism, or by causing systemic poisoning (Mangan and Johns, 1957). In some cases the bloat resulting may be of the free-gas type rather than foamy. Some of the ill-effects of imbalances in plant nitrogen-phosphorus and calcium-phosphorus ratios postulated by Cooper (1957a, 1957b; Cooper and Hall, 1956; Cooper et al., 1958; Cooper and Woodle, 1957) are as follows. Wide ratios, leading to phosphorus shortages may lead to deficiencies of phosphorus-containing compounds important to the animal--lecithin, cephalin, phosphatides, nucleic acids and nucleoproteins. Shortage of these compounds, important in neurological reactions, may lead to ill effects upon the nerves and muscles of the rumen, depressing eructation and causing a loss of muscle tone (distention). Phosphorus deficiency may also favor the accumulation within the plant of cyanogenic compounds, levo-rotatory glucosides and alkaloids, all of which exert a depressing effect upon the nerves of the rumen. Evidence in support of this hypothesis is found in the work of Troughton (1955). Excess calcium may, according to Cooper, lead to mineralization of the phosphorus in the soft tissues of the body; then the lack of phosphorus-containing compounds could exert an effect upon
the nerves, while the accumulation of choline leads to the formation of poisonous compounds. Cooper presents no data to confirm his hypotheses. Heinemann et al., (1957a, 1957b) present data showing that alfalfa low in phosphorus does have profound physiological effects upon the body (of rabbits) and can change the calcium-phosphorus ratios of the bones.

As mentioned previously, many of the tympanogenic effects of the saponins seem to be due to their pharmacological activity rather than to surface activity. In the studies of Lindahl et al. (1957) involving in vivo (intra-ruminal, intravenous, and intestinal administration of alfalfa saponins) and in vitro tests, the saponins were shown to possess marked physiological effects, particularly in inhibiting the action of smooth muscle in many parts of the body. They were also quite toxic, and hemolysis of the blood was observed commonly. Physiological responses were more pronounced in the triterpenoid saponins (alfalfa, quillai) than in the steroidal saponins (yucca). Bloat resulted in many cases with relatively little foam, suggesting that the saponins may have exerted their effect by blocking eructation or causing a lack of tone of the rumen musculature. Similar results were obtained in studies reviewed by Maclay and Thompson (Cole et al., 1956), Johns (1956a, 1958b), Reber et al., (1957), and Wilson et al., (1956). Doizaki et al., (1958) found an apparent activation of bovine erythrocyte acetylcholinesterase by saponin.
Cyanide has been mentioned from time to time as a cause of bloat, possibly by inhibiting eructation, but recent experiments in which the cyanide content of birdsfoot trefoil, a non-tympanogenic forage plant, was found to be much higher than that of the common bloat-provoking clovers and alfalfas suggest that it is not a factor (Blake, 1955; Maclay and Thompson in Cole et al., 1956; Johns, 1956a; Lindahl et al., 1957). On the other hand, Troughton (1955) extrapolates from the work of another investigator with sudan grass in suggesting that increases of bloat noted on plots low in soil phosphate may have resulted from increased cyanide content of the clover forage consumed. Total intake of cyanide was correlated with bloat incidence.

According to Johns (1956a) a number of workers have postulated that the central feature of bloat in ruminants is a paralysis of the rumen musculature by histamine or some similar substance. Some workers found that administration of histamine paralyzed the rumen and others found that antihistamines were efficacious in treating certain cases of pasture bloat. Dain et al. (1955) found histamine and tyramine in the rumen ingesta of experimentally over-fed sheep, but Johns (1954) found that treatment of bloat with antihistamines was ineffective and even dangerous.

Johns (1956a) says that interest in choline esterase arises from the fact that it is responsible for the hydrolysis
of acetylcholine which is the chemical mediator of the parasympathetic nervous system. Choline esterase is strongly inhibited by certain alkaloids in which case acetylcholine synthesis continues and the concentration rises. An excess of acetylcholine may cause a muscular spasm and some of the anticholinesterases have been shown to cause bloat. Research has shown little correlation of plant anticholinesterases with bloat, however, and there is some indication that saponin may activate acetylcholinesterase (Doizaki et al., 1958). Jackson et al., (1959) found no difference in acetylcholinesterase or plasma ascorbic acid during bloat. Blood cholesterol increases during bloat.

Work by Ferguson (cited by Maclay and Thompson in Cole et al., 1956) suggested that a natural flavone tricin occurring in bloat-provoking clover had strong muscle-inhibiting action. Ferguson and Terry (1955) were unable to induce bloat by administering quercetin, another flavone with greater physiological activity. Lindahl et al. (1957) reported that the amount of tricin in alfalfa is extremely small and concluded on the basis of their studies that the flavones are probably not involved in pasture bloat.

Ammonia and ammonium carbamate as possible causative agents are discussed briefly by Johns (1956a). Results of studies cited tend to be somewhat contradictory and no clear-cut conclusions can be reached.
A number of writers (Pfizer, 1958a; Jackson et al., 1959; Johns, 1956a, 1958b; Maclay and Thompson in Cole et al., 1956; Parham et al., 1956) mention other "toxic factors" thought to cause bloat.

d) Soil fertility Johns (1956a) stated that both fertilizer treatment and soil mineral deficiency have been claimed to induce bloat, but it is difficult to determine whether the effect of treatment is upon the chemical composition of the plant or whether, by making conditions more nearly optimal for growth, the balance of species among the pasture plants has been altered.

Cooper (1957a, 1957b; Cooper and Hall, 1956; Cooper et al., 1958; Cooper and Woodle, 1957) postulated that since the legume crops are relatively independent of the effect of added soil nitrogen the nitrogen-phosphorus and calcium-phosphorus ratios could best be kept in balance by phosphate fertilization. As discussed previously, this should prevent bloat. He found that both phosphorus and potassium were necessary for optimal yields. Troughton (1955) also obtained results suggesting that low soil phosphorus and potassium levels were conducive to bloat. Parham et al., (1956) cite Canadian work by McIntosh which indicated that highly fertile pastures did not cause bloat while fields of low fertility did.

On the other hand, Ward (1959) reports that phosphorus
fertilization did not prevent bloat while Barrentine (1959) found evidence that high phosphorus levels aggravated bloat. Power et al. (1955) note that the chemical composition of plants is determined by many factors other than the level of soil fertility. These factors include soil moisture, light intensity and duration, temperature, species and variety of plant, plant organ or tissue analyzed and stage of maturity, and may be considered either genetic or environmental in nature. Genetic factors have long been studied but recently the effects of environment—for example, the effect of soil type or climate—upon plant composition have received more attention and have been found to exert a greater influence than fertility levels. Thus, frequent contradictions reported in the literature concerning fertilization effects upon composition may be explained by quantitative and qualitative differences in environmental factors. Power and his co-workers did find that under their conditions the treatment of alfalfa with lime, phosphorus or potassium had profound effects upon the concentration of various plant constituents (protein, phosphorus, calcium) mentioned in connection with bloat. Gerwig (1956), Gross (1956), Nelson (1956) and Wilkins et al., (1958) have discussed the effects of fertilization upon plant composition. Heinemann et al., (1957a, 1957b) cite many other studies on soil-plant and plant-animal interrelationships and on the basis of their own trials in which rabbits received
alfalfa hay from plots low or high in phosphorus, suggest
definite soil-plant-animal interrelationships for that min-
eral.

2) Physical characteristics of plants Huffman
and Cole (Cole et al., 1956) and Johns (1956a) reviewed
thoroughly the papers pertaining to the importance of the
physical nature of the feed in bloat. A lack of scabrous
material in the rumen during ingestion of lush legumes has
often been incriminated and several mechanisms related to
those discussed previously are suggested to account for the
phenomenon. Generally speaking, the mechanisms suggested in-
volve failure to stimulate salivary flow (thus forming a more
viscous rumen ingesta) or a failure in the eructation mech-
anism due to a lack of an effective stimulus. Huffman and
Cole concluded that the correlation of lack of scabrous materi-
al in the diet and bloat was more accidental than causal since
some bloat resulted on quite coarse diets and bloat did not
always result from diets lacking coarse material.

Although the "old" physical deficiency theory may not
hold, recent work suggests the importance of certain physical
characteristics of forage plants. Mangan and Johns (1957) con-
cluded that differences between bloating and non-bloating forage
were probably not due to differences in concentrations of chemi-
cal constituents, but rather due to the degree of maceration of
the plant during the first chewing. This degree of maceration is probably related to the succulence of the plant and physical status of the forage may thus play an important role. Colvin et al., (1958a) attributed differences in rate of fermentation in vitro to differences in availability of fermentable substrates. Conrad et al., (1958) found that their results and those of other studies suggested that stable foam might arise from interaction of several units of the legume plant cell—cell wall, middle lamella and cell sap. Green alfalfa fiber composed mainly of cell wall structures provided the structural network for a stable foam when blended in vitro with water or rumen liquid. The fiber of birdsfoot trefoil and grasses had no such effect.

3) Climatic and other factors Various climatic conditions have been incriminated as a cause of bloat from early times (Beddows, 1959), with conditions leading to wet forage (rain, dew) being the ones most often mentioned. Johns (1956a) reviews several papers in which many different weather conditions are suggested as being responsible for bloat. None of the conditions mentioned were actually correlated consistently with the production of bloat. Johns et al. (1957) found no effects due to climate in their bloat trials. Troughton (1955) found no correlations between maximum and minimum temperatures, rainfall, sunshine, or humidity and the incidence of bloat. Barrentine (1959) found no basis for the
belief that grazing dew- or rain-wet legumes causes bloat and suggested that most cases of critical bloat actually occur on clear warm days. The Mississippi workers (Barrentine et al., 1956b) found that intensity of bloat appears to increase two or three days after a rain if the rain is preceded by a dry period. Blake (1955) found little distinct correlation between air movement, mean temperature, mean relative humidity, rainfall or cloudiness and bloat. Alder and Davies (1958) found varied weather conditions when they obtained bloat and could not correlate bloat and weather. Mild bloat occurred when either wet or dry forage was fed. Jackson et al., (1959) found no consistent correlation between bloat and daily precipitation or temperature. Gerwig (1956) found that the amount and distribution of rainfall during the growing season were important in determining balances of nutrients in plants.

Barrentine et al., (1956b) and Colvin et al., (1958b, 1959) found that animals pastured or fed twice daily bloated to about the same extent in morning and evening. However, Colvin et al., (1959) observed more bloat in the morning than in the evening among cattle fed soilage. Blake (1955) found that animals continuously on pasture bloated more in the evening than in the morning, but Troughton (1955) found no differences. Johns (1954) cites other studies leading him to conclude that the time of day when maximum bloat occurred varied with conditions. Work cited by Maclay and Thompson
(Cole et al., 1956), work of Bailey (1958b) and findings of Tukey et al. (1957) indicate that diurnal variations in plant composition, particularly of the carbohydrate fraction, may be responsible for differences observed.

Johns et al., (1957) and Barrentine (1959) noted that a day or two was needed for adaptation before animals bloated after first being put on legume pastures. Troughton (1955) found that most bloat occurred during the first 24 hours animals grazed a given plot.

2. Other theories of bloat

In most reviews (Brown, 1959; Cole et al., 1956; Johns, 1956a, 1956b; Parham et al., 1956) the foam theory is considered separately from several other theories. For the purposes of the present review, however, since most legume bloat is now generally considered to be frothy bloat, the other theories have been considered as they may pertain to the foam theory.

G. Prophylaxis

Reid (1956; Sears and Reid, 1955) suggests that the most logical program of bloat prevention includes pasture management as the long-range objective, with grazing control, feeding of roughage or feeding of anti-foam agents used to combat the problem on a short-term basis. To these measures may be
added the feeding of antibiotics (Barrentine, 1959) which has been an innovation since that time and certain other measures which will be mentioned. It is interesting to note that all of the measures discussed by Reid were in use in one form or another in the eighteenth century (Beddows, 1952, 1959).

1. Pasture management

Reid (1956) stresses the use of mature, grass-dominant legume pastures as the best single measure of protection against bloat. The most efficient way to prevent bloat, perhaps, would be to eliminate the legumes, but their feed value is extremely high and the more logical procedure is to reduce the intake of potent forage to safe levels by diluting it with harmless feed. The "safe" level of legume to use in the mixture is difficult to determine because bloat may occur with relatively low proportions of legumes when they become bloat-provoking. A proportion of less than 50 per cent legumes is often considered safe but bloat may occur on pastures containing 25 to 30 per cent legumes. Maintaining the proper balance of the grass and legume species requires close attention to fertilization, drainage, fencing, more persistent strains of grass, weed and insect control, grazing control and other managerial factors. Cole and Colvin, (Cole et al., 1956) mention the importance of regular clipping to prevent development of unpalatability in the grasses, but Parham
et al., (1956) mention clipping as a cause of unpalatability which resulted in increased consumption of clover and increased bloat. Cooper's (Cooper and Woodle, 1957) suggestion that phosphate fertilization prevents bloat seems to be contradicted by the recommendations presented above since phosphate fertilization tends to boost growth of the legumes and will therefore increase the proportion of legumes in a pasture mixture. Nitrogen fertilization is helpful in bringing grasses along and keeping their proportion high. Other aspects of the problem of maintaining palatability are discussed by Cole and Colvin (Cole et al., 1956).

2. Grazing control

From early times (Beddows, 1952, 1959) various methods of grazing control were advocated to prevent bloat. Introducing the animals to legume pasture gradually and keeping them off dew- or rain-wet pastures are traditional measures, but Barrentine (1959) has found that bloat does not result when animals first graze legumes anyway, and the lack of correlation of bloating with wet forage has already been discussed.

According to Reid (1956), there are two main objectives in measures involving grazing control. They are: a) restriction of selection and prevention of "skimming" of the succulent
tops of the plants believed to be more potent than the remainder of the plant; and b) alteration of the grazing pattern and reduction of the rate of intake to levels permitting the animal to cope with the potent material.

a. Selection control—soilage  Reid (1956) mentions control of selection by cutting the forage and feeding it in another location or allowing the animals to pick it up themselves. The former method, known as "green chopping," "soiling," or "zero grazing", has been discussed by Brown (1959), who noted that this method has been successfully used in the experimental production of bloat in spite of a postulated preventive effect due to consumption of the entire plant. Johns (1956a) cites the studies of Newbold, who found that when stalks and leaves of red clover were fed separately, bloat occurred on both. If selection of the forage is to be prevented when systems other than zero grazing are used, palatability becomes of prime importance (Cole and Colvin in Cole et al., 1956).

b. Alteration of the grazing pattern  Hancock's (1954) trials with identical twins are classics in this area. He found that strip grazing, with or without restrictions of intake, gave no effective control of bloat. Frequent short periods of pasturing showed some promise, but required much extra labor. Similar results were found in studies reviewed
by Cole and Colvin (Cole et al., 1956). Barrentine (1959) and Parham et al., (1956) cite studies in which alternate grazings on grass and legume pasture were effective but Sears and Reid (1955) and other authors cited by Parham et al. (1956) advise against this procedure since they feel it encourages selection due to differences in palatability.

3. Roughage feeding

Beddows (1952, 1959) again cites early writings pointing to the use of coarse roughages as a bloat preventive. Cole and Colvin (Cole et al., 1956) have reviewed the papers concerning this method of prevention. It has been found that alfalfa and barley hays are not effective, but that sudan hay is an effective preventive when fed overnight before grazing. Barrentine (1959) feels that although the practice may be sound it is not practical. Reid (1956) found that pre-feeding hay was not successful, while hay made from bloat-provoking red clover caused bloat. Geddes (Johns, 1956a) found pre-feeding hay ineffective, as did Thomas (1956). Colvin et al., (1958b) found that the overnight feeding of an average of 12 pounds of oat hay per cow significantly reduced the incidence and severity of acute legume bloat. Colvin and his co-workers (1958b, 1959) postulated three possible mechanisms by which oat or sudan hay may prevent bloat: a) by acting physically as anti-foamers; b) by acting chemically as anti-
foamers; or c) by stimulating ruminal motility and eructation through their effect upon the nerve receptors in the rumen wall. Dyer (1959) postulates that hay acts as a physical barrier to prevent micro-organisms from attacking the succulent forage and also reduces the intake of bloat-provoking feeds. Johns (1956a) expresses interest in the possibility of feeding silage to prevent bloat, but at the time of his review there were no reports in the literature concerning the use of silage as a pre-feed in bloat control.

4. **Anti-foaming agents**

If bloat is largely due to an accumulation of foam it seems logical to use anti-foaming agents to prevent the condition. Colvin and Cole (Cole et al., 1956) mention anti-foaming agents only casually and the work that has been done in that area has been reported since 1954. Eighteenth century farmers, however, (Beddows, 1952, 1959) used anti-foamers. Sears and Reid (1955) and Johns (1956a) stress the efficacy of anti-foaming agents in preventing bloat even though the agents used are lost rapidly from the rumen, probably by passing on through the digestive tract. They suggest overcoming this problem by giving larger amounts of the agent at intervals, or giving smaller amounts continuously with the feed. Reid (1958) suggests that any practical preventive agent must be cheap, and must not affect health or appetite.
of the animal or the production of its milk or butterfat.

Ross (1950) conducted an exhaustive general investigation of foam inhibitors and suggests that the most pronounced foam inhibitors are generally insoluble in the foaming systems against which they are effective. His results indicate that the chemical inhibition of foams can be accomplished by more than one mechanism and several factors may be simultaneously active. He furnishes a description of the mechanics of some phenomena found to be associated with foam destruction and discusses a number of chemical agents. Some of these are the long chain alcohols, fatty acids and fatty acid esters, amines and amides, ethers, phosphate esters and metallic soaps of fatty acids. He concludes that the ability of a substance to act as an anti-foamer depends on its spreading ability in the foam under consideration. Ross and Butler (1956) found a significant parallel between the concentration ranges for effective foam inhibition and those in which the agents showed marked inhibitory destructive action on the formation of a plastic surface film (high surface viscosity).

Lienert and Kienel (1957a, 1957b, 1957c) used an in vitro technique to test the effects of a great number of foam inhibitors upon foams from saponin solution or potato juice. Results indicated a rather wide variation in ability to prevent foam formation or to break stable foams among members of
a group of inhibitors, among groups of inhibitors and within any inhibitor on the two different foam systems used. This suggests that although many inhibitors seem to be effective it may be difficult to choose those effective against bloat on the basis of *in vitro* trials.

Nichols (1957b; Nichols *et al.*, 1957) screened some 250 surface-active compounds for their effects upon rumen fluid and micro-organisms and concluded that although many of them were effective foam breakers and effective in treatment, their effectiveness in prevention was limited by the short time which they remained in the rumen. He found that the length of reduction of surface tension did not exceed $1.5$ hours for any of the agents studied.

*a. Oils* Berkman and Egloff (1934) mentioned the use of certain oils as foam inhibitors 25 years ago. Long before that (Beddows, 1952, 1959; Pfizer, 1958a) the oils were used in bloat prevention. The New Zealand workers have been particularly active in developing the use of certain oils in bloat prevention. Johns (1954) reported that paraffin, peanut oil, olive oil, soybean oil and turpentine were effective in preventing bloat in cattle stall-fed red clover. Reid and Johns (1957) found that various methods of administration of any of the vegetable oils, whale oil, emulsified tallow, or liquid paraffins to cattle before feeding bloat-provoking red clover
protected those animals from bloating, but only for a limited time. Dose rates as low as 50 ml. of the oils or 30 gm. of tallow were found effective. When bloat was prevented by pre-feeding treatment the intake of potent forage increased as much as twice over that of bloating animals. Doses of oil up to 250 ml. failed to give any protection at a subsequent feeding, but 750 ml. of undiluted peanut oil given before morning feeding carried over to the afternoon feeding. No treatments given before the afternoon feeding carried over to the next morning. Mixing the oils with various carriers (grain feed, bran, alfalfa, chaff or sawdust) may have prolonged the effect very slightly. The limited duration of effect may be due to the lack of solubility of the oils and low specific gravity—factors contributing to their rapid loss from the rumen. The effects of the oils are variable with respect to surface tension and their modes of action appear to depend upon their individual physical characteristics. Ferguson and Terry (1955) found the sodium salt of a highly sulphated oil ineffective when administered (3 gm.) to sheep drenched with red clover juice.

Reid (1955, 1956, 1958a; Sears and Reid, 1955) found that spraying pasture with oils is an effective preventive of bloat. The theory behind pasture spraying is that the animal consumes the anti-foaming agent continuously with the forage and thus the effect of rapid elimination from the rumen is
overcome. Oils used and found effective were emulsified peanut oil (25-30 ml. per cow), emulsified tallow (30 gm. per cow) and cream (15-60 gm. butterfat per cow). Oil was applied two ways: by spraying the total area to be grazed in a day, or by spraying a small strip of the total area to be grazed in a day. Both methods were effective in preventing bloat but Reid felt that the strip-spraying method would limit oil intake to a relatively short time and thereby have the same effect as pre-feeding the oil—duration of effect would be limited. Also, some animals may not wish to graze in the sprayed strip. On the other hand, spraying the total area requires careful calculation of the area needed, but furnishes constant protection. Strip spraying caused some wilting of the plants in the area sprayed but neither method affected subsequent growth. When spraying, the amount of oil (or fat equivalent) recommended is 3 ounces per head per day. Various techniques, emulsifiers and types of equipment for spraying are discussed.

Geddes (Johns, 1956a) and Flynn (1957) have confirmed the effectiveness of pasture spraying as a preventive in work in Australia. Peanut oil (2-3 ounces per head per day) was used in both studies; Geddes also used emulsified tallow with good results.

Reid (1955, 1958a; Sears and Reid, 1955) early recognized the alternate possibility of treating the drinking water with
the oils to be used for prevention and cited several advantages for this method—little labor required, no capital outlay for equipment, no restrictions on grazing management. However, water treatment appeared to be less reliable than spraying because of variations in drinking patterns among animals from day to day. Water intake is markedly affected by factors such as the air temperature, the dry matter intake, the dry matter content of the forage, level of milk production and other management practices. The method is not practical in fields where cattle have access to a stream or pond. It may be used as a valuable supplement to spraying—during periods of mild bloat spraying might be discontinued in favor of water treatment and then resumed when bloat became severe. Peanut oil is recommended, at a daily rate of 3 ounces per head, and need not be emulsified. Southcott and Hewetson (1958) poured peanut oil into the drinking water of two groups of animals. One of the groups also received hay treated with the oil. Treatment was least effective in the morning, probably due to failure to drink the treated water before early morning grazing. The oil treatment apparently increased weight gains when bloating was serious, but not when bloat was mild; the authors felt that this effect was probably due to increased dry matter intake by animals in which bloat was prevented by the oil, as suggested by the report of Reid and Johns (1957). Mitchell et al., (1958) gave 0.1 per cent crude lecithin, 0.67 per cent emulsified crude soybean oil
or 0.67 per cent emulsified crude soybean oil concentrate in the drinking water to steers grazing mixed legume pastures. Some reduction in bloat was noted but protection was far from complete with any of the oils.

Reid (1958a) suggested oil-treated hays or licks as a possibility, but he felt these too were undependable because intake varies considerably. Relative palatability of the forage would be the limiting factor. Erwin et al., (1957) added fat to the concentrate mixture fed to steers on green-chopped alfalfa and found decreased bloat incidence and severity and increased weight gains. They also postulated that the increased weight gains may have been at least partly due to decreased bloating. Johnson, Dolge, et al., (1956) found that inedible tallow fed to calves in a calf starter (10 per cent, by weight, of the starter) decreased bloating. Boda et al., (1957) administered vegetable oil to cattle during artificial bloat studies and found that it kept intraruminal pressures from increasing without affecting the number and rate of eructations or the total amount of gas produced. Clavin et al., (1959) found that administration of Wesson oil (175 ml.) before feeding alfalfa tops prevented increases in intraruminal pressure while administration of the same amount of oil after bloat has begun to develop caused the rapid reduction of pressure. Under feed-lot conditions oil fed on soilage decreased the incidence and severity of bloat during the feeding period at which fed when
intakes were in excess of 0.06 pounds of oil per animal. There was little carry-over effect to the next feeding period. Similar results were obtained by feeding tallow or yellow grease in a concentrate mixture.

New Zealand workers conducted a series of investigations to investigate side effects of the use of oils in bloat prevention. McDowall, Patchell and Reid (1957) found that drenching cattle with 300 ml. of whale oil twice daily for three days did not cause any change in milk yield, fat or solids-not-fat content of the milk, but very objectionable off-flavors developed in the milk, cream and butter for several days after drenching. Butterfat properties were adversely affected. Drenching for six days caused similar flavor changes and also depressed milk production, fat test and fat yield as well as changing the butterfat characteristics. Emulsification did not modify the effects and the authors concluded that whale oil is unsuitable for bloat prophylaxis and therapy. McDowall, Reid and Patchell (1957) drenched cattle twice daily for three days with 300 ml. of linseed oil, soybean oil or peanut oil or with 125 gm. of emulsified mixed beef and mutton tallow. Such treatment did not affect milk yield, fat test or solids-not-fat content of the milk. Giving smaller doses of peanut oil for longer periods of time or spraying the pasture with peanut oil did not affect milk yield or composition over a period of 21 days.
The linseed oil and soybean oil drenches produced off-flavors in the milk, but peanut oil or tallow had no serious effects on flavor. The oils produced some effects upon butterfat characteristics, even at low levels, but the effect of the tallows was negligible. The authors concluded that it would be inadvisable to treat more than a small proportion of the herd at one time with high dose rates of vegetable oils, with peanut oil being the oil of preference. At the rates recommended for treatment or prophylaxis tallow and vegetable oils could all be given safely to the herd over long periods.

Liquid paraffins (mineral oils) were as effective as vegetable oils in relieving bloated animals and are cheaper, but possible side effects needed investigation. Reid and his co-workers conducted a series of experiments on the effects of ingestion of paraffins by ruminants. Reid (1957b) found that the light paraffins reduced feed intake seriously and since they are not superior to heavy paraffins for treatment or prevention, their use is contraindicated. Single doses of heavy paraffins (200 ml.) were without effect on feed intake. McDowall, McGillivray and Reid (1957) found that ingestion of heavy liquid paraffin at the rate of 75 ml. twice daily for 26 days did not affect the yield or composition of the milk and butterfat, with the exception of depression of the vitamin A and E content, which paralleled decreases in blood
carotene and tocopherol. Color of the butter was lighter.

McGillivray (1957) investigated plasma and milk fat levels of carotene and vitamin A and concluded that depression of levels of these compounds in the plasma is proportional to the dosage level of paraffin. He found that dosage with paraffin oil is not dangerous to the health of the cow, but may have nutritional implications for humans through decreased vitamin A content of the milk produced. McGillivray and Worker (1958) noted that the depressant effect of the paraffins upon fat soluble vitamins varied with the melting point of the paraffin. With respect to a possible depression of vitamin K, Reid and Hutchings (1959) found no changes in blood plasma prothrombin times when cows were drenched twice daily for 26 days with 75 ml. of heavy paraffin. McGillivray et al., (1959) discovered no subsequent effect upon milk and fat yields when heavy liquid paraffins were administered to cows near parturition. The vitamin A activity and tocopherol content of the first milk drawn after parturition were unaffected but these values subsequently decreased more rapidly than usual, suggesting a reduced vitamin potency of the colostrum for calf feeding. Blood carotene and tocopherol levels decreased markedly in the cattle. Of possible interest in this connection was the finding of an unidentified factor in alfalfa which counteracts mineral oil toxicity in the rat and mouse (Ershoff and Hernandez, 1958). Hardison et al., (1956)
found that feeding soybean lecithin did not decrease dry matter digestibility of a hay ration, and therefore, according to those authors, should not affect digestibility of green pasture.

Although the preventive action of oils is generally considered to be due to their anti-foaming properties, Dyer (1959) feels that the action is due to the formation of a physical barrier by the fat upon the plant within the rumen, slowing down the attack of microorganisms. The two suggested modes of action may be additive in their effects.

b. Detergents Blake (1955, et seq.) fed a detergent (Ultrawet "K", a sodium alkyl aryl sulfonate) to cattle on pasture at the rate of 18 or 30 gm. per 1000 lb. of live weight; the higher level decreased bloat incidence and severity significantly, while depressing surface tension, viscosity and foamability of the rumen ingesta. The beneficial effect was not obtained, however, when the detergent was fed with forage extracts. Lack of palatability of the detergent was a problem. Barrentine et al., (1956b, 1957) fed Ultrawet "K" to steers on ladino pasture and found that bloat was not prevented at levels of detergent up to 8 gm. per day; at 10 gm. animals went off feed. Single dose administration of 20 to 30 gm. of detergent reduced bloat somewhat for a half day. Several detergents administered at
the 10 gm. level to sheep failed to reduce bloat (Ferguson and Terry, 1955). Nichols et al., (1957) mention several interesting characteristics of the detergents—detergency, surface activity, emulsification, wetting ability, foaming ability, bacteriocidal activity, resistance to pH change, dispersibility and penetrability. Reid (1955, et seq.) used the detergents as emulsifiers in oil sprays for pastures. Oxford (1959) found that pluronic detergents were lethal to certain rumen protozoa possibly associated with bloat. Hardison et al., (1956) found results suggesting that detergents may lower dry matter digestibility of the ration.

c. Silicones Johns (1954) mentioned that silicones were effective in treating and preventing bloat; however, those he used were dissolved in paraffin oil and the reduction in bloat may have been due to the paraffin as much as to the silicone. He has since concluded (Johns, 1958b) that the silicones are completely unreliable in bloat control for some reason that is not clear. Ferguson and Terry (1955) obtained encouraging results from administration of DC 550 to sheep. Barrentine (1959; Barrentine et al., 1956b) mentions trials where 20 gm. DC Antifoam A, a pure silicone, given before grazing, prevented bloat, but only for a few hours. Some commercial products tested, containing methyl silicone, were not effective when fed at five times the recommended dose, making their use economically unfeasible. Ad-
ministration is also a problem. Reid (1958a) found that spraying the pasture with as much as 4 gm. of AC Antifoam AF per cow was ineffective in preventing bloat although the animals consumed the sprayed pasture readily. Reid and Johns (1957) mention trials by several other researchers in which silicones were found unreliable as a preventative. Jacobson et al., (1957) also found them unreliable, as did Miltimore (Nicholson, 1955). Fox et al., (1947) discuss the surface-active qualities of the silicones. The surface tension of the various polymers of methyl silicone range from 16 dynes for the dimer to 20 dynes for the 17-mer. Blake (1955; Blake et al., 1957) found that various silicone-containing products lowered surface tension of the rumen fluid, both in vivo and in vitro. Schumacher (1957) found that silicone destroyed foams on samples of rumen fluid from bloating cattle. It also decreased the surface tension and raised the viscosity (at high concentrations) of the rumen ingesta. Inhibition of foaming was not complete but was optimal at a concentration of 0.3 per cent of the rumen fluid. Schumacher stresses the importance of pre-feeding the silicones to implement mixing before foaming begins. Nichols et al., (1957) found that the silicones they tested had an intermediate effect in lowering surface tension, but did reduce gas production slightly and controlled foaming. Johns et al., (1957) concluded that the silicones are unreliable
and that although they are highly surface active they may not possess the ability to spread and mix through the rumen ingesta, coating instead some of the solid material present. The latter phenomenon may explain Nichols' observation of reduced gas production, and may account in part for whatever beneficial effects of the silicones have been observed.

d. Other anti-foamers Among other anti-foamers used in bloat prevention is mucin. Bartley (1957, 1958) found that feeding 1 to 2 lb. of linseed meal, a feed relatively rich in mucin, reduced bloat incidence and severity during a subsequent grazing period. In vitro trials indicated that mucin may exert its effect by reducing the viscosity of the rumen ingesta, thus preventing gas entrapment.

Reid (1958a) used Avlinox, a ricinoleic acid derivative, successfully in preventing bloat in sheep by spraying it on the pasture. The effect lasted 4-6 hours. Drenching cattle with 10-15 ml. of Avlinox also afforded some protection during grazing (Reid and Johns, 1957). Indications are that a dose of 15 ml. is necessary for cattle. Ferguson and Terry (1955) used Avlinox (3-10 ml.) successfully on sheep. Other anti-foamers have been used from time to time.

5. Antibiotics

Administration of antibiotics is the newest form of bloat prophylaxis. Barrentine (1956; Barrentine et al., 1956a) re-
ported that 75 mg. per head of procaine penicillin gave complete protection for a period up to 3 days to yearling steers grazing clover. Chlortetracycline, oxytetracycline, bacitracin and streptomycin were also tested, but penicillin was the only antibiotic which inhibited bloat when given in doses of less than 300 mg. There was some indication that doses as low as 25 mg. were effective. It required several hours for the antibiotic to become effective after administration. The nature of the procaine penicillin carrier and concentration of penicillin in the carrier appeared to have little effect. Barrentine and co-workers (1956b) later suggested that the dosage should be increased to 100 mg. or more. The Mississippi workers (Barrentine et al., 1957) also field-tested a penicillin-salt mixture (50 mg. penicillin per ounce of salt) and concluded that the mixture was of definite value in reducing the incidence of bloat in cattle grazing legume pastures. In some trials, however, effectiveness was quite low. Salt consumption in all trials varied from 0.3 oz. to 1.37 oz. per day; the average was about 0.7 oz., at which level penicillin intake was well below the 50-100 mg. recommendation. Another disadvantage of feeding the penicillin with salt is that the penicillin is relatively unstable when the mixture is exposed to air and moisture and potency decreases appreciably after two to three days. In later trials Barrentine et al., (1958) found that erythromycin was
as effective in controlling bloat as penicillin, although somewhat more expensive. Thiostrepton was tested and found ineffective in doses up to 300 mg. Bacitracin and oxytetracycline were re-tested and although bacitracin again proved ineffective in doses up to 300 mg., the results with oxytetracycline were more promising than before. It was still considerably less effective than penicillin in equal doses, however. The Mississippi workers also noted the development of resistance to penicillin, erythromycin and oxytetracycline and concluded that it was not resistance to an individual antibiotic but rather a generalized cross-resistance. On the basis of these findings they suggested that penicillin-feeding should not be started until needed. Barrentine (1959) has reported that 50 mg. per head daily of penicillin fed to steers controlled bloat for 28 days. There was some loss of efficiency about the sixteenth day, but efficiency again increased and protection was good on the 28th day, after which feeding was discontinued and incidence and severity of bloat increased. As nearly as can be determined no controls were employed and it seems possible that the increased efficiency observed after the sixteenth day, together with the increase in bloat after feeding was discontinued, may have been coincidental with whatever conditions were responsible for the day-to-day variation in bloating among untreated animals. Barrentine also observed that even though some animals began to bloat after 10 days to two weeks, the rest of the
herd still received some protection from the antibiotic.

Emery et al., (1958) reduced the incidence of bloat on pasture by about two-thirds by feeding 100 mg. penicillin per cow daily, either with the grain or in the salt. Efficiency of treatment decreased as the season progressed but bloat incidence also decreased. They recommended feeding 50 mg. of penicillin when bloat becomes a problem and gradually increasing to 100 mg.

Thomas (1956) found that administration of single doses of penicillin (100 mg.) to cows prevented bloat after 12 hours and up to 96 hours. Studies on the rumen ingesta of fistulated cattle indicated that foaming was depressed. Digestibility of the forage was not affected by doses of penicillin up to 300 mg.

Johnson and Bailey (1958) found that 38 mg. of penicillin, equal to 62,500 units (author's note--this appears to be an inconsistency, as most relatively pure penicillin contains about 1000 units of activity per mg.), reduced the incidence, but not the severity, of bloat in dairy cows on lush alfalfa pasture. Jacobson et al., (1957) found penicillin (dosage not given) effective in preventing bloat in 12 of 13 cows under known bloating conditions. Moore et al., (1957b) found that a single dose of 25 mg. of penicillin given to sheep be-
fore drenching with alfalfa juice reduced bloat by about 77 per cent the day after administration; the effectiveness of the treatment decreased rapidly thereafter.

Johns (1958b) obtained fairly effective control of bloat by using 200 mg. of penicillin every 48 hours. Some animals did not respond to the treatment, and in other trials (Johns, 1957) he found it was only 50 per cent effective. He states that antibiotics exert their effect by depressing gas production; most rumen bacteria are gram negative except those responsible for the last stages of fermentation and gas production and against which penicillin is effective. Thus, penicillin in the rumen probably reduces gas and acid production without influencing seriously the remainder of the bacterial digestion. Johns et al., (1959) conducted a series of studies on possible harmful effects of penicillin. Cattle were given 100 mg. daily for 15 days, 500 mg. daily for 12 days, or 200 mg. per day for 5 months. There was no evidence of transfer of penicillin to the milk or of any adverse effects upon the general well-being of the cattle or upon their milk and butterfat. In some cases, marked increases in appetite were noted, resulting occasionally in overeating and subsequent failure to let down the milk. Adverse effects reported by other workers (mostly resulting from high levels of penicillin administration) are reviewed. Mangan et al., (1959) investigated the effects of penicillin in doses of 100 to
500 mg. upon the fermentation and foaming properties of rumen contents. Foaming decreased markedly as did volatile fatty acid and ammonia production and protein breakdown. Reducing sugars and lactic acid accumulated while soluble protein concentration rose rapidly during feeding on red clover. These effects disappeared with repeated dosing. The sensitivity to penicillin apparently returned after two months without penicillin. The authors postulated then that penicillin probably exerts its preventive effect by inhibiting rumen bacteria which normally modify the chloroplast lipid in some way to depress its anti-foaming activity—probably by hydrogenation or by the action of microbial lipase. Results also indicated that the penicillin may slow down particular steps in fermentation and gas production. Stern and his co-workers (Murphy, 1952) found that penicillin at low levels lowers the surface tension of the contents of the intestine of chicks, suggesting a possible similar effect upon rumen ingesta.

Examination of the Handbook of Toxicology (Spector, 1957) reveals some interesting facts about the antibiotics used in bloat studies. The antibiotics found effective—penicillin, erythromycin and oxytetracycline—vary widely in chemical structure, but are effective against Gram positive bacteria. Contrary to the assertion of Barrentine et al., (1958) there is no generalized development of resistance of organisms to
all antibiotics. Occasional cross-resistance develops between two specific antibiotics; i.e., between erythromycin and carbomycin, or among the tetracyclines, but there is no cross-resistance between penicillin and erythromycin, for example. The failure of chlortetracycline to give good results in Barrentine's trials when oxytetracycline did may have been due to the order in which they were fed; cross-resistance can be expected among compounds with similar chemical structures. The failure of thiostrepton and bacitracin to prevent bloat, even though they are effective against Gram-positive bacteria, may have been due to their polypeptide nature. It is possible that they are rapidly hydrolyzed in the rumen and lose their effectiveness. Other commercially available antibiotics which might be expected to be effective on the basis of structure, lack of cross-resistance and spectrum include vancomycin, chloramphenicol, neomycin and novobiocin. Others which might be effective but have demonstrated cross-resistance with erythromycin are carbomycin and oleandomycin. The polymixins, subtilin and tyrothricin might also be effective but are polypeptides. Other newer antibiotics about which relatively little has been written are also effective against the Gram-positive bacteria; these include Spontin and tylosin.

6. Other preventatives

The number of prophylactic agents purported to be suc-
cessful in treating bloat is legion. Beddows (1953, 1959) cites many different compounds tried during the eighteenth century. Blake (1955; Blake et al., 1957) found that trisodium phosphate (30 gm. per 1000 lb. body weight), a compound supposed to be effective in altering the pH of the ruminal contents, reduced bloat very slightly. Addition of cholesterol, a saponin-precipitant, did not prevent bloat caused by administration of alfalfa juice. Johns (1957) reported that lime added to the drinking water failed to give any protection against bloat. The anti-foaming agents and antibiotics still seem to offer the most promise in prevention. Fuller and Dougherty (1956) report success in preventing bloat in an animal which has bloated seriously by emptying the rumen (rumenotomy had been performed to save the cow) and reinoculating with ingesta from another animal.

H. Therapy

Many of the investigations involving prevention have also included treatment, and many of the substances found effective in prevention, particularly the anti-foamers, have proven successful in therapy. In fact, in the ordinary sequence of events it has been those compounds that were therapeutically effective that have been subsequently tested as preventives. Many studies point out the difficulty in evaluating therapeutic measures; without adequate controls
one can never be sure that recovery is not spontaneous.

1. **Anti-foamers**

Reid (1958b) states that, in his experience, the only reliable method of treating bloat, other than by opening the rumen, is drenching with anti-foaming agents. Nichols (1957b) found a great number of compounds with varying degrees of surface activity which should be suitable for bloat therapy, but Lienert and Kienel (1957b) found that these varied in their ability to destroy foam *in vitro*. Successful treatment of bloat with anti-foamers has given much support to the foam theory.

a. **Oils**  
The work in New Zealand has already been thoroughly discussed in connection with prevention of bloat by use of oils. Reid and Johns (1957) found that vegetable oils (peanut, raw linseed, soybean and olive) vegetable turpentine, emulsified tallow, whale oil, cream, lanolin, liquid paraffins and paraffin-wax emulsions given in doses ranging from 50 to 300 ml. were highly effective in relieving serious bloat. In an experiment involving 58 drenchings little difference in deflation times was found between oils or between dose rates. Deflation was usually complete in about 30 minutes (15-60 minutes). Turpentine was not as effective as the vegetable oils and has undesirable side-effects. The most desirable agents appear to be peanut oil (120 ml.;
4 fl. oz.) or emulsified tallow (90 gm.). The oils may not, however, be effective against foaming in feed-lot bloat because of the more stable foam involved. The agents may be administered as a drench or by direct injection into the rumen through the left paralumbar fossa. The New Zealand workers stress that the oils may not always be effective, and the use of trocar and cannula or knife still remains the most sure method of relief. The effects of the oils upon animal health and production have been discussed, and peanut oil and tallow have been found harmless; if effective, they certainly produce less stress on the animal than does the knife.

California workers (Boda et al., 1957; Boda, 1958; Colvin et al., 1959) have also found oils effective in treating bloat. Vegetable oil (Wesson oil) in 100 to 175 ml. doses reduced intraruminal pressures promptly. Jacobson et al., (1957) effectively treated bloat in cattle with corn oil.

b. Detergents In work reviewed by Johns (1956a) detergents were found effective in clearing the rumen of froth. Reid and Johns (1957) obtained variable results when drenching with detergents and concluded that even the best results were not comparable with those observed with oils.

c. Silicones Johns (1956a) reviews some work in which silicones were found effective in treating serious
cases of bloat; however, in his own work he found the sil­
cones generally unreliable. Reid and Johns (1957) reported
that a number of silicone preparations were tried at doses
up to 3.4 gm., but results were extremely variable and in no
case approached the efficiency of oil treatment. Parham et
al., (1956) discuss several commercial preparations report­
edly giving excellent results.

German and Swiss workers have been very active in this
field. Feuerstein (1955) was able to relieve bloat with
silicone and a stomach-tube. Behrens (1957) found an immedi­
ate decrease in frothing upon administration of a commer­
cially prepared methyl silicone; no detrimental effects on
the animals were noted. Dorn (1956) reported the successful
use of methyl silicone for treating acute bloat in sheep,
while Dorn (1957) obtained the same results with seriously
bloated cattle. Hiepe (1957) Schulze and Hiepe, (1957) re­
ported successful treatment of bloat in small ruminants with
the silicones, but only about 60 per cent of the cattle so
treated responded. Schumacher (1958) found that the sili­
cones had little effect on gas production and exerted their
effects by breaking foam; he mentions the necessity of
simultaneous use of the stomach tube in removing gases freed
from foam.

d. Other anti-foamers   Turpentine and certain phen-
olic compounds have been used successfully in bloat treat­
ment (Johns, 1959a); however, these compounds have adverse
effects upon the flavor of the meat and milk (Feuerstein,
1955; Blake, 1955). Nicholson (1955) and Behrens (1957) both
mention successful use of Rumene, a proprietary compound con­
taining pelargonic acid, propylene glycol monolaurate, and
isopropyl alcohol. Gyorgy (1958) recommends the use of 20
to 30 ml. of a mixture of equal parts of ethyl and normal
butyl alcohols as a foam breaker in bloat cases. Oral or in­
traruminal administration of acetyltributyl citrate in 20 ml.
doses has been found effective (Pfizer, 1958a). In addition
to those anti-foamers mentioned already in previous sections,
Reid and Johns (1957) tried diethyl ether (variable results)
and glycerol (ineffective).

2. Physical methods

The physical methods commonly used today in treating bloat
have been used for a long time; Beddows (1952, 1959) cites the
use by farmers during the eighteenth century of such emer­
gency procedures as trocarization, rumenotomy and intubation.
The first two mentioned, although admittedly drastic, are
commonly accepted as the only relatively sure methods, with
rumenotomy receiving preference as the more efficient and
trocarization being less drastic. The efficiency of the
trocar and cannula depends upon the extent of frothing in the
Ingesta; if free gas is present in large amounts the cannula will successfully relieve pressure, but where frothing becomes extensive the cannula soon becomes plugged and release of pressure is halted. A description of trocarization, designed for the layman, has been published (New South Wales, 1955). Dorn (1957) has discussed some of the pitfalls of trocarization. Howarth (1956) has described an improved trocar and cannula. Fuller and Dougherty's description (1956) of the technique for repairing an emergency rumenotomy done by a layman make it obvious why the procedure is recommended only as a last resort. A similar report is that of Gonella (1958). Reid (1958b) stresses the importance of caution in opening the rumen, since a sudden release of pressure can kill the animal instantly.

Intubation, or the use of the stomach tube, is recommended where the relative amount of froth is not great; where frothing is pronounced it is about as efficient as trocarization. The use of the stomach tube is a valuable adjunct to therapy involving the anti-foaming agents, as a route for both administering the agents intraruminally (Hiepe, 1957) and for allowing the rapid escape of the gases released during the breakdown of foam (Feuerstein, 1955). An improved stomach tube has been designed by Madsen (1956).

Using a bottle for drenching with anti-foaming agents has been mentioned (Feuerstein, 1955) but is a dangerous
procedure due to the possibility of getting oil or other harmful agents into the lungs (Sears and Reid, 1955). The use of the stomach tube (assuming an experienced operator) is better, or as an alternate procedure, direct injection of anti-foamers through the distended left flank with a syringe and needle (Feuerstein, 1955; Sears and Reid, 1955) or through a cannula (Hiepe, 1957).

Other physical means for relieving bloat include placing the animal with its forequarters raised slightly, putting a gag in the mouth, walking the animal and some other procedures of rather doubtful efficacy. Specht et al., (1956) have found a permanent fistula successful in treating and preventing certain cases of chronic bloat.

3. Other treatments

Some research cited by Johns (1954) suggested the possibility of using antihistamines as a therapeutic agent in bloat; in his own trials he found that both adrenalin and mepyramine maleate (Anthisan) were ineffective in alleviating bloat. In fact, their use in several cases seemed to increase bloat to dangerous levels and had other undesirable side effects. Williams (1956) found that antihistamines gave variable results.

Many different substances have been used from time to time in bloat therapy. Successful use of formalin is men-
tioned by Feuerstein (1955) and recommended by Australian workers (New South Wales, 1955). Feuerstein also mentions salicylic acid and chloral hydrate. Reid and Johns (1957) found that treatments without anti-foaming action failed to give relief. These included sal volatile, sodium bicarbonate, ferric chloride, sodium thiosulphate and a preparation containing acetotrimethylcolchicinic acid. Senior (1956) used oxytetracycline successfully with supporting medication consisting of calcium gluconate and dextrose intravenously administered. The latter two substances served as energy sources to aid in detoxification of the gases present and as a muscle stimulant. Rydell (1955) found that intravenous calcium therapy restored eructation to normal. Vintan et al. (1957) tested several therapeutic agents (magnesium sulphate, sodium sulphate, salicylic acid, hydrochloric acid, sodium hyposulphate, sodium benzoate) at various levels and found that the sodium benzoate was the best agent tested on the basis of anti-fermentative action and absence of ill-effects upon the rumen flora and meat. The suggested dose is 20 gm. per 100 kg. up to 90 gm. Russian workers have used several different substances: Kresan (1956) suggests 15 gm. of ichthiol in water followed with subcutaneous injections of caffeine and carboxoline; Chernenko (1956) recommended hellebore, a rather violent, poisonous cathartic, while Yakovlev (1956) used magnesium oxide in doses of 50 to 100 gm., depending on
the size of the animal.

Reid (1956) has considered the possibility of using ultrasonic waves to break the foam in bloat cases.
...Upon pressing my fist smartly in the cavity between the hip bone and ribs on the near side, I did imagine I could feel the paunch, or great receptacle of the intestines, distended to this immoderate size.

Of this fact I wanted to be satisfied being myself unacquainted with the anatomy of the parts: I therefore went to a butcher, who answered my questions to a confirmation of my former imaginations; upon which I returned with a determined resolution of passing a pen-knife into that part of the cow, about three inches below the back bone, and about four inches from the point of the hip bone; but in my return I considered the cow, as she really is a valuable one; and as I knew not how the blood vessels lay, I own I began to have some doubts how to proceed; upon which another experiment occurred to me.

--An Englishman, 1764 (Beddows, 1959)

This section of the dissertation is divided into four parts corresponding to the four years in which the studies described were carried out. It is further subdivided into individual trials with a description of the procedures used and results obtained in each. The results of each trial are discussed briefly, but the major implications of the findings will be more thoroughly discussed in the following section.

In the studies described herein the pasture season extended from the first or second week in May to the third or fourth week in September. Laboratory work has generally continued on a year-around basis.
A. 1956 Season

The 1956 trials were mainly devoted to testing the preventive effect of an anti-foaming agent (lard oil, a water-dispersible oil supplied by Midwest Dried Milk Co., Dundee, Ill.). Use of the oil in therapy was investigated together with certain etiological factors.

1. Preliminary trials with lard oil

Before the start of the pasture season, a series of trials was carried out to determine the effect of lard oil upon rumen fluid characteristics and to discover any possible ill effects that administration of the oil to cattle could be expected to have.

a. Equipment and methods used in laboratory studies

The equipment and methods used to obtain and evaluate rumen ingesta samples in the 1956 season were the same as those used by Blake (1955) and Brown (1959) except as otherwise noted. Laboratory analyses of the samples included measurement of surface tension, pH, viscosity, specific gravity, percent solids, fermentation rate (as determined by ingesta-volume-increase), and foam volume and stability. Samples were not analyzed for dry matter, since it was felt that results would not merit the extra time required for accurate analysis by the toluene method. The method previously used
(drying a pre-weighed aliquot of rumen fluid in the oven and comparing the dry weight with original weight) was judged to be too crude.

In later trials in the 1956 series a hydrometer replaced the somewhat crude method that Blake (1955) used to determine specific gravity. The hydrometer used was a specific gravity hydrometer for light liquids (Chicago Apparatus Company catalogue number 32430C). Samples were stirred and poured into a 100 ml volumetric cylinder in such a way as to minimize foaming. Specific gravity was read at the liquid-air interface as soon as the hydrometer ceased to rise and fall. Three possible criticisms of this method arise from the fact that extreme variations in viscosity affect the reading, that it is difficult to determine precisely where to read the hydrometer on foamy samples and that it was necessary to extrapolate values for samples with specific gravity greater than 1.002.

A modification of Blake's procedure (1955) for determining the liquid/solid ratio was adopted since gravity separation of the two phases was often incomplete or non-occurring and required much time and space. The procedure adopted was one in which stirred aliquots of strained rumen fluid were poured into 50 ml Pyrex graduated centrifuge tubes and centrifuged for 30 minutes at approximately 1800
rpm in an International centrifuge, size 2, with a 16-inch head. Originally, the samples were centrifuged at 2000 rpm but excessive breakage of tubes occurred and the modified procedure gave satisfactory results. The centrifuged samples were taken from the centrifuge and read immediately, before mixing could occur. Usually a heavy layer of greenish solids was observed, topped by a thin layer of white solids, and finally the straw-colored liquid layer. Occasionally, a gray, powdery scum was observed on top of the liquid layer. The volume of the solid fraction was divided by the volume of the total liquid and solid fractions and the results multiplied by 100 to obtain per cent solids.

The procedures for determining foam volume and half-life (Blake, 1955) were also modified. It was felt that the time required for dispersal of one-half of the foam volume produced originally was often longer than two hours, the maximum time over which Blake made his observations. Accurate determination of the interface between foam and liquid was extremely difficult. Accordingly, the procedure was modified and is called by this author "foam volume and stability." A stirred sample of 50 ml. of rumen fluid, exclusive of any surface foam, was whipped for two minutes in a Waring blender. The sample was immediately poured into a 100 ml. graduated cylinder, the cylinder marked at the foam-air interface, and the time noted. One hour later the foam-air interface
was marked again. The foam volume was computed as total volume of liquid and foam, immediately after stirring, minus the original volume of liquid. Foam stability was computed as the quotient of foam volume one hour after stirring divided by the foam volume immediately after stirring, times 100.

A crude artificial rumen was set up to investigate the effects of the oil upon rumen fluid characteristics, in vitro. It consisted of a constant-temperature water bath, over which hung a gas manifold connected to a carbon dioxide tank. Samples of ingesta were taken at the farm, transported to the laboratory in vacuum bottles, strained through four layers of cheese cloth, and placed in 600 ml. beakers. The beakers were then placed in the water bath maintained at about 39°C. throughout the course of the experiment; carbon dioxide was bubbled through the samples slowly and continually. Aliquots were removed from the various beakers from time to time for analysis. No provision was made for removal of the end-products of fermentation, imposing a practical limitation upon the procedure.

b. Effect of lard oil on rumen fluid characteristics
Although lard oil was first proposed as a source of fat in milk replacers, the reports of Johns (1954) and Reid (1955) suggested the possibility of using such a water-dispersible
oil as an anti-foaming agent to prevent bloat. A series of short experiments established the following facts:

1) Addition of lard oil (at levels ranging from 1 per cent to 0.01 per cent) to foamy rumen ingesta in vitro consistently defoamed the ingesta and lowered surface tension.

2) Administration of 1/2 lb. of lard oil before drenching calves with freshly extracted alfalfa juice may have reduced bloat somewhat, but results were extremely variable. Surface tension of the rumen ingesta was consistently lower in the treated animals than in the controls, but none of the other rumen fluid characteristics examined were affected.

3) Lard oil administered intraruminally to calves on a hay and grain diet or added to rumen ingesta incubated in an artificial rumen depressed the surface tension and kept it at a relatively low level for several hours (see Figure 1), both in vivo and in vitro.

c. Effect of lard oil in the drinking water on feed and water consumption, weight gains and surface tension of rumen fluid Since lard oil consistently lowered the surface tension of rumen fluid, both in vivo and in vitro, it seemed plausible that the oil might be successful in preventing pasture bloat. Although Reid (1955) suggested spraying the pasture as the best means of administering oils it was felt that the excessive labor involved would prohibit such a system of prevention in this country. The alternate sugges-
Figure 1. Surface tension of rumen ingesta after treatment with 1% lard oil (0 hr. = just before treatment with oil)
tion of Reid was then considered—that of adding the oil to the drinking water. This procedure also seemed logical because of the dispersibility of the oil in water. It was decided that it would be wise to first determine whether lard oil administered in such a manner would have any adverse effects upon feed and water consumption and weight gains.

Twelve ruminating dairy heifers (ranging from 6 to 9 months of age and in weight from 350 to 485 lb.) were divided at random among three treatment groups of two pens of two animals each (four heifers per group). Four breeds were represented (Holstein, Brown Swiss, Ayrshire and Guernsey), but allotment was without regard to breed; each group contained members of at least two breeds. The trial began on January 15, 1956, and since winter conditions prevailed during most of the experiment the animals were housed in the barn. When the weather was good they were turned out daily for exercise, during which time feed and water were not available. Animals were fed weighed amounts of good quality alfalfa hay, ad libitum, and each received four pounds per day of corn-oats-soybean oil meal mixture. All water was weighed and given to the animals in metal baskets secured in such a manner as to avoid tipping by the animals. The water not consumed was weighed back daily and replaced with a fresh supply to encourage the animals to drink as much as possible. Oil was added to the water at the levels indicated in Table 1;
Table 1. Experimental design and results of preliminary trial of lard oil as a drinking water additive; 1956

<table>
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<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Group one</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Oil, % by wt.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2.0%</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Hay consumption, lb.</td>
<td>320</td>
<td>286</td>
<td>290</td>
<td>237</td>
<td>215</td>
<td>309</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Water consumption, lb.</td>
<td>1278</td>
<td>1021</td>
<td>1247</td>
<td>1205</td>
<td>1137</td>
<td>1167</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Weight gain, lb.</td>
<td>-28</td>
<td>68</td>
<td>25</td>
<td>5</td>
<td>73</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface tension, D/cm.</td>
<td>52</td>
<td>53</td>
<td>55</td>
<td>58</td>
<td>54</td>
<td></td>
<td></td>
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<tr>
<td>Group two</td>
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</tr>
<tr>
<td>Oil, % by wt.</td>
<td>0</td>
<td>0.01%</td>
<td>0.1%</td>
<td>0.2%</td>
<td>1.0%</td>
<td>0</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Hay consumption, lb.</td>
<td>325</td>
<td>314</td>
<td>277</td>
<td>259</td>
<td>235</td>
<td>297</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water consumption, lb.</td>
<td>1203</td>
<td>1096</td>
<td>1136</td>
<td>1274</td>
<td>1240</td>
<td>1231</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight gain, lb.</td>
<td>28</td>
<td>64</td>
<td>50</td>
<td>5</td>
<td>97</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface tension, D/cm.</td>
<td>49</td>
<td>54</td>
<td>58</td>
<td>57</td>
<td>56</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Group three</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Oil, % by wt.</td>
<td>0</td>
<td>1.0%</td>
<td>0.2%</td>
<td>0.1%</td>
<td>0.01%</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hay consumption, lb.</td>
<td>326</td>
<td>312</td>
<td>277</td>
<td>252</td>
<td>226</td>
<td>296</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water consumption, lb.</td>
<td>1284</td>
<td>1156</td>
<td>1246</td>
<td>1272</td>
<td>1245</td>
<td>1202</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Weight gain, lb.</td>
<td>42</td>
<td>69</td>
<td>75</td>
<td>42</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface tension, D/cm.</td>
<td>53</td>
<td>53</td>
<td>54</td>
<td>57</td>
<td>57</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Amounts were changed weekly, on the basis of the weight of the animals. Animals were weighed weekly after the first week. Rumen fluid samples were taken weekly by stomach tube and the surface tension checked to observe the effect of the oil. Table 1 indicates the experimental design and the results obtained.
Results indicate that hay consumption increased slightly with oil treatment while water consumption was generally increased. Weight gains were not consistent, but since the animals were weighed only one day per week it is probable that much of the fluctuation can be attributed to variation in fill at the time of weighing. No undesirable side effects of the oil were observed. Failure of the lard oil to lower the surface tension of the rumen ingesta was very puzzling to the author, but it seems probable that the samples (which were always taken at the same time—early Saturday afternoon) were taken at a time when the animals had not consumed any of the treated water for several hours. Reid (1955, 1956) and Nichols (1957b) have pointed out that the anti-foaming agents are rapidly removed from the rumen. No observations on drinking habits were made, so it is impossible to state with certainty that such was the case.

2. Field trials to investigate the use of lard oil in the drinking water as a prophylactic agent in legume pasture bloat

Twenty-five Holstein steers (average initial weight, 620 lb.) were purchased early in May for the 1956 trials, and after arrival at the University were numbered with ear-tags for permanent identification. The numbers were also painted on the animals for quick observation in the field. Fecal samples were taken from all animals for determination of parasite infection (practically negative in all cases) and
all animals were tested for tuberculosis (negative in all cases). A rotational grazing scheme was followed in which a 21-acre portion of the field located north of Lincoln Way and east of Beech Avenue was divided with electric fences from north to south into eight plots of approximately equal size. A lane was located at the north end of the field providing access from the plots to the corral located in the northeast corner of the field. Block salt was available in the plots at all times. The forage was mainly alfalfa, although weed infestation became an increasingly serious problem as the season progressed.

Table 2 shows the experimental design employed in the pasture trials. The 25 steers were divided randomly into two groups, each of which was then placed in a plot of alfalfa and allowed to stay there until the forage had been grazed from the plot. Most of the time the animals were on adjoining plots to eliminate as much as possible of the effect due to different soil and plant conditions in different parts of the field. During a series of 9- to 15-day sub-periods each group received lard oil in the drinking water or served as control. The year was an extremely dry one, and the drought resulted in a shortage of pasture, particularly during the latter part of July and early August. During this period the animals were confined to dry lot and fed grain and alfalfa soilage from another field. Water was available on each plot
Table 2. Experimental design: 1956 alfalfa pasture trials

<table>
<thead>
<tr>
<th>Period</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>May 15 to May 28</td>
<td>June 11 to June 24</td>
<td>July 9 to July 22</td>
<td>Aug. 23 to Sept. 7</td>
</tr>
<tr>
<td></td>
<td>May 29 to June 10</td>
<td>June 25 to July 8</td>
<td>Aug. 9 to Aug. 22</td>
<td>Sept. 6 to Sept. 15</td>
</tr>
</tbody>
</table>

Group 1: 1% oil Control 1% oil Control 1% oil Control 2% oil Control
Group 2: Control 1% oil Control 1% oil Control 1% oil Control 2% oil Control

*Pasture was exhausted due to drought. Animals were not on pasture from July 23 to Aug. 8.*
in 325-gallon tanks and the oil was added to the water and mixed by stirring; due to its dispersibility it was readily miscible with water. The initial level of 1 per cent was later increased to 2 per cent as water consumption decreased with the advent of cooler weather and considerable rain in period 4. Throughout the daylight hours observations of incidence and severity of bloat, grazing intensity and water consumption were taken hourly. The scale used in evaluating bloat severity and incidence is shown in Table 3. Grazing intensity was estimated according to the following scale: 0, not grazing; 1, sporadic grazing; 2, full grazing. Water consumption was estimated by measuring the depth (in inches) of the water in the tanks once each hour. This system was probably exact enough for the purposes of the experiment, although it failed to take into account water loss from evaporation. During some hot spells this amounted to as much as 15 to 20 lb. per hour.

Weather observations were taken in the field four times daily, at 6 a.m., at noon, and at 4 and 8 p.m. Cloudiness was estimated as that part (in tenths) of the sky covered with clouds; i.e., 5 meant that the sky was approximately half covered with clouds. Air movement was estimated as 0, calm; 1, intermittent breeze; 2, steady, strong breeze; 3, windy; 4, strong wind of gale force. The presence of dew or
Table 3. Scale used in assigning bloat scores

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No bloat—No distention in left paralumbar fossa</td>
</tr>
<tr>
<td>1</td>
<td>Slight—Slight distention in left paralumbar fossa; &quot;puffy&quot;</td>
</tr>
<tr>
<td>2</td>
<td>Mild—Marked distention in left paralumbar fossa; well rounded out between hip and rib on left side; little or no distention on right side</td>
</tr>
<tr>
<td>3</td>
<td>Moderate—Well rounded out on left side, drumlike; full on right side; restless</td>
</tr>
<tr>
<td>4</td>
<td>Severe—Both sides badly distended; left hip nearly hidden; skin tight; defecation; urination; incoordination; protruding anus; mild respiratory distress</td>
</tr>
<tr>
<td>5</td>
<td>Terminal—Extreme abdominal distention; severe respiratory distress; cyanosis; prostration; death unless treated</td>
</tr>
</tbody>
</table>

moisture upon the forage was also noted. The official rainfall and relative humidity for the Ames area (taken from the records at the University Agronomy Farm, approximately five miles from the pasture) were also entered in the records. No correlation of any weather observation with incidence or severity of bloat was found. A serious outbreak of bloat occurred in early September after a series of rains broke the drought and caused rapid growth of the alfalfa.

Note was made of the condition of the forage. The animals were weighed at the beginning of each sub-period. Rumen
ingesta samples were taken routinely from equal numbers of animals in each group and subjected to the laboratory analyses discussed previously. Statistical analyses were carried out according to the methods described in Snedecor (1956).

a. Effect of lard oil on incidence and severity of bloat

Observations on bloat, grazing intensity, water consumption, and weight gains are summarized in Table 4. Daily oil consumption was 0.95, 1.56, 1.15 and 1.50 lb. per animal per day during periods 1, 2, 3 and 4, respectively. Bloat severity was computed for each animal within each of the sub-periods both as the mean bloat severity and as the mean maximum bloat severity. The mean bloat severity represents the average of all hourly observations per day on a per animal basis, and it will be noted that the values given seem quite low in relation to the scale used for rating bloat severity (Table 3); however, since the main incidence of bloating was confined to relatively few hours in the morning and evening there is a preponderance of zero values; this has had the effect of coding the average severity to the low values given in Table 4. This effect is further emphasized by the fact that many of the animals bloated only occasionally. The average maximum values given in Table 4 were computed by adding the highest observed bloat score for each animal over all animals in a group and over all days in a sub-period and then dividing
Table 4. Summary of the effects of lard oil on bloat severity, feed and water consumption, and weight gains; 1956 alfalfa pasture trials

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Period</th>
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<td>2</td>
<td></td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Oil</td>
<td>Control</td>
<td>Oil</td>
<td>Control</td>
<td>Oil</td>
<td>Control</td>
<td>Oil</td>
</tr>
<tr>
<td>Bloat severity:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Av./animal/day(^a)</td>
<td>0.04</td>
<td>0.09</td>
<td>0.09</td>
<td>0.20</td>
<td>0.16</td>
<td>0.22</td>
<td>0.23</td>
</tr>
<tr>
<td>Av.max./animal/day(^b)</td>
<td>0.35*</td>
<td>0.59</td>
<td>0.58**</td>
<td>0.87</td>
<td>0.78</td>
<td>0.91</td>
<td>0.99**</td>
</tr>
<tr>
<td>Grazing intensity(^c)</td>
<td>0.53</td>
<td>0.58</td>
<td>0.76</td>
<td>0.73</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Water consumption/animal/day,lb.</td>
<td>95</td>
<td>82</td>
<td>156</td>
<td>130</td>
<td>115</td>
<td>102</td>
<td>75</td>
</tr>
<tr>
<td>Av.daily wt. gains, lb.</td>
<td>3.73</td>
<td>3.47</td>
<td>1.55</td>
<td>0.68</td>
<td>0.51</td>
<td>-0.04</td>
<td>1.44</td>
</tr>
</tbody>
</table>

\(^a\)Based on rating from 0 (no bloat) to 5 (severe bloat); average of all hourly observations per day.

\(^b\)Average of maximum values for each animal.

\(^c\)Estimate of grazing intensity (during first 8 weeks).

*Significant at P = 0.05.

**Significant at P = 0.01.
by the number of animal-days in a sub-period. Results are presented graphically in Figure 2. An analysis of variance of these average maximum bloat severity values was computed for each of the periods. The interaction of treatments with animals within groups was used as the estimate of error for treatments. The mean maximum bloat for the animals on the oil treatment was significantly less than that for the control animals at \( P = .01 \) in periods 2 and 4 and at \( P = .05 \) in period 1. Although bloat severity was less in the group receiving oil in period 3 (Figure 2), the difference was not significant at \( P = .05 \). It seems logical that the most significant effects were obtained when oil intake was higher. Group differences in mean bloat for the four periods were extremely small, indicating no important, real inter-group differences in bloat susceptibility.

Throughout the season more bloat was observed in the evening than at any other time of the day in both the group receiving oil and the control group (Figure 3). There was a small peak in the morning also which was more pronounced in the treated than in the control group, probably due to the fact that little water was consumed until it began to warm up and the forage dried. A similar observation was made by Southcott and Hewetson (1958).

Additional evidence of the effectiveness of the lard oil
Figure 2. Average maximum bloat severity on an animal-day basis, by periods; alfalfa pasture trials, 1956.
Figure 3. The effect of lard oil on diurnal variations in bloat severity, water consumption and grazing intensity on alfalfa pasture, 1956
TREATED

CONTROL

AVERAGE MAXIMUM BLOAT SEVERITY

WATER CONSUMPTION, LB. PER ANIMAL

GRAZING INTENSITY
as a preventive agent was gained in early September. Following the drought conditions of the summer there was a series of rains in late August after which the alfalfa began to grow rapidly. On September 4 the treated group received oil in the water at the usual rate (1 per cent at the time) but the day was cold and the forage was wet, so that the animals did not drink much. The control group had no oil in their water. Both groups were held through the afternoon on plots which had been grazed very closely and little feed was available to them. At 4 p.m. both groups were moved to new plots where the rapidly growing alfalfa was lush and plentiful. Two hours later the observations summarized in Table 5 were made. The two animals scored as 5 collapsed and were treated, but one of them died in spite of treatment. The other required further treatment but eventually recovered. One other animal from the treated group required treatment and all animals were removed to the corral to prevent further cases that night. Although some of the animals from the treated group had consumed oil in the water early in the afternoon they all bloated, evidence that the oil was either ineffective, rapidly inactivated or rapidly removed from the rumen. Further observations on subsequent days established the effectiveness of the oil.

On September 5 no oil was available so the animals were held on the grazed-over plots used the previous day until late in the afternoon when a new shipment of oil arrived. Between
Table 5. Bloat observations two hours after turning all animals on lush alfalfa pasture, September 4, 1956

<table>
<thead>
<tr>
<th>Bloat score</th>
<th>Animals in each group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Oil-treated</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
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<tr>
<td>3</td>
<td>4</td>
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<tr>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
</tr>
</tbody>
</table>

5:30 and 6 p.m. each animal in the treated group was given one pound of lard oil by stomach tube and all animals were turned out to pasture at 6 p.m. During the evening none of the treated animals showed any appreciable degree of bloat, but at the end of two hours, three of the control animals were scored as 5 (two of these died, one was saved by treatment) and most of the others were bloated to a more or less serious extent. Several were given treatment when they were scored as 4 and all were confined to the corral to avoid further outbreaks. The treated group was left on pasture with no ill effects until morning.

On the following day the level of oil in the water was increased to 2 per cent and very few cases of bloat were observed in the treated group; the control group, however, continued to bloat. None of them required treatment but in the
late evening they were again confined to the corral. On September 7 the groups were reversed and the new control group began to bloat at once while the bloat decreased considerably in the new treated group. The foregoing observations demonstrated that lard oil is effective in preventing bloat if present intraruminally in sufficient concentration. In a concurrent trial Brown (1959) found that lard oil (\(\frac{1}{4}\) lb. per animal), unemulsified lard oil (\(\frac{1}{4}\) lb.) or soybean oil (\(\frac{1}{4}\) to \(\frac{1}{2}\) lb.) sprayed or sprinkled over alfalfa soilage reduced bloat as long as the animals ate the treated forage. This is a variation of the pasture-spraying technique of Reid (1955, 1956, 1958a). These findings were subsequently confirmed by Brown on extensive trials during 1957 (Brown, 1959).

b. Effect of lard oil on grazing intensity

Table 4 also shows the effect of lard oil on overall grazing intensity during periods 1 and 2. The same effects are shown graphically in a slightly different manner in Figure 3 where grazing intensity is plotted for both treated and control groups by hour of the day. Due to the extremely small and non-consistent differences in grazing intensity for both groups during the first and second periods the observations were not tabulated for later periods. This was justifiable, it was felt, since no changes in the grazing patterns attributable to oil treatment were observed at any time during the trials. The fact that heights of the peaks of morning and evening grazing cor-
respond approximately to the relative heights of the peaks in morning and evening bloat severity (Figure 3) probably explains the previous observation that peaks in bloat severity occurred in the evening and in the morning. In any event, these observations served as the basis for the practice followed in subsequent seasons of confining the animals and releasing them to graze for a three- to four-hour period in the morning and again in the evening.

c. The effect of lard oil on water consumption Table 4 shows the effect of lard oil administration in the drinking water upon water (and oil) intake. The animals quite consistently consumed more of the treated water, and this is shown graphically, by hours, in Figure 3.

d. The effect of lard oil on weight gains Average daily weight gains (Table 4) varied considerably from period to period and were greater for the treated groups in the first three periods, but not in the fourth. Average daily gains of the 14 animals for which weights were taken during all four periods were 1.76 and 1.52 lb. for the treated and control animals, respectively.

e. The use of lard oil as a therapeutic agent In all of the severe cases of bloat occurring in the studies mentioned above attempts were made to relieve the animals by passing a stomach tube into the rumen to remove the gas. In most in-
stances this procedure failed to bring adequate relief even though some free gas was encountered in almost every case. When an animal failed to respond to the stomach-tube treatment, 100 ml. of lard oil was injected intraruminally by means of a large syringe and needle. Brown (1959) used the same procedure successfully. In 11 of 12 cases where the bloat was rated as 3 or higher, an injection of oil apparently brought about a release of gas from the ingesta (results are summarized in Table 23, along with those from succeeding years); the animals either began to eructate voluntarily in 15 to 40 minutes, or passage of a stomach tube brought release of large amounts of free gas, and the animals recovered. However, the possibility of spontaneous recovery cannot be ignored. One of the animals died shortly after injection, perhaps before the oil could take effect, since the animal appeared moribund when the oil was administered. Two cases of peritonitis, one fatal, were attributed to improper use of tympanol needles; the walls of these needles are perforated and may permit the escape of oils or other liquids during injection into the body cavity unless fully inserted. The trouble did not recur after the tympanol needles were replaced by a long, solid-walled needle, but it seemed that an even better method might be to discard the needle and syringe completely and to introduce the oil through a stomach tube (except in extreme cases where high intraruminal pressure makes it impossible to insert a stomach tube).
f. The relationship of forage composition to bloat

Samples of alfalfa forage were taken from the pasture plots during and after the serious outbreak of bloat in September. These were analyzed for dry matter, total nitrogen, non-protein nitrogen, protein nitrogen, two nitrate fractions, crude saponin, reducing sugars, and invert sugars by Professor Lester Yoder and his associates in the Iowa State University Chemistry Department. No correlation of any component with bloat was readily visible (as was also the case in a greater number of samples in the concurrent study by Brown, 1959). There were too few observations to permit meaningful statistical treatment of the data. No cyanide was found in two samples taken during the outbreak of bloat.

g. Effect of lard oil and of bloat severity on rumen fluid characteristics

During the course of the summer, rumen fluid samples were routinely collected by stomach pump and tube from equal numbers of animals in each group. An attempt was made to sample each animal the same number of times and this procedure limited somewhat the opportunity to sample animals with the higher degrees of bloat; i.e., once an animal had been sampled it was not eligible for further sampling until all other animals had been sampled. Further, the same animal was never sampled at two successive collections. Samples were generally taken in the evening, at or close to the hour of maximum bloat. They were collected in vacuum bottles and
transported to the laboratory immediately upon completion of the sampling which usually required 30 to 50 minutes. Upon arrival at the laboratory they were strained through four layers of cheese-cloth and the analyses begun.

Results are summarized in Table 6, together with the calculated probability of any relationships existing between either treatment or bloat severity and the individual fluid characteristics. Statistical analysis was by multiple linear regression. Increases in bloat severity were highly correlated \( (P < .001) \) with increases in surface tension, percent solids, relative viscosity and ingesta-volume-increase and decreases in specific gravity. The relationships of bloat severity with pH and foam volume and stability were not significant. Treatment apparently exerted a highly significant effect in decreasing surface tension and pH and in increasing viscosity. A treatment effect of some significance \( (P < .10) \) on foam stability was found but foam volume and specific gravity appeared to be independent of treatment. Per cent solids and ingesta-volume-increase increased slightly with treatment, but the differences were not statistically significant at the usual levels.

Multiple regression measures the relationship of each rumen fluid characteristic \( Y \) to each \( X \) (i.e., treatment, bloat severity, treatment period, and treatment group) independent of every other \( X \). This is of importance in that sig-
Table 6. Summary of the effects of bloat severity and of lard oil treatment on rumen fluid characteristics; alfalfa pasture trials, 1956

<table>
<thead>
<tr>
<th>Bloat severity</th>
<th>Treatment</th>
<th>Observations</th>
<th>Surface tension (D/cm.)</th>
<th>pH</th>
<th>Per cent solids (%)</th>
<th>Foam stability (%)</th>
<th>Foam volume (cc.)</th>
<th>Relative viscosity (%)</th>
<th>Specific gravity</th>
<th>Ingesta increase (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Treated</td>
<td>162</td>
<td>58.7</td>
<td>6.73</td>
<td>14.2</td>
<td>73</td>
<td>31</td>
<td>1.018</td>
<td>1.000</td>
<td>22</td>
</tr>
<tr>
<td>Control</td>
<td>132</td>
<td></td>
<td>65.0</td>
<td>6.82</td>
<td>13.6</td>
<td>78</td>
<td>31</td>
<td>1.016</td>
<td>0.999</td>
<td>21</td>
</tr>
<tr>
<td>1</td>
<td>Treated</td>
<td>21</td>
<td>65.7</td>
<td>6.78</td>
<td>16.7</td>
<td>76</td>
<td>35</td>
<td>1.036</td>
<td>0.986</td>
<td>34</td>
</tr>
<tr>
<td>Control</td>
<td>39</td>
<td></td>
<td>66.9</td>
<td>6.85</td>
<td>15.9</td>
<td>73</td>
<td>30</td>
<td>1.024</td>
<td>0.991</td>
<td>28</td>
</tr>
<tr>
<td>2</td>
<td>Treated</td>
<td>8</td>
<td>73.2</td>
<td>6.90</td>
<td>20.1</td>
<td>78</td>
<td>29</td>
<td>1.053</td>
<td>0.974</td>
<td>36</td>
</tr>
<tr>
<td>Control</td>
<td>13</td>
<td></td>
<td>64.5</td>
<td>6.62</td>
<td>18.6</td>
<td>76</td>
<td>27</td>
<td>1.022</td>
<td>0.987</td>
<td>35</td>
</tr>
</tbody>
</table>

Treatment effect, \( P < \) (.001) (.025) -- (.10) -- (.01) -- --

B.S. effect, \( P < \) (.001) -- (.001) -- -- (.001) (.001) (.001)

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significant differences between groups and among periods for some of the rumen fluid characteristics were found; their effect is obviated in the probability values given in Table 6. One further fact noted in the regression analysis was that the low values obtained for $R (R < .50)$ for all characteristics except surface tension, indicate that only a relatively small part of the total variance (less than 50 per cent) was accounted for by the multiple regression; i.e., by the $X$'s. The rest of the variance was due to experimental error and indicated a necessity for improved techniques, or inclusion of other $X$'s. In contrast, $R = .65$ for surface tension measurements and indicates a higher efficiency with the technique used in measuring that characteristic.

The high correlations between surface tension and treatment and bloat severity lend credence to the previously expressed hypothesis that lard oil exerts its preventive effect upon bloat by lowering the surface tension of the rumen ingesta. Little effect of treatment or of bloat severity upon foam volume and stability could be found, and this might lead one to conclude that reduction of surface tension has little effect on foam characteristics. The necessity for improved techniques has been pointed out, however, both by the high values for experimental error computed for foam characteristic determinations and by the work of Mangan.
(1958). The defoaming action of lard oil may still be due to its ability to reduce surface tension.

The significant decrease of specific gravity and increase of viscosity with increasing bloat severity is probably due to incorporation of gas into the frothy ingesta. Increases of ingesta-volume-increase with increases in bloat severity indicate an accelerated rate of fermentation not affected by treatment with the anti-foaming agent. It is difficult to explain why relative viscosity increases both with treatment and bloat severity; however, there is little observed difference in the viscosity of samples from treated and control animals that were not bloated and the wider differences between bloated treated and control animals may be accidental, even though $P < 0.01$.

One further observation worthy of note is that although one group was designated treated, it was impossible to determine how much oil each animal actually consumed; therefore, many samples taken from treated animals, particularly those that were bloated, might have been considered as controls, had the actual oil consumption been known.

Brown (1959) also investigated rumen fluid characteristics during his 1956 soilage and feed-lot bloat trials. He found the usual statistically significant increase in surface tension with increases in bloat severity. There were slight
increases in pH with increased bloat severity and there were marked increases in per cent solids leading to or resulting from bloat in his soilage trials; increases in solids were not significant in his feed-lot bloat trial. Statistically significant decreases in foam stability resulted during the soilage and feed-lot trials. Specific gravity decreased significantly and ingesta-volume-increase increased significantly with bloat in both studies. Brown's results are in agreement with those of the pasture trials except insofar as pH and relative viscosity are concerned. Penicillin treatment did exert some effect on pH and foam stability and volume in Brown's soilage trials; no significant effects were observed in his feed-lot trials.

3. Field trials to investigate the use of lard oil in the drinking water as a prophylactic agent in feed-lot bloat

At the close of the 1956 pasture season the 18 steers remaining of the original 25 (four died and three were removed for other reasons) were confined to a feed lot and were fed medium quality alfalfa hay and a concentrate mixture consisting of 70 parts corn, 27 parts soybean oil meal, and 1 part each of calcium carbonate, dicalcium phosphate and sodium chloride. When on full feed each animal consumed approximately 17 lb. per day of the concentrates plus 6.5 lb. of hay. The animals were then divided into two groups with
an attempt being made to divide the most susceptible bloaters evenly between the groups. Each group either received 1 per cent oil in the drinking water or alternately served as control during three 10-day periods. Animals were fed at 6 a.m. and 4 p.m. Following the morning feeding, observations of bloat severity (Table 3) were taken hourly through 10 a.m. and in the afternoon at 4 and at 5 p.m. The animals were weighed at the beginning of each period. Three times during each period samples of rumen fluid were collected by stomach tube from an equal number of animals in each group. Thus, each animal was sampled three or four times during the trials. Data were analyzed statistically using the methods of Snedecor (1956).

a. Effect of lard oil on incidence and severity of bloat, water consumption and weight gains Results of the feedlot study are summarized in Table 7. The incidence of feedlot bloat was low and although lard oil appeared to have a small beneficial effect this effect was not statistically significant at $P = .05$.

As in the pasture study, water consumption was consistently higher for the treated group although the differences were smaller. On the basis of water consumption by the treated group and the level of oil treatment employed, the average daily oil intake per treated animal during periods
Table 7. Summary of the effects of lard oil on bloat severity, water consumption and weight gains; feed-lot trials, 1956

<table>
<thead>
<tr>
<th>Period</th>
<th>Oil</th>
<th>Control</th>
<th>Oil</th>
<th>Control</th>
<th>Oil</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bloat severity:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Av./animal/day</td>
<td>0.08</td>
<td>0.25</td>
<td>0.17</td>
<td>0.12</td>
<td>0.15</td>
<td>0.17</td>
</tr>
<tr>
<td>Av. max./animal/ day</td>
<td>0.24</td>
<td>0.49</td>
<td>0.38</td>
<td>0.32</td>
<td>0.33</td>
<td>0.42</td>
</tr>
<tr>
<td>Water consumption /animal/day, lb.</td>
<td>82</td>
<td>79</td>
<td>89</td>
<td>86</td>
<td>76</td>
<td>72</td>
</tr>
<tr>
<td>Av. daily wt. gains, lb.</td>
<td>2.10</td>
<td>1.04</td>
<td>2.56</td>
<td>1.33</td>
<td>1.39</td>
<td>-0.97</td>
</tr>
</tbody>
</table>

\( \text{a} \) See footnotes in Table 4.

\( \text{b} \) Analysis of variance was made over all periods. \( F \) was non-significant (at \( P = .05 \)) for treatments vs. animals within groups x treatments or for groups vs. animals within groups.

1, 2 and 3 was 0.82, 0.89 and 0.76 lb., respectively. Average daily weight gains were consistently in favor of the treated group (2.01 lb. per day for treated animals versus 0.47 lb. for the controls); however, as in the case of the pasture trials the animals were weighed only on one day at the beginning and end of each period and variations were great, probably reflecting differences in fill rather than actual gains. The differences were not statistically significant.
b. Effect of lard oil and of bloat severity on rumen fluid characteristics

The procedures followed in collecting the samples and determining their characteristics were essentially the same as those followed in the pasture trials. Results are summarized in Table 8. Linear multiple regression analysis indicated highly significant increases in surface tension, per cent solids, relative viscosity and ingesta-volume-increase with bloat severity; there was also a highly significant decrease in specific gravity with bloat severity. Treatment effected a highly significant decrease in surface tension and a highly significant increase in specific gravity.

The results of the surface tension determinations are in agreement with those obtained in the pasture trials, and again indicate that lard oil lowers surface tension. The significant effect of treatment upon specific gravity also supports the conclusion reached in the pasture studies that the decreases in specific gravity are due to incorporation of gases into the frothy ingesta and that lard oil treatment prevents the formation of such foam. Determinations of foam stability and volume were not significantly correlated with bloat severity or treatment, in agreement with the results of the pasture trials. Neither treatment nor bloat severity affected pH significantly although there was a tendency for the pH to be higher in samples from treated animals (the opposite was true in the pasture trials). The significant increases
Table 8. Summary of the effects of bloat severity and of lard oil treatment on rumen fluid characteristics; feed lot trials, 1956

<table>
<thead>
<tr>
<th>Bloat severity</th>
<th>Treatment</th>
<th>Observations</th>
<th>Surface tension (D/cm.)</th>
<th>Percent solids (%)</th>
<th>Foam stability (%)</th>
<th>Foam volume (cc.)</th>
<th>Relative specific gravity</th>
<th>Ingesta incr. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Treated</td>
<td>30</td>
<td>47.8</td>
<td>6.21</td>
<td>17.5</td>
<td>82</td>
<td>17</td>
<td>1.036</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>23</td>
<td>56.8</td>
<td>6.13</td>
<td>20.7</td>
<td>75</td>
<td>16</td>
<td>1.052</td>
</tr>
<tr>
<td>1</td>
<td>Treated</td>
<td>2</td>
<td>57.2</td>
<td>6.26</td>
<td>26.6</td>
<td>84</td>
<td>12</td>
<td>1.078</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>6</td>
<td>61.3</td>
<td>6.10</td>
<td>27.5</td>
<td>80</td>
<td>12</td>
<td>1.069</td>
</tr>
<tr>
<td>2</td>
<td>Treated</td>
<td>2</td>
<td>54.4</td>
<td>6.26</td>
<td>32.4</td>
<td>75</td>
<td>17</td>
<td>1.084</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>5</td>
<td>60.8</td>
<td>6.24</td>
<td>27.5</td>
<td>83</td>
<td>23</td>
<td>1.065</td>
</tr>
<tr>
<td>Treatment effect, ( P )</td>
<td>( .001 )</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>B.S. Effect, ( P )</td>
<td>( .005 )</td>
<td>--</td>
<td>(( .001 ))</td>
<td>--</td>
<td>--</td>
<td>(( .025 ))</td>
<td>(( .005 ))</td>
<td>(( .001 ))</td>
</tr>
</tbody>
</table>
in ingesta-volume-increase again indicate that the higher rate of fermentation associated with bloat severity is not decreased appreciably by treatment with lard oil. As in the pasture trials, there were some small differences between groups and among periods, but generally a greater part of the variance was accounted for by the regression analysis. This indicates that the low efficiency of the procedures for determination of rumen fluid characteristics suggested in the case of the pasture trials may be mainly due to differences in the behavior of individual animals while on pasture. In the feed-lot trials the animals were more closely confined and total bloat severity and incidence were lower.

B. 1957 Season

As in 1956, a series of studies was carried out by the author and his colleagues during the winter months to obtain more information about the prophylactic agents to be employed in the summer field trials.

1. Trials to investigate the effect of oils administered in grain on feed intake and on weight gains

Pre-feeding of oil in a small amount of grain was suggested as a practical method of overcoming the variations in oil and water intake experienced in the 1956 trials. It was hoped that more uniform protection might be afforded for a longer period of time in this manner. Preliminary trials
were conducted to determine possible ill effects of administering oils this way. Oils chosen were lard oil and soybean oil; these selections were based on the results obtained in the 1956 trials, including those of Brown (1959).

a. Lard oil In December, 1956, twelve dairy heifers, ranging in weight from 175 to 309 lb. (average, 262 lb.) and in age from 4½ to 6 months, were divided into 6 pairs. Pair members were of the same breed and as close as possible in age and weight. Each animal was assigned to an individual pen which was bedded with wood shavings. Each received all the weighed chopped alfalfa hay it would consume, although an effort was made to avoid wastage due to overfeeding. Each animal also received 4 lb. per day (2 lb. in a.m., 2 lb. in p.m.) of a grain mixture composed of the following: 300 parts cracked corn, 300 parts ground oats, 200 parts wheat bran, 100 parts soybean oil meal, 70 parts linseed oil meal, 20 parts steamed bone meal, 10 parts salt, 7 parts vitamin A supplement and 1 part irradiated yeast. A preliminary trial, four weeks in length, was carried out to establish the pattern of weight gains. One animal from each pair was then chosen to receive oil with the other to serve as control. Assignments to treated and control groups were not random, but were made in such a manner that the mean total gains of the animals in the two groups were about equal during the preliminary period. (1.69 lb. per day for one group versus 1.60
1b. for the other). Lard oil was mixed by hand with the grain ration of the calves that were to receive it, at the rate of 0.15 lb. of oil per day per 100 lb. of body weight. The amount of oil each received was adjusted weekly on the basis of the average of body weights taken on 3 successive days at the end of the week. The weights were recorded, together with the amounts of hay fed and weighed back; failure to consume the grain mixture completely was also noted, although this was a rare occurrence. Water was available to the animals at all times in automatic waterers.

Treatment remained the same for a period of 9 weeks; the groups then were switched for a period of 3 weeks. Results are summarized in Table 9. The summary in table 9 includes data for only the first 4 and the last 3 weeks of the 9 weeks in period 1. The animals were vaccinated on February 4 and subsequently went off feed for several days, reducing oil and hay intake for the week of February 3-9 and the weights taken at the end of the week. The abnormal weights affected the gains not only for the week of February 3-9, but also during the following week and therefore were omitted. Hay consumption during the following week may have been affected, so those data were eliminated.

Average daily oil intake was 242 gm. per treated animal in period 1 and 301 gm. in period 2. Analysis of vari-
Table 9. Summary of effects of oils administered in grain on hay consumption and weight gains; preliminary trials, 1957

<table>
<thead>
<tr>
<th>Period</th>
<th>Hay consumption (lb./day)</th>
<th>Average daily gain (lb.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Treated</td>
<td>Control</td>
</tr>
<tr>
<td>Lard Oil</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 (7 wks.)</td>
<td>6.4</td>
<td>7.1</td>
</tr>
<tr>
<td>2 (3 wks.)</td>
<td>9.0</td>
<td>8.7</td>
</tr>
<tr>
<td>Soybean Oil</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 (3 wks.)</td>
<td>9.6</td>
<td>10.0</td>
</tr>
<tr>
<td>4 (3 wks.)</td>
<td>9.7</td>
<td>10.0</td>
</tr>
</tbody>
</table>

* Treatment effect statistically significant at P = .05.
^ Each figure is mean of values for six animals.
^ Treatment effect approached significance of P = .05.

ance indicated that weight gains were decreased significantly (P < .05 in period 1; P closely approaches .05 in period 2) by oil treatment. Whether this depression was due to decreased intake of nutrients, decreased utilization of nutrients or other factors was not clear.

b. Soybean oil At the end of March, 1957, the heifers used in the preceding trial were immediately placed on another trial to study the effect of soybean oil on hay consumption and weight gains. The same pairings and general procedure were used. Those animals which had last received
lard oil were the first to receive soybean oil; i.e., the treated group in the last three weeks of the lard oil trial served as the treated group in the first period of the soybean oil trial. Two periods of three weeks were used and the treatment groups were switched at the end of the third week. Average daily oil intake was 317 gm. per treated animal in period 1 and 352 gm. in period 2. The results of this trial, summarized in Table 9, were subjected to analysis of variance (Snedecor, 1956) which showed that soybean oil had a less pronounced effect on weight gains than was the case in the lard oil trials. There was no significant difference in weight gains during period 1, but during period 2 there was a decrease in gain due to oil, approaching significance at P = 0.05. As in the lard oil trials, it was difficult to determine the reason for the decrease.

2. In vitro trials with proposed prophylactic agents

During the spring and summer of 1957 extensive trials were run in the laboratory to test certain effects (particularly surface tension) of a series of proposed prophylactic agents. Most of these trials were conducted by the author; one group, however, was carried out by an undergraduate student at Iowa State University as a special project. Procedures varied somewhat from one compound to another and the results do not merit further attention here since they are
extremely voluminous, only relatively indicative and do not lend themselves to summary. Those preparations which were the most efficient surface agents were tested in the field trials. The original data are on file in the Dairy Husbandry Office at Iowa State University.

3. General description of the 1957 field trials

Thirty-six steers (average initial weight, 556 lb.) of mixed beef breeding were purchased early in May for the 1957 trials, and after arrival at the University were numbered with ear-tags for permanent identification. Each animal was also given a neck-chain with a large plastic numbered tag for quick identification in the field. Samples of freshly-voided feces were collected for determination of parasite infection and the animals were tested for tuberculosis. Tuberculosis tests were all negative and there were essentially no parasites present. A rotational grazing scheme was followed in which a 26-acre field (designated E-3 on the map of the Bottom-Southeast at Iowa State University and located south of Lincoln Way and east of Beech Avenue) was divided from north to south with electric fences into nine plots. Size of the plots varied considerably, due mainly to restrictions imposed by irrigation of three of the plots. The result was three fairly narrow plots (7, 8 and 9) at the west end of the field, three wider plots (4, 5 and 6, irrigated with 5.5
inches of water in early May) in the middle of the field, and three quite wide plots (1, 2 and 3) at the east end of the field. A lane at the north end of the field provided access to the corral located in the northwest corner of the field. In addition, each plot had a strip immediately south of the lane fenced off from the rest of the plot to provide a holding pen. The main part of the corral was about 40 x 50 feet, with a smaller, funnel-shaped pen at one end leading through a chute and scales. Block salt and fresh water were available in the plots at all times. The forage was mainly alfalfa, although weed infestation became an increasingly serious problem as the season progressed. Severe flooding of the field in the middle of June caused temporary suspension of operations and killed some of the alfalfa. A weather station was set up about one-fourth mile south of the pasture, and contained a hygrothermograph (which records relative humidity and temperature continuously) and a rain gauge.

Table 10 shows the experimental design employed in the pasture trials. Considerable severe bloat occurred throughout most of the season although severity was noticeably less during the later trials. Animals grazed daily approximately from 6:30 to 10 a.m., and from 3:30 to 7 p.m. Immediately preceding grazing, all groups were offered equal amounts (on a per animal basis) of grain or grain mixed with preventive. During and for some time after each grazing period the animals
Table 10. Experimental design; alfalfa pasture trials, 1957

<table>
<thead>
<tr>
<th>Trial</th>
<th>Date</th>
<th>Grain</th>
<th>Treatment</th>
<th>Level</th>
<th>Times daily</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5/18-6/1</td>
<td>1.0</td>
<td>LO</td>
<td>0.25 lb.</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>6/2-6/15</td>
<td>1.5</td>
<td>LO</td>
<td>0.25 lb.</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>6/21-7/6</td>
<td>1.5</td>
<td>SBO</td>
<td>0.25 lb.</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>7/7-7/20</td>
<td>1.5</td>
<td>SBO</td>
<td>0.25 lb.</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>7/29-8/25</td>
<td>1.5</td>
<td>--</td>
<td>Control</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>8/29-9/2</td>
<td>2.0</td>
<td>--</td>
<td>Control</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>9/9-9/12</td>
<td>3.0</td>
<td>SBO</td>
<td>0.53 lb.</td>
<td>2</td>
</tr>
<tr>
<td>8c</td>
<td>9/16-9/18</td>
<td>1.5</td>
<td>SBO</td>
<td>0.25 lb.</td>
<td>1</td>
</tr>
</tbody>
</table>

**Treatment** group 1

<table>
<thead>
<tr>
<th>Trial</th>
<th>Date</th>
<th>Grain</th>
<th>Treatment</th>
<th>Level</th>
<th>Times daily</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5/18-6/1</td>
<td>1.0</td>
<td>--</td>
<td>Control</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>6/2-6/15</td>
<td>1.5</td>
<td>--</td>
<td>Control</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>6/21-7/6</td>
<td>1.5</td>
<td>P</td>
<td>75 mg.</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>7/7-7/20</td>
<td>1.5</td>
<td>P</td>
<td>125 mg.</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>7/29-8/25</td>
<td>1.5</td>
<td>L</td>
<td>0.19 lb.</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>8/29-9/2</td>
<td>2.0</td>
<td>L</td>
<td>0.27 lb.</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>9/9-9/12</td>
<td>3.0</td>
<td>SBO</td>
<td>0.35 lb.</td>
<td>2</td>
</tr>
<tr>
<td>8c</td>
<td>9/16-9/18</td>
<td>1.5</td>
<td>SBO</td>
<td>0.25 lb.</td>
<td>1</td>
</tr>
</tbody>
</table>

**Treatment** group 2

<table>
<thead>
<tr>
<th>Trial</th>
<th>Date</th>
<th>Grain</th>
<th>Treatment</th>
<th>Level</th>
<th>Times daily</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5/18-6/1</td>
<td>1.0</td>
<td>LO in water</td>
<td>2%</td>
<td>Continuous</td>
</tr>
<tr>
<td>2</td>
<td>6/2-6/15</td>
<td>1.5</td>
<td>LO in water</td>
<td>2%</td>
<td>Continuous</td>
</tr>
<tr>
<td>3</td>
<td>6/21-7/6</td>
<td>1.5</td>
<td>--</td>
<td>Control</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>7/7-7/20</td>
<td>1.5</td>
<td>--</td>
<td>Control</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>7/29-8/25</td>
<td>1.5</td>
<td>L</td>
<td>0.19 lb.</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>8/29-9/2</td>
<td>2.0</td>
<td>SBO</td>
<td>0.06 lb.</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>9/9-9/12</td>
<td>3.0</td>
<td>SBO</td>
<td>0.27 lb.</td>
<td>2</td>
</tr>
<tr>
<td>8c</td>
<td>9/16-9/18</td>
<td>1.5</td>
<td>--</td>
<td>Control</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Treatment</th>
<th>group 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5/18-6/1</td>
</tr>
<tr>
<td>2</td>
<td>6/2-6/15</td>
</tr>
<tr>
<td>3</td>
<td>6/21-7/6</td>
</tr>
<tr>
<td>4</td>
<td>7/7-7/20</td>
</tr>
<tr>
<td>5</td>
<td>7/29-8/25</td>
</tr>
<tr>
<td>6</td>
<td>8/29-9/2</td>
</tr>
<tr>
<td>7</td>
<td>9/9-9/12</td>
</tr>
<tr>
<td>8c</td>
<td>9/16-9/18</td>
</tr>
</tbody>
</table>

---

**Total grain, or grain and treatment, lb. per animal per feeding.**

**b** (LO) Lard oil—a water dispersible product derived from lard; (L) Lecithin—Alcolec; (P) Penicillin—Procaine penicillin; (SBO) Crude soybean oil.

**c** Animals received alfalfa soilage, ad lib., in dry lot (all other trials on pasture). (Group 1 received SBO sprinkled over soilage; Group 2 received SBO in grain.)
were under constant observation for bloat which was evaluated visually (Table 3) as in 1956. Preceding each trial individual animals were ranked by the cumulative bloat scores over a period of several days and blocked according to bloat score. The three animals with the highest scores were allotted randomly to three groups; then the three animals with the next highest scores were similarly allotted and so on, so that on the basis of past performance the three groups used in each trial had approximately equal bloating potentials.

The animals were weighed on a portable scales at the beginning and completion of each trial. Rumen fluid samples were collected for analysis from animals with varying degrees of bloat and receiving the different treatments. Samples of forage were taken from the pasture plots and analyzed for a number of components. Possible interrelationships among forage composition, rumen fluid characteristics, weather and incidence and severity of bloat were investigated. Data were analyzed statistically by the methods of Snedecor (1956).

In trials 1 and 2 one group received lard oil in the drinking water and in trial 8 one group received soybean oil sprinkled over soilage. In all other trials the preventives were mixed with grain. Mixing was usually done at each feeding but in some cases several days' supply was prepared in advance and stored at 40°F. until used. Due to its consis-
tency, lecithin (trials 5 and 6) could not be easily mixed with grain; therefore, it was pre-mixed with oil and then incorporated into grain. Penicillin (trials 3 and 4) was added to the grain once daily, in the a.m., by pre-mixing with a small amount of grain in the laboratory and mixing at the time of feeding with the total amount of grain to be fed. When soybean oil was sprinkled over the soilage (trial 8) it was done only once daily, over the entire allotment of soilage; in all other trials the preventive was administered twice daily. In addition to the preventives listed in Table 10, choice white grease and a product composed of methyl esters of fatty acids (Lebcol T-40, supplied by Lyle Branchflower Co., Seattle, Wash.) were evaluated separately by addition to grain; at the relatively high level employed (17.5%) lack of palatability prevented adequate consumption of either mixture and use of these products was discontinued. These trials are not included in Table 10 nor in any of the subsequent discussion.

4. Effect of lard oil, soybean oil, penicillin and soybean lecithin on bloat severity

The effect of the various prophylactic agents on bloat severity is summarized in Tables 11 and 12. Analysis of variance of the pasture bloat observations showed a statistically significant decrease of average bloat severity and
of average maximum bloat severity with all treatments em-
ployed (P<.05 or <.01) except in trials 7 and 8. The non-
significant differences in trials 7 and 8 probably resulted
from a relatively low incidence and severity of bloat during
these periods. This reasoning is supported by the very good
control of bloat achieved in the concurrent series of soilage
trials by Brown (1959) who sprinkled soybean oil over soil-
age at the rate of 0.25 lb. oil per 1000 lb. of body weight
daily. Also, in the earlier pasture trials soybean oil in
the grain was effective at much lower levels with a higher
incidence and severity of bloat. The effect of penicillin
(75 mg. per day), although statistically significant at P<.01,
was transitory; after 9 days the incidence and severity of
bloat in the treated animals rose to approximately the same
levels as the controls. Increasing the level of penicillin
supplementation to 125 mg. per day in trial 4 reduced bloat
for 2 days, after which bloating was noticeably more severe
and approached the level of the controls.

Considerable difficulty was experienced in inducing some
animals to consume the grain treated with the lard oil and
lecithin mixture (trials 5 and 6), perhaps because the mix-
ture became quite lumpy and hard, even during a short storage
period. Soybean oil was the most palatable oil employed and
nearly all animals relished it. Lard oil (trials 1 and 2)
appeared less palatable than soybean oil, possibly because it
Table 11. Summary of the effect of lard oil, soybean oil, penicillin and soybean lecithin on bloat severity; alfalfa pasture trials, 1957

<table>
<thead>
<tr>
<th>Trial</th>
<th>Treatmenta</th>
<th>Av./animal/dayb</th>
<th>Av. max./animal/dayc</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>LO(g)</td>
<td>0.15</td>
<td>0.56</td>
</tr>
<tr>
<td></td>
<td>LO(w)</td>
<td>0.17</td>
<td>0.76</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>0.39</td>
<td>1.34</td>
</tr>
<tr>
<td>2</td>
<td>LO(g)</td>
<td>0.13</td>
<td>0.47</td>
</tr>
<tr>
<td></td>
<td>LO(w)</td>
<td>0.21</td>
<td>1.07</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>0.66</td>
<td>1.94</td>
</tr>
<tr>
<td>3</td>
<td>SBO(g)</td>
<td>0.09</td>
<td>0.46</td>
</tr>
<tr>
<td></td>
<td>Penicillin(g)</td>
<td>0.20</td>
<td>0.87</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>0.46</td>
<td>1.49</td>
</tr>
<tr>
<td>4</td>
<td>SBO(g)</td>
<td>0.06</td>
<td>0.27</td>
</tr>
<tr>
<td></td>
<td>Penicillin(g)</td>
<td>0.14</td>
<td>0.58</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>0.32</td>
<td>1.06</td>
</tr>
<tr>
<td>5</td>
<td>L and LO(g)</td>
<td>0.09</td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td>L and SBO(g)</td>
<td>0.07</td>
<td>0.42</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>0.23</td>
<td>0.95</td>
</tr>
<tr>
<td>6</td>
<td>L and LO(g)</td>
<td>0.06</td>
<td>0.30</td>
</tr>
<tr>
<td></td>
<td>L and SBO(g)</td>
<td>0.04</td>
<td>0.23</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>0.31</td>
<td>1.26</td>
</tr>
<tr>
<td>7</td>
<td>SBO (0.53 lb.) (g)</td>
<td>0.06</td>
<td>0.49</td>
</tr>
<tr>
<td></td>
<td>SBO (0.35 lb.) (g)</td>
<td>0.17</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>0.29</td>
<td>1.15</td>
</tr>
<tr>
<td>8</td>
<td>SBO(s)</td>
<td>0.01</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>SBO(g)</td>
<td>0.11</td>
<td>0.47</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>0.15</td>
<td>0.57</td>
</tr>
</tbody>
</table>

aLO = lard oil, SBO = soybean oil, L = Lecithin, g = mixed with grain, w = mixed with water, s = sprinkled over soilage (see Table 10 for levels).

bAverage of all observations taken periodically throughout day (see Table 3 for explanation of bloat ratings).

cAverage of maximum values for each animal.

was the first oil fed in the grain; there was a marked improvement in consumption as lard oil feeding continued. At least part of the lower efficiency of lard oil in the drinking water when compared to administration of the same type
Table 12. Effect of regularity of treatment on bloat severity; alfalfa pasture trials, 1957

<table>
<thead>
<tr>
<th>Regularity of treatment</th>
<th>Average bloat severity&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Daily av.&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>00&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.57</td>
</tr>
<tr>
<td>01&lt;sup&gt;e&lt;/sup&gt;</td>
<td>0.25</td>
</tr>
<tr>
<td>10&lt;sup&gt;f&lt;/sup&gt;</td>
<td>0.15</td>
</tr>
<tr>
<td>11&lt;sup&gt;g&lt;/sup&gt;</td>
<td>0.05</td>
</tr>
</tbody>
</table>

<sup>a</sup>See Table 3 for explanation of bloat ratings.

<sup>b</sup>Average of all observations taken periodically throughout day.

<sup>c</sup>Average of maximum values for each animal.

<sup>d</sup>Consumed no treated grain.

<sup>e</sup>Consumed no treated grain in a.m., consumed treated grain in p.m.

<sup>f</sup>Consumed no treated grain in p.m., consumed treated grain in a.m.

<sup>g</sup>Consumed treated grain a.m. and p.m.

Of oil in grain probably was due to decreased consumption of treated water during and shortly after rainy periods. Cool weather during trials 1 and 2 also reduced water and oil intake somewhat.

In several trials (particularly 1, 2, 5 and 6) treatment effect was more pronounced when adjustments were made for
animals in the treated groups which failed to consume the treated grain. Values in Table 11 include all animals in each treatment group, even though some of the animals refused to eat treated grain occasionally or frequently. Data in Table 12, however, show the difference in bloating behaviour during trials 1, 2, 5 and 6 among the animals in the treated groups which consumed the treated grain at certain times but not at others. The tendency not to eat the treated grain was less noticeable during the remaining periods (although one animal consistently refused to eat any grain and oil) and these trials are not represented in Table 12. Data in Table 12 indicate that there apparently was a carry-over effect of treatment from morning to evening (animals treated in the morning but not the same evening did not bloat as much that evening as did the controls). The carry-over effect of treatment from evening to the next morning was somewhat less, probably because of the longer time elapsing between treatment in the afternoon and the morning grazing. A prolonged effect of oil fed at a high level had been demonstrated in the 1956 season during the severe outbreak of bloat in September. Then, animals which received one lb. of lard oil experienced no bloat for 12 to 14 hours while several control animals died or required drastic treatment.

As in the 1956 trials, attention again should be called to the fact that the low values for mean and mean maximum
bloat severity in Tables 11 and 12 (when these are compared to the scale in Table 3) is an artifact due largely to the inclusion of many zero observations during hours when very few animals bloated and from the inclusion of all animals, some of which seldom or never bloated. Another 1956 observation repeated in 1957 was the higher incidence and severity of bloat in the evening hours. The pattern followed was essentially the same as that for the control group; shown in Figure 3.

5. Effect of lard oil, soybean oil, penicillin and soybean lecithin on weight gains

Apart from the reluctance of some of the animals to consume the lard oil or lard oil-lecithin mixtures there were no other indications that feed intake, growth, or general well-being were in any way adversely affected by any of the materials employed in these studies. On the contrary, weight gains (Table 13) were increased markedly in many cases, a fact which makes it possible to charge part of the cost of the preventive to weight gains and to make the actual prevention of bloat more feasible from an economic standpoint. Analysis of variance of the weight gains indicated significant increases due to treatment in trials 1, 2, 3 and 4. In trials 5 and 6 lecithin plus soybean oil in the grain brought about a significant increase in gains, but differences between the control animals and those receiving lecithin and
Table 13. Effect of lard oil, soybean oil, penicillin and soybean lecithin on weight gains; alfalfa pasture trials, 1957

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Average daily gain lb.</th>
<th>Increase over control lb.</th>
</tr>
</thead>
<tbody>
<tr>
<td>LO(g)</td>
<td>1.84</td>
<td>0.62</td>
</tr>
<tr>
<td>LO(w)</td>
<td>1.97</td>
<td>0.75</td>
</tr>
<tr>
<td>Control</td>
<td>1.22</td>
<td></td>
</tr>
<tr>
<td>SBO(g)</td>
<td>1.54</td>
<td>0.72</td>
</tr>
<tr>
<td>Penicillin(g)</td>
<td>1.26</td>
<td>0.44</td>
</tr>
<tr>
<td>Control</td>
<td>0.82</td>
<td></td>
</tr>
<tr>
<td>L and LO(g)</td>
<td>1.56</td>
<td>0.07</td>
</tr>
<tr>
<td>L and SBO(g)</td>
<td>1.73</td>
<td>0.24</td>
</tr>
<tr>
<td>Control</td>
<td>1.49</td>
<td></td>
</tr>
</tbody>
</table>

*a*See Table 11 for explanation of symbols.

Lard oil were not statistically significant.

6. The use of lard oil as a therapeutic agent

As a result of the techniques suggested by the 1956 studies, an attempt was made to release any free gas with a stomach tube when animals bloated severely. This usually was unsuccessful and an anti-foaming agent then was administered by stomach tube or by hypodermic needle. When inserting the stomach tube it was found best to keep the tube coiled and to make the actual insertion with the end of the tube pointing upward. This procedure allowed the maximum ease of insertion with a minimum opportunity for misdirection into the lungs. This procedure also directs the lower end of the tube
upward in the rumen; thus any free gas in the dorsal part of this organ can be removed. The odor of rumen gases issuing from the tube is indicative that the tube is in the rumen and not in the lungs. In the pasture trials the agent employed was lard oil; in the concurrent soilage trials (Brown, 1959) n-decyl alcohol was used. Results are summarized, together with those from other years, in Table 23. The oral administration of 150-250 ml. of lard oil was followed soon by the release of large quantities of gas from the rumen via stomach tube and/or eructation. Recovery was usually complete within 30 to 40 minutes and animals so treated did not bloat before the next grazing period, even when they returned to pasture and resumed eating, as was often the case. n-Decyl alcohol in approximately 25 ml. doses caused a prompt reduction in bloat, but the effect lasted for only about two hours.

7. The effect of forage composition on bloat

Samples of the alfalfa were taken from the pasture plots on 31 different days during the grazing season. Results of the analyses carried out are presented in Table 14, together with correlation coefficients for each constituent of the alfalfa with bloat severity. In the 31 samples analyzed, only reducing sugars and total ash were correlated significantly with bloat. Subsequent analysis of 11 of the samples
<table>
<thead>
<tr>
<th>Date</th>
<th>Bloat severity (%)</th>
<th>Dry matter (%)</th>
<th>Nitrogen$^a$ (%)</th>
<th>NH$_2$ (%)</th>
<th>Red. sugar$^a$ (%)</th>
<th>Total ash$^a$ (%)</th>
<th>Ca$^a$ (%)</th>
<th>P$^a$ (%)</th>
<th>K$^a$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5/24</td>
<td>0.535</td>
<td>24.46</td>
<td>4.67</td>
<td>0.453</td>
<td>0.160</td>
<td>2.19</td>
<td>8.14</td>
<td>0.421</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>0.564</td>
<td>22.86</td>
<td>4.74</td>
<td>0.499</td>
<td>0.174</td>
<td>2.75</td>
<td>8.32</td>
<td>0.416</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>0.479</td>
<td>24.22</td>
<td>4.41</td>
<td>0.422</td>
<td>0.134</td>
<td>2.55</td>
<td>8.76</td>
<td>1.90</td>
<td>0.378</td>
</tr>
<tr>
<td>6/3</td>
<td>0.675</td>
<td>25.80</td>
<td>4.13</td>
<td>0.420</td>
<td>0.148</td>
<td>2.36</td>
<td>9.27</td>
<td>2.05</td>
<td>0.350</td>
</tr>
<tr>
<td>6</td>
<td>0.768</td>
<td>26.32</td>
<td>4.08</td>
<td>0.438</td>
<td>0.170</td>
<td>2.11</td>
<td>8.63</td>
<td>2.15</td>
<td>0.341</td>
</tr>
<tr>
<td>10</td>
<td>0.700</td>
<td>21.24</td>
<td>4.09</td>
<td>0.432</td>
<td>0.141</td>
<td>1.27</td>
<td>8.56</td>
<td>2.75</td>
<td>0.361</td>
</tr>
<tr>
<td>13</td>
<td>0.291</td>
<td>20.26</td>
<td>5.24</td>
<td>0.656</td>
<td>0.248</td>
<td>1.81</td>
<td>9.09</td>
<td>1.24</td>
<td>0.497</td>
</tr>
<tr>
<td>24</td>
<td>0.140</td>
<td>24.53</td>
<td>3.93</td>
<td>0.413</td>
<td>0.140</td>
<td>1.77</td>
<td>9.17</td>
<td>1.58</td>
<td>0.366</td>
</tr>
<tr>
<td>27</td>
<td>0.767</td>
<td>15.44</td>
<td>5.45</td>
<td>0.668</td>
<td>0.226</td>
<td>2.67</td>
<td>9.52</td>
<td>1.42</td>
<td>0.504</td>
</tr>
<tr>
<td>7/1</td>
<td>0.650</td>
<td>20.38</td>
<td>5.26</td>
<td>0.652</td>
<td>0.204</td>
<td>2.17</td>
<td>9.44</td>
<td>1.38</td>
<td>0.474</td>
</tr>
<tr>
<td>3</td>
<td>0.590</td>
<td>20.67</td>
<td>5.01</td>
<td>0.551</td>
<td>0.175</td>
<td>2.69</td>
<td>8.70</td>
<td>0.469</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0.330</td>
<td>24.33</td>
<td>4.05</td>
<td>0.445</td>
<td>0.141</td>
<td>2.02</td>
<td>9.46</td>
<td>1.18</td>
<td>0.392</td>
</tr>
<tr>
<td>11</td>
<td>0.282</td>
<td>24.94</td>
<td>4.18</td>
<td>0.392</td>
<td>0.123</td>
<td>1.75</td>
<td>8.12</td>
<td>1.02</td>
<td>0.384</td>
</tr>
<tr>
<td>15</td>
<td>0.473</td>
<td>27.86</td>
<td>3.41</td>
<td>0.356</td>
<td>0.109</td>
<td>1.54</td>
<td>7.22</td>
<td>1.11</td>
<td>0.321</td>
</tr>
<tr>
<td>18</td>
<td>0.273</td>
<td>31.04</td>
<td>3.09</td>
<td>0.353</td>
<td>0.111</td>
<td>1.81</td>
<td>6.66</td>
<td>0.291</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>0.403</td>
<td>32.43</td>
<td>2.67</td>
<td>0.326</td>
<td>0.123</td>
<td>1.83</td>
<td>5.70</td>
<td>0.245</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>0.098</td>
<td>30.82</td>
<td>2.96</td>
<td>0.376</td>
<td>0.124</td>
<td>1.86</td>
<td>5.67</td>
<td>0.259</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>0.183</td>
<td>23.42</td>
<td>4.14</td>
<td>0.507</td>
<td>0.816</td>
<td>1.96</td>
<td>6.48</td>
<td>0.394</td>
<td></td>
</tr>
</tbody>
</table>

$^a$Dry matter basis.

$^b$Average bloat severity of control group.
Table 14. (Continued)

<table>
<thead>
<tr>
<th>Date</th>
<th>Bloat severity (%)</th>
<th>Dry matter (%)</th>
<th>Nitrogena</th>
<th>Red. sugara</th>
<th>Total asha</th>
<th>Ca a</th>
<th>P a</th>
<th>K a</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total (%)</td>
<td>NPN (%)</td>
<td>NH2 (%)</td>
<td>(%)</td>
<td>(%)</td>
<td>(%)</td>
</tr>
<tr>
<td>8/7</td>
<td>0.376</td>
<td>25.86</td>
<td>4.36</td>
<td>0.439</td>
<td>0.152</td>
<td>2.08</td>
<td>6.97</td>
<td>0.361</td>
</tr>
<tr>
<td>12</td>
<td>0.239</td>
<td>23.32</td>
<td>4.91</td>
<td>0.528</td>
<td>0.196</td>
<td>1.64</td>
<td>7.74</td>
<td>0.448</td>
</tr>
<tr>
<td>15</td>
<td>0.459</td>
<td>24.01</td>
<td>4.62</td>
<td>0.524</td>
<td>0.197</td>
<td>2.24</td>
<td>7.51</td>
<td>0.442</td>
</tr>
<tr>
<td>16</td>
<td>0.125</td>
<td>22.90</td>
<td>4.74</td>
<td>0.480</td>
<td>0.177</td>
<td>1.74</td>
<td>7.83</td>
<td>0.438</td>
</tr>
<tr>
<td>26</td>
<td>0.536</td>
<td>24.46</td>
<td>4.47</td>
<td>0.416</td>
<td>0.149</td>
<td>1.52</td>
<td>7.69</td>
<td>0.392</td>
</tr>
<tr>
<td>29</td>
<td>0.506</td>
<td>20.52</td>
<td>5.10</td>
<td>0.506</td>
<td>0.167</td>
<td>1.53</td>
<td>7.56</td>
<td>0.450</td>
</tr>
<tr>
<td>9/4</td>
<td>0.136</td>
<td>23.88</td>
<td>4.83</td>
<td>0.485</td>
<td>0.179</td>
<td>1.88</td>
<td>7.28</td>
<td>0.446</td>
</tr>
<tr>
<td>6</td>
<td>0.127</td>
<td>20.90</td>
<td>5.22</td>
<td>0.626</td>
<td>0.222</td>
<td>1.27</td>
<td>7.94</td>
<td>0.452</td>
</tr>
<tr>
<td>9</td>
<td>0.358</td>
<td>21.74</td>
<td>5.08</td>
<td>0.535</td>
<td>0.195</td>
<td>1.65</td>
<td>7.78</td>
<td>0.444</td>
</tr>
<tr>
<td>10</td>
<td>0.391</td>
<td>18.48</td>
<td>5.73</td>
<td>0.682</td>
<td>0.297</td>
<td>1.92</td>
<td>8.21</td>
<td>0.551</td>
</tr>
<tr>
<td>11</td>
<td>0.058</td>
<td>16.70</td>
<td>5.97</td>
<td>0.658</td>
<td>0.271</td>
<td>1.49</td>
<td>8.46</td>
<td>0.564</td>
</tr>
<tr>
<td>12</td>
<td>0.337</td>
<td>20.44</td>
<td>5.72</td>
<td>0.793</td>
<td>0.336</td>
<td>1.98</td>
<td>7.64</td>
<td>0.520</td>
</tr>
<tr>
<td>14</td>
<td>0.142</td>
<td>16.64</td>
<td>6.29</td>
<td>0.821</td>
<td>0.313</td>
<td>1.23</td>
<td>8.77</td>
<td>0.581</td>
</tr>
</tbody>
</table>

Correlation with bloat severity

\[ r = \begin{pmatrix} -0.053 & -0.063 & -0.117 & -0.191 & 0.504** & 0.375* & 0.556* & 0.125 & -0.203 \\ \end{pmatrix} \]

Soilage samples,\(^c\)

\[ r = \begin{pmatrix} -0.335 & 0.876** & 0.380 & 0.467* & 0.052 & 0.289 & -0.787** & 0.798** & 0.701^d \end{pmatrix} \]

\(^c\)From concurrent study of Brown (1959).

\(^d\)Correlation approached statistical significance at \(P = .05\).

**Correlation statistically significant at \(P = .01\).

*Correlation statistically significant at \(P = .05\).
for calcium indicated that calcium content was also correlated significantly with bloat; phosphorus and potassium (11 samples only) were not. Correlation coefficients of bloat severity with dry matter, total nitrogen, non-protein nitrogen and amino nitrogen were low and not statistically significant at the usual levels. These results are not in agreement with those obtained from analysis of soilage in the concurrent study by Brown (1959). Variations in the correlation coefficients between the two studies (Table 14) are obvious. Brown (1959) has discussed the implications of these variations.

Gould (1957) analyzed several of the samples for organic acid content; his results are summarized in Table 15. No definite relationship between bloat and acids was observed, although there was some indication that the acids might be precursors of bloat-provoking substances. There is also a possibility that malic acid content and malic-malonic acid ratio may bear some relationship to bloat.

Diurnal variation in the composition of alfalfa tops was determined on first crop pre-bloom alfalfa in early May for all the constituents described in the previous paragraph. There seemed to be no clear-cut relationship between the observed diurnal changes and bloat; although afternoon bloat was somewhat more severe than morning bloat, it does not seem
Table 15. Comparison of bloat severity with organic acid content of forage; alfalfa pasture trials, 1957 (after Gould, 1957)

<table>
<thead>
<tr>
<th>Date</th>
<th>Bloat severity</th>
<th>Total acidity</th>
<th>Citric acid(^a)</th>
<th>Malic acid</th>
<th>Malonic acid(^a)</th>
<th>Succinic acid(^a)</th>
<th>Fumaric acid</th>
<th>Unknown acids</th>
</tr>
</thead>
<tbody>
<tr>
<td>6/13</td>
<td>0.291</td>
<td>0.537</td>
<td>0.04</td>
<td>0.116</td>
<td>0.157</td>
<td>0.033</td>
<td>0.031</td>
<td>0.160</td>
</tr>
<tr>
<td>24</td>
<td>0.140</td>
<td>0.627</td>
<td>0.036</td>
<td>0.127</td>
<td>0.161</td>
<td>0.026</td>
<td>T</td>
<td>0.322</td>
</tr>
<tr>
<td>27</td>
<td>0.767</td>
<td>0.639</td>
<td>0.037</td>
<td>0.148</td>
<td>0.15</td>
<td>T</td>
<td>T</td>
<td>0.304</td>
</tr>
<tr>
<td>7/1</td>
<td>0.650</td>
<td>0.487</td>
<td>0.028</td>
<td>0.143</td>
<td>0.164</td>
<td>T</td>
<td>T</td>
<td>0.152</td>
</tr>
<tr>
<td>3</td>
<td>0.590</td>
<td>0.509</td>
<td>T</td>
<td>0.08</td>
<td>0.113</td>
<td>0.06</td>
<td>T</td>
<td>0.256</td>
</tr>
<tr>
<td>8</td>
<td>0.330</td>
<td>0.491</td>
<td>T</td>
<td>0.088</td>
<td>0.147</td>
<td>0.035</td>
<td>T</td>
<td>0.221</td>
</tr>
<tr>
<td>11</td>
<td>0.282</td>
<td>0.455</td>
<td>T</td>
<td>0.065</td>
<td>0.11</td>
<td>0.03</td>
<td>T</td>
<td>0.250</td>
</tr>
</tbody>
</table>

\(^a\)Trace amount found.
possible to attribute this to diurnal changes in forage composition.

The effect of irrigation on forage composition was also investigated (Allen, et al., 1957) by analyzing a series of samples taken before and at 2, 9, 18, 27 and 37 hours after sprinkling with 5.5 inches of water. Irrigation had little effect on reducing sugar, total nitrogen, ash and phosphorus, but there was a significant increase in non-protein nitrogen with increasing time after irrigation and a gradual but limited increase in amino nitrogen.

8. The effect of lard oil, soybean oil, penicillin, soybean lecithin and bloat severity on rumen fluid characteristics

Samples of rumen fluid were collected using the same procedures as in the 1956 studies. Characteristics determined by the same methods as in 1956 included surface tension, foam volume and stability and ingesta-volume-increase. Rumen ammonia was determined by the aeration method of Van Slyke and Cullen, as modified by Hawk, et al., (1954). Sodium hydroxide (50%) was used in place of the saturated potassium carbonate recommended, to increase the rapidity and efficiency of release of the ammonia from the rumen fluid.

Results are summarized and presented with the appropriate probability figures in Table 16. Statistical analysis was by the method of multiple linear regression. Table 16
Table 16. Summary of effect of treatments and of bloat severity on rumen fluid characteristics; alfalfa pasture trials, 1957

<table>
<thead>
<tr>
<th>Bloat severity</th>
<th>Surface tens.</th>
<th>Foam volume</th>
<th>Foam stability</th>
<th>Ingesta-vol-inc.</th>
<th>Ammonia</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LOg^a</td>
<td>LOw</td>
<td>C</td>
<td>LOg</td>
<td>LOw</td>
</tr>
<tr>
<td>PT /</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>0</td>
<td>51.6</td>
<td>50.8</td>
<td>57.3</td>
<td>28</td>
<td>27</td>
</tr>
<tr>
<td>1</td>
<td>65.5</td>
<td>54.7</td>
<td>62.0</td>
<td>7</td>
<td>26</td>
</tr>
<tr>
<td>2</td>
<td>--</td>
<td>54.5</td>
<td>65.1</td>
<td>--</td>
<td>26</td>
</tr>
<tr>
<td>3</td>
<td>--</td>
<td>55.3</td>
<td>64.2</td>
<td>--</td>
<td>15</td>
</tr>
<tr>
<td>PBS /</td>
<td>(0.10)</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>PT / (0.05)</td>
<td>--</td>
<td>SBO</td>
<td>Penic.</td>
<td>C</td>
<td>SBO</td>
</tr>
<tr>
<td>0</td>
<td>51.3</td>
<td>52.5</td>
<td>58.7</td>
<td>18</td>
<td>20</td>
</tr>
<tr>
<td>1</td>
<td>60.1</td>
<td>56.5</td>
<td>59.5</td>
<td>14</td>
<td>19</td>
</tr>
<tr>
<td>2</td>
<td>--</td>
<td>65.8</td>
<td>63.3</td>
<td>--</td>
<td>22</td>
</tr>
<tr>
<td>3</td>
<td>--</td>
<td>54.5</td>
<td>64.2</td>
<td>--</td>
<td>15</td>
</tr>
<tr>
<td>PBS /</td>
<td>(0.025)</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>L+LO</td>
<td>L+SBO</td>
<td>C</td>
<td>L+LO</td>
<td>L+SBO</td>
</tr>
<tr>
<td>PT /</td>
<td>--</td>
<td>(0.05)</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>0</td>
<td>50.4</td>
<td>48.6</td>
<td>55.2</td>
<td>32</td>
<td>25</td>
</tr>
<tr>
<td>1</td>
<td>54.9</td>
<td>46.9</td>
<td>54.7</td>
<td>28</td>
<td>28</td>
</tr>
<tr>
<td>2</td>
<td>--</td>
<td>62.2</td>
<td>--</td>
<td>32</td>
<td>--</td>
</tr>
<tr>
<td>4</td>
<td>--</td>
<td>59.6</td>
<td>--</td>
<td>10</td>
<td>--</td>
</tr>
<tr>
<td>PBS /</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>(0.025)</td>
<td>(0.10)</td>
</tr>
</tbody>
</table>

^aSee Table 10 for explanation of symbols.

^bFigure in parentheses indicates level of statistical probability of effect of bloat severity (PBS) or of treatment (PT); -- indicates .10 \( \geq P \).
shows that surface tension tended to increase somewhat with bloat severity in four of the trials and was decreased significantly by adding lard oil to the drinking water or soybean oil, penicillin, or lecithin and soybean oil to the grain. Penicillin increased foam stability significantly but none of the other treatments had significant effects on any of the rumen fluid characteristics tested except, as noted previously, in the case of surface tension. Increased foam stability was associated with increasing bloat severity in trials 5 and 6, and there were some increases in ingesta-volume-increase and rumen ammonia associated with bloat in trials 3, 4, 5 and 6.

In the concurrent soilage trials conducted by Brown (1959) surface tension values agreed with those in the pasture trials; surface tension generally increased with bloat severity and decreased with treatment. Unlike the pasture trials, however, soybean oil sprinkled over the soilage decreased foam volume and stability somewhat, and there was little or no relationship between ingesta-volume-increase or rumen ammonia and bloat severity or treatment.

9. Correlation of weather observations and bloat severity

Temperature, relative humidity and rainfall during the preceding 12 hours were measured at 6 a.m. and at 6 p.m.
with the instruments in the weather station; the other ob-
servations were taken more subjectively by the methods used
in 1956 and included cloud cover, wind, and moisture on the
forage. Correlation coefficients of each weather observa-
tion with the average daily maximum bloat are presented in
Table 17. Only cloudiness was correlated at a significant
level, although moisture on forage approached a significant
correlation, at the 5 per cent level, with bloat severity.

As in 1956, it was observed that the more severe bloat
seemed to follow periods of heavier rainfall after which the
forage grew more rapidly; however, statistical correlation
did not show this effect when the figure used for bloat se-
verity was that occurring 0, 1, 2 or 3 days after a rela-
tively heavy rainfall.

Table 17. Correlation coefficients of bloat severity with
weather observations; alfalfa pasture trials, 1957

<table>
<thead>
<tr>
<th>Observation</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>0.004</td>
</tr>
<tr>
<td>Relative humidity</td>
<td>-0.025</td>
</tr>
<tr>
<td>Rainfall</td>
<td>0.025a</td>
</tr>
<tr>
<td>Cloudiness</td>
<td>0.200*</td>
</tr>
<tr>
<td>Wind</td>
<td>0.008</td>
</tr>
<tr>
<td>Moisture on forage</td>
<td>0.185b</td>
</tr>
</tbody>
</table>

*Statistically significant at the 5% level.

a Also no significant correlation with BS 0, 1, 2, 3
days after rain.

b Approached statistical significance at the 5% level.
C. 1958 Season

The 1958 pasture bloat research program consisted of field trials conducted by the author to investigate various prophylactic measures and etiological factors, and of laboratory studies on composition of blood and rumen fluid and their changes, conducted by Brown (1959). In addition, the author also conducted a series of studies on the rate of ruminal forage digestion in vivo with the assistance of Dr. R. S. Allen who directed other studies involving analysis of the forage. Investigations were carried out with sheep and with cattle by other workers.

1. General description of the 1958 field trials

During the 1958 pasture season 41 dairy and beef cattle were utilized for grazing trials. Six of these were yearling dairy steers which had rumen fistulas inserted in February, 1958. The fistulas were inserted in two stages at the Veterinary Clinic on the Iowa State University campus by Dr. Burnell W. Kingrey and his students. In the first stage, a circular incision was made in the left paralumbar fossa large enough to admit the plastic fistula plug used; the rumen wall was then sutured to the body wall around the incision and allowed to heal. In approximately two weeks a corresponding circular incision was made in the rumen wall,
and a 4 1/2 inch (outside diameter) plastic plug inserted immediately. These were equipped with screw caps which could be removed for obtaining samples of rumen ingesta or inserting test substances. Of the six animals originally fistulated, one developed complications and died; it was replaced by another steer and this one and the other five all recovered promptly from the operation with no apparent ill effects. The other 35 animals consisted of 22 Hereford yearling heifers and steers purchased in early May and of 12 dairy steers and a freemartin which had been raised at the University dairy farm. Animals were identified with numbered plastic tags on neck chains.

The alfalfa pasture was an 18.9 acre field (designated E-1 on the map of the Bottom-Southeast at Iowa State University and located just south of Lincoln Way between Beech Avenue and Squaw Creek) which had been the source of the alfalfa soilage used during the 1957 trials. The alfalfa was second-year growth. A rotational grazing scheme was followed in which the field was divided with electric fence into nine plots. These were irregular in shape and size, and were laid out according to a soil-phosphorus survey so that there were two plots of relatively high soil-phosphorus content, six of medium phosphorus content, and one of low phosphorus. The two plots with a high phosphorus level were subsequently fertilized in April with 500 lb. per acre of
0-46-0 fertilizer to raise the phosphorus level still further. A lane at the south side of the field provided access to the corral located in the southeast corner of the field. The corral had two adjoining pens, each about 20 x 25 feet, with a third, smaller, funnel-shaped pen at one end leading through a chute and scales. The corral was surrounded by a larger (about 100 x 60 feet) holding pen where the animals were retained between grazings and where fresh water and salt were always available. A feed bunk was placed in each of the larger pens and in the holding pen; the animals could then be divided into three groups for administration of prophylactic agents. Fresh water was available on the pasture plots. The forage was mainly alfalfa, although there was a temporary problem with Shepherd's Purse at the beginning of the season. Severe flooding of the field in early July caused a temporary suspension of operations and killed some of the alfalfa. A weather station was set up near the corral and contained a thermometer, psychrometer and rain-gauge.

The animals were allowed to graze twice daily, from 7 to 10 a.m., and from 4 to 7 p.m. Before grazing, each treatment group received grain mixed with preventive or grain alone at the rate of 1 1/2 lb. of total mixture per animal. Bloat severity was observed continuously from horseback during grazing periods and for a time afterward; evaluation was visual, using the scale described previously (Table 3).
After an initial control period to establish the bloating pattern, the animals were divided into three groups of approximately equal bloating potential by the same method used in 1957. A large number of surface-active agents considered as possible preventives were evaluated \textit{in vitro} by measuring their effect on surface tension. The most promising were selected for field trials. Experimental periods were not fixed; rather, it was deemed important to test as many compounds as possible and each was used until it proved unsatisfactory or showed some promise. Severe cases of bloat were treated by the same method previously found successful. All data were analyzed statistically by the methods of Snedecor (1956).

Weather observations were made four times daily, at the beginning and close of each grazing period. Samples of rumen fluid and blood were collected from animals with varying degrees of bloat and receiving the different treatments; Brown (1959) analyzed these in the laboratory for various components. Samples of forage taken periodically from the pasture plots just before the evening grazing period were quick-frozen in a dry ice chest in the field and stored in a freezer. They were analyzed for dry matter, total nitrogen, calcium and phosphorus. A study of diurnal variations in the composition of alfalfa tops was also carried out.

A series of trials was conducted to determine the ef-
effects of age of plant, of oil treatment, and of phosphate fertilization on the rate of digestion of alfalfa in vivo. It was hoped to discover thereby the relationship of these factors to bloat.

An attempt was made to investigate Cooper's theory, discussed previously, that unbalanced nitrogen-phosphorus and calcium-phosphorus ratios cause bloat. Observations were made of the relative amounts of bloat occurring on the plots which were heavily fertilized with phosphorus and those which tested low in soil phosphorus. Following the finding by Warner and Woods (1958) that spraying forage with urea increased bloat in lambs, a similar trial was made with the cattle.

2. The effects of various prophylactic agents on bloat severity

Table 18 shows the various prophylactic agents employed, the level of each used, the amount of grain with which each was mixed, and their relative efficiencies. In most cases the data are rather limited and do not lend themselves readily to summary in a manner different from the subjective evaluation employed.

a. Soybean oil Table 19 shows numerical values of the effect of the various methods of administering soybean
Table 18. Relative efficiency of preventives tested; alfalfa pasture trials, 1958

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Amt. per feeding</th>
<th>Grain per feeding</th>
<th>Relative efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soybean oil</td>
<td>1/4 lb.</td>
<td>1 1/2 lb.</td>
<td>+++</td>
</tr>
<tr>
<td></td>
<td>1/2 lb.</td>
<td>1 lb.</td>
<td>++ to +++</td>
</tr>
<tr>
<td></td>
<td>1/3 lb.</td>
<td>5/8 lb.+5/8 lb. cobs</td>
<td>+ to ++</td>
</tr>
<tr>
<td>Ground soybeans</td>
<td>1/2 lb.</td>
<td>None</td>
<td>0 to -</td>
</tr>
<tr>
<td>Soybean flakes</td>
<td>1 1/2 lb.</td>
<td>None</td>
<td>0 to -</td>
</tr>
<tr>
<td>Gastric mucin</td>
<td>50-100 gm.</td>
<td>1 lb.</td>
<td>0 to -</td>
</tr>
<tr>
<td>Erythromycin</td>
<td>75 mg.\textsuperscript{a}</td>
<td>1 1/2 lb.</td>
<td>+ to 0</td>
</tr>
<tr>
<td>Trace minerals</td>
<td>10 gm.\textsuperscript{a}</td>
<td>1 1/2 lb.</td>
<td>0</td>
</tr>
<tr>
<td>Corn distillers' dried solubles</td>
<td>1/3 lb.</td>
<td>1 1/6 lb.</td>
<td>0</td>
</tr>
<tr>
<td>Timothy hay</td>
<td>Ad 1 lb.\textsuperscript{b}</td>
<td>1 1/2 lb.</td>
<td>0</td>
</tr>
<tr>
<td>Soybean lecithin (75%) +methyl esters (25%)</td>
<td>1/4 lb.</td>
<td>1 1/2 lb.</td>
<td>+</td>
</tr>
<tr>
<td>Corn lecithin (35%) + spent germ flakes (65%)</td>
<td>3/4 lb.</td>
<td>3/4 lb.</td>
<td>+</td>
</tr>
<tr>
<td>Tall oil fatty acids</td>
<td>1/4 lb.</td>
<td>1 1/2 lb.</td>
<td>0</td>
</tr>
</tbody>
</table>

\textsuperscript{a}Fed in a.m. grain; grain alone fed in p.m.

\textsuperscript{b}Actual consumption, 7-8 lb. hay per day per animal.

Oil upon bloat severity. Feeding 1/4 lb. of soybean oil in the grain gave very effective protection for a period of 3 to 4 hours, as in 1957. In an attempt to prolong the effect of the soybean oil the amount of oil fed was increased by increasing the proportion of oil in the mixture of oil
and grain. It was then found that the mixture was less palatable and some animals ate less. The overall efficiency of the treatment was therefore less than in 1957 when the level of grain was also increased to keep the ratio of grain to oil about the same. Prolongation was also attempted by mixing the oil with a very absorptive material—in this case a mixture of 50 per cent dried ground corn cobs and 50 per cent of the regular grain mix. The mixture appeared less oily than when the oil was mixed with grain alone; the oil was presumably better absorbed by the cobs. Some reduction in bloat occurred but the overall effect was less and some severe cases of bloat resulted. It appeared that the oil was not released readily from the corn cobs.

b. **Soybeans** Ground soybeans and soybean flakes were fed in the hope that the oil might be released slowly from the particles of beans; however, no preventive effect was observed and there was some indication of an increase in bloat incidence among the animals receiving the treatments. Severe cases of bloat resulted on both treatments, so the treatments were discontinued.

c. **Gastric mucin** Bartley (1957, 1958) reported that 1 to 2 lb. of linseed meal seemed to reduce bloat, probably due to its mucin content. The author calculated the effective level of mucin to be approximately 50 gm. of mucin and
Table 19. Effect of soybean oil upon bloat severity; alfalfa pasture trials, 1958

<table>
<thead>
<tr>
<th>Method</th>
<th>Average severity</th>
<th></th>
<th>Average max. severity</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Treated</td>
<td>Control</td>
<td>Treated</td>
<td>Control</td>
</tr>
<tr>
<td>$\frac{1}{2}$ lb. in grain, all observations</td>
<td>0.08</td>
<td>0.27</td>
<td>0.3</td>
<td>0.8</td>
</tr>
<tr>
<td>$\frac{3}{4}$ lb. in grain vs.</td>
<td>0.12</td>
<td>0.19</td>
<td>0.4</td>
<td>0.7</td>
</tr>
<tr>
<td>$\frac{3}{4}$ lb. in grain + cobs vs.</td>
<td>0.07</td>
<td>0.16</td>
<td>0.3</td>
<td>0.6</td>
</tr>
<tr>
<td>$\frac{1}{2}$ lb. in grain</td>
<td>0.09</td>
<td>0.4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

tried to feed two levels of gastric mucin, 50 and 100 gm. Lack of palatability was a serious problem and even when only 50 gm. of mucin were mixed with grain and molasses some animals refused to consume the mixture. The actual amount consumed by those that did eat could not be determined, but no preventive effect was observed and there was increased foaming among the fistulated animals that consumed mucin. The source of mucin may be a critical factor in determining the response to treatment and explaining the different results obtained in these studies and those of Bartley.

d. Erythromycin Figure 4 illustrates graphically the effect of erythromycin (which, like penicillin, is effective primarily against gram-positive bacteria) on bloat severity. When fed at the level of 75 mg. per animal daily
Figure 4. Effect of erythromycin upon bloat severity; alfalfa pasture trials, 1958
it exerted a definite preventive effect for about 7 or 8 days; after that, bloat severity was about equal to that of the control group. It appears that some type of resistance to the antibiotic develops. Attempts to overcome or reverse this resistance by withholding the antibiotic for varying periods of time were unsuccessful. When erythromycin was introduced for the third time to the same group it was also given to another group for the first time; it apparently gave considerable protection to that group, but the group which had received it earlier bloated even more than did the control animals.

e. **Trace minerals** "Trace minerals" have been suggested for bloat prevention from time to time. When the mixture of trace minerals described in Table 20 was fed at the rate of 10 gm. per animal daily there was no reduction in bloat and many severe cases were observed among animals fed the trace minerals.

f. **Distillers' dried solubles** Work at this station (Jacobson, Lambert and Ratcliff, 1956; Ratcliff and Jacobson, 1957) has indicated that addition of distillers' dried solubles to the ration of calves receiving certain milk replacers prevents the bloat which otherwise frequently results. That type of bloat appears to be different from pasture bloat, however, and the addition of 1/3 lb. per animal
of corn distillers' dried solubles to the grain twice daily failed to exert any prophylactic effect.

g. **Timothy hay**  Colvin et al.,  (1958b) reported that 12 lb. of oat hay per day was effective in preventing pasture bloat. In the present study, the animals were allowed free access to timothy hay (average daily consumption, 7 to 8 lb.) between grazing periods; no preventive effect was obtained.

Table 20. Trace mineral mixture; alfalfa pasture trials, 1958

<table>
<thead>
<tr>
<th>Per cent</th>
<th>Element</th>
<th>In form of</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.063</td>
<td>Mn</td>
<td>MnSO₄</td>
</tr>
<tr>
<td>8.000</td>
<td>Fe</td>
<td>FeSO₄ and FeO</td>
</tr>
<tr>
<td>0.638</td>
<td>Cu</td>
<td>CuSO₄</td>
</tr>
<tr>
<td>0.285</td>
<td>Co</td>
<td>CoCO₃</td>
</tr>
<tr>
<td>3.212</td>
<td>Zn</td>
<td>ZnO</td>
</tr>
<tr>
<td>0.225</td>
<td>K</td>
<td>K₂SO₄</td>
</tr>
<tr>
<td>0.137</td>
<td>I</td>
<td>KI with Ca Stearate</td>
</tr>
<tr>
<td>24.8</td>
<td>Ca</td>
<td>CaCO₃ carrier</td>
</tr>
</tbody>
</table>

h. **Soybean lecithin**  Soybean lecithin was mixed with methyl esters of tallow fatty acids as a "cutting" agent and then fed with grain at the level shown in Table 18. Although some preventive effect was observed the mixture
was undependable and considerable severe bloat was observed among animals thus treated. The soybean lecithin-methyl ester mixture was not as effective as the mixture of soybean lecithin and soybean oil tested in 1957; it compared approximately in effectiveness with the mixture of soybean lecithin and lard oil.

i. Corn lecithin In in vitro tests of surface activity corn lecithin gave the greatest reduction in surface tension of any of the agents tested. Corn lecithin was mixed with spent germ flakes (solvent-extracted corn oil cake) and the regular grain mixture and fed to the animals. It seemed to give good control but only a small amount of the product was available for testing; further studies seem advisable.

j. Tall oil fatty acids Tall oil fatty acids, a by-product of the paper-milling industry, were mixed with grain and fed at the level indicated in Table 18. This mixture was quite unpalatable to the animals and most refused to consume it; therefore it was evaluated as being of zero efficiency in preventing bloat even though the number of observations is extremely limited.

3. Use of oil in bloat therapy

Twenty-five cases of bloat that were scored 3 or higher recovered promptly following introduction of 100 to 300 ml.
of lard oil (in 22 cases) or soybean oil (in 3 cases) into the rumen through a stomach tube (Table 23). In two cases that were scored 5 the oil was injected directly into the rumen at the left paralumbar fossa with a needle and syringe. This procedure had proven effective in previous years, but both of these animals were moribund when treatment was initiated and died during treatment.

4. **The effect of weather on bloat severity**

At the beginning and close of each grazing period the temperature, relative humidity and forage surface moisture were recorded. Forage surface moisture was evaluated by the procedure used in 1956. Rainfall during the previous 24 hours was recorded once daily. Correlation coefficients were computed between average daily maximum bloat severity of the control animals and daily rainfall and days since last rainfall as well as between average maximum bloat severity during each of the two daily grazing periods and the mean temperature, mean relative humidity, and mean moisture on forage for that period. None of the correlation coefficients showed any significant relationships with the possible exception of that between bloat severity and daily rainfall which approached significance at the 5 per cent level. The correlation coefficients are presented in Table 21.


Table 21. Correlation coefficients of bloat severity with weather observations; alfalfa pasture trials, 1958

<table>
<thead>
<tr>
<th>Bloat evaluation</th>
<th>Daily rainfall</th>
<th>Weather observations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Days since last rain</td>
</tr>
<tr>
<td>Daily maximum</td>
<td>-0.184&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-0.015</td>
</tr>
<tr>
<td>Morning maximum</td>
<td>0.111</td>
<td>0.024</td>
</tr>
<tr>
<td>Afternoon maximum</td>
<td>0.034</td>
<td>0.008</td>
</tr>
</tbody>
</table>

<sup>a</sup>Approached statistical significance at P = .05, all other values non-significant.

5. The effect of bloat and of grazing alfalfa on various constituents of the blood and rumen fluid

Brown (1959) found, in studies closely associated with the present work, that blood ammonia and non-protein-nitrogen changed little during bloat. Whole blood phosphorus tended to increase during bloat, with certain phosphorus fractions increasing significantly. Blood phosphorus levels also increased during grazing. With respect to rumen fluid, the level of amide nitrogen was not affected appreciably by grazing, but the level of rumen ammonia increased considerably during and for a time after grazing.
6. Relation of forage composition to bloat

Ten of the forage samples were chosen for analysis; five from the phosphate-fertilized plots and five from plots that received no phosphate fertilizer. These were analyzed for dry matter, nitrogen, calcium, and phosphorus. The ratios of nitrogen and calcium to phosphorus were calculated. Results are summarized in Table 22, together with the correlation coefficients of each component or each ratio with bloat severity. Bloat severity corresponding to the samples taken from the fertilized plots was much higher than that corresponding to the samples from the non-fertilized plots; this is probably due, however, mostly to the fact that forage from the fertilized plots seemed to grow more rapidly and was the lush type usually associated with bloat. It also had a high nitrogen content which, although correlated significantly with bloat, is again more likely the effect of the fertilizer on plant growth than a cause of bloat per se. Nitrogen (particularly protein-nitrogen) is increased by addition of phosphorus to the soil (Gerwig, 1956; Heinemann et al., 1957a, 1957b). The correlation coefficient of nitrogen with bloat severity was not significant at the usual levels in the 1957 trials where larger numbers of samples were analyzed. Calcium content and calcium-phosphorus ratio were significantly but inversely correlated with bloat severity. These may be causative agents of bloat, or accidental ef-
Table 22. Summary of the relationship of forage composition to bloat severity; alfalfa pasture trials, 1958

<table>
<thead>
<tr>
<th></th>
<th>Percent dry matter</th>
<th>Percent nitrogen</th>
<th>Percent calcium</th>
<th>Percent phosphorus</th>
<th>N:P</th>
<th>Ca:P</th>
<th>Average max. B.S.</th>
</tr>
</thead>
<tbody>
<tr>
<td>High phosphorus</td>
<td>18.54</td>
<td>5.43</td>
<td>1.26</td>
<td>.531</td>
<td>10.23</td>
<td>2.37</td>
<td>.805</td>
</tr>
<tr>
<td></td>
<td>20.42</td>
<td>4.94</td>
<td>1.47</td>
<td>.484</td>
<td>10.21</td>
<td>3.04</td>
<td>.634</td>
</tr>
<tr>
<td></td>
<td>21.76</td>
<td>5.04</td>
<td>1.54</td>
<td>.467</td>
<td>10.79</td>
<td>3.30</td>
<td>1.700</td>
</tr>
<tr>
<td></td>
<td>21.46</td>
<td>5.03</td>
<td>1.50</td>
<td>.436</td>
<td>11.54</td>
<td>3.44</td>
<td>1.100</td>
</tr>
<tr>
<td></td>
<td>22.92</td>
<td>4.72</td>
<td>1.70</td>
<td>.416</td>
<td>11.35</td>
<td>4.09</td>
<td>.900</td>
</tr>
<tr>
<td>Mean, high P</td>
<td>21.02</td>
<td>5.03</td>
<td>1.49</td>
<td>.467</td>
<td>10.77</td>
<td>3.19</td>
<td>1.03</td>
</tr>
<tr>
<td>Low phosphorus</td>
<td>21.46</td>
<td>4.98</td>
<td>1.48</td>
<td>.492</td>
<td>10.12</td>
<td>3.01</td>
<td>.909</td>
</tr>
<tr>
<td></td>
<td>20.19</td>
<td>4.96</td>
<td>1.32</td>
<td>.463</td>
<td>10.71</td>
<td>2.85</td>
<td>1.182</td>
</tr>
<tr>
<td></td>
<td>19.57</td>
<td>5.16</td>
<td>1.59</td>
<td>.474</td>
<td>10.89</td>
<td>3.35</td>
<td>.636</td>
</tr>
<tr>
<td></td>
<td>25.34</td>
<td>4.24</td>
<td>1.54</td>
<td>.380</td>
<td>11.16</td>
<td>4.05</td>
<td>.800</td>
</tr>
<tr>
<td></td>
<td>22.36</td>
<td>4.25</td>
<td>1.67</td>
<td>.382</td>
<td>11.13</td>
<td>4.37</td>
<td>.200</td>
</tr>
<tr>
<td>Mean, low P</td>
<td>21.78</td>
<td>4.72</td>
<td>1.52</td>
<td>.438</td>
<td>10.78</td>
<td>3.47</td>
<td>.74</td>
</tr>
<tr>
<td>Correlation coefficients with BS</td>
<td>-0.035 approx. 1**</td>
<td>-0.707* 0.264</td>
<td>0.045 -0.898**</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Statistically significant at P = .01.  
*Statistically significant at P = .05.
fects due to the different forage types.

Diurnal variation in the composition of alfalfa tops was studied in four trials under the direction of Dr. R. S. Allen. Samples were collected at 6 and 10 a.m., and at 2, 6 and 10 p.m. Trends were similar in the four trials. Values for reducing sugars increased to maxima at 10 a.m., then declined. Ash content declined to minima at 2 p.m., then increased. Values for phosphorus and total nitrogen declined to minima at 6 p.m., then increased. Calcium, amino-nitrogen, and non-protein-nitrogen changed very little during the day. There seems to be no clear-cut relationship between the diurnal changes and bloat. Although afternoon bloat has consistently been somewhat more severe than morning bloat it does not seem to be related to diurnal changes in any of the constituents of the forage for which determinations were made.

7. The effects of age of plant, of oil treatment and of phosphate fertilization on the rate of digestion of alfalfa in vivo

Samples of alfalfa tops (3 to 4 inches in length) picked at different stages of maturity were weighed into nylon bags and introduced into the rumens of the fistulated steers. The animals received their normal preventive and were permitted to graze. The samples were removed at pre-determined intervals, rinsed lightly to remove adhering
particles, and then analyzed (as were concurrently collected samples of the original forage) for dry matter, ash, ether extract and protein. A "carbohydrate fraction" was also determined as the difference between the sum of the ash, ether extract and protein fractions and the total dry matter content.

Determinations of ether extract, total nitrogen, ash and carbohydrate fraction indicated no appreciable differences due to time, type of forage or treatment; however, sample variation was high in all components. The effects of time and of soybean oil treatment on dry matter digestion are presented in Figure 5. The steers digested the dry matter of young tops more rapidly while on a hay diet than when grazing alfalfa; however, the alfalfa tops used in the experiment with the hay diet were very young and lush, which may have contributed to the rapid digestion. Administering \( \frac{1}{2} \) lb. of soybean oil in \( 1\frac{1}{4} \) lb. of grain slowed the rate and extent of dry matter digestion somewhat, lending support to the theory that oils may exert some of their preventive effect by coating the plant and thereby decreasing the rate of microbial attack and subsequent fermentation and gas production (Dyer, 1959). When the oil was mixed with the cob-grain mixture described previously, dry matter digestion proceeded to about the same extent as in the grain-fed controls. Apparently the oil is not released readily from the cobs.
Figure 5. Effect of time and of oil treatment upon intraruminal dry matter digestion of alfalfa tops in nylon bags.
Old forage is digested more slowly than young forage (Figure 6). The animals digested about the same proportion of dry matter from forage samples of high (10.7% DM digested) and low (11.2% DM digested) phosphorus content, but much less phosphorus disappeared from the forage of relatively high phosphorus content (2.17% P digested) as compared with samples with low phosphorus (17.33% P digested). The reason for this phenomenon is not clear. The bag technique requires modification to remove sources of variation and improve precision.

8. The effect of phosphorus fertilization on bloat severity

It has already been mentioned in connection with the effect of forage composition on bloat that forage from the phosphate-fertilized plots caused more bloat than did that from non-fertilized plots (Table 22) and that this was probably due to the effect of the fertilizer in increasing plant growth, rather than a direct effect in causing bloat. This is in contradiction to the theory of Cooper, discussed earlier. Forage analyses showed that samples from both fertilized and control plots were well within the ratios that Cooper defined as bloat-preventing, yet considerable bloat resulted on all plots.

9. The effect upon bloat severity of spraying alfalfa with urea

One of the pasture plots was sprayed with crystalline
Figure 6. Effect of age of plant on intraruminal dry matter digestion of alfalfa tops in nylon bags.
urea in water at the rate of approximately 30 lb. of urea per acre. After 36 hours the herd was divided into two otherwise untreated groups and allowed to graze the urea-sprayed plot and an adjoining control plot. Samples of the alfalfa were taken from both plots before spraying and before grazing, but analyses had not been completed at the time of writing.

Although the level of bloat was quite high in both groups, it appeared that the animals grazing the urea-treated forage bloated earlier and slightly more severely than did the controls. Differences were not pronounced, however, and the work should be repeated before attaching much significance to it.

D. 1959 Season

The 1959 pasture bloat research program consisted of field trials conducted by the author to investigate the prophylactic effect of feeding various antibiotics in combination or in rotation and to develop an effective and acceptable therapeutic agent for serious cases of bloat. Dr. Lynn R. Brown conducted a concurrent study of changes in blood composition associated with bloat; Dr. Paul A. Hartman of the Bacteriology Department investigated bacteriological changes during antibiotic prophylaxis and Dr. R. S. Allen of the Chemistry Department studied forage composition and
its relationship to bloat and the effects of pectic substances administered as possible precursors of foam. Additional investigations were carried out with sheep and with cattle by other workers.

1. General description of the 1959 field trials

During the 1959 pasture season 45 dairy and beef cattle (average initial weight, 639 lb.) were utilized for grazing trials. Six were the same fistulated steers used in the 1958 season; they were used for bacteriological studies, antibiotic assays and to investigate the effects of administering pectins and enzymes. The other 39 animals consisted of 16 dairy steers and 2 sterile heifers from the University dairy farm and 21 dairy and beef steers purchased at open sale. The latter animals were tested upon arrival for tuberculosis, brucellosis and leptospirosis. Results of the tuberculin tests were all negative, but one animal had leptospirosis, and another was suspected of having brucellosis; these animals were promptly removed. Later in the season another animal was removed because of ill health and two died, one from bloat and the other from an intestinal abnormality. Each animal was identified by a numbered plastic or aluminum tag on a neck-chain.

The alfalfa pasture was an 18.9 acre-field (designated E-2 on the map of the Bottom Southeast at Iowa State Univer-
sity and located between the two fields used during the two preceding years). The alfalfa was mostly second-year growth and relatively free from weeds; parts of the field had been replanted the previous summer after floods had killed some of the forage. A rotational grazing scheme was followed in which the field was divided, with electric fences, from north to south into seven plots of approximately equal size. Soil-phosphorus was determined and the plots were treated with varying amounts of 0-46-0 fertilizer in order to promote maximal plant growth. A lane at the north side of the field permitted passage from the plots to the holding pen, located at first in the same location as during 1958 and later moved to higher ground in the northwest corner of field E-2. The holding pen, corral and feed-bunks were arranged as in 1958. Fresh water and trace-mineral salt were always available in the holding pen and an attempt was made to have fresh water available on the pasture plots. This was not always possible due to weather conditions which occasionally made passage with the water-truck impossible.

The animals were allowed to graze twice daily, from 7 to 10 a.m. and from 4 to 7 p.m. Before grazing, each treatment group received grain mixed with antibiotics or grain alone at the rate of 1 1/2 lb. of total mixture per animal. Antibiotics were fed once daily, in the p.m. Bloat severity was observed continuously from horseback during grazing
periods and for a time afterward; evaluation was visual, using the scale described previously (Table 3). Considerable severe bloat occurred from the beginning of the season until early August. After an initial control period for establishment of the bloating pattern, the animals were divided into three groups of approximately equal bloating potential by blocking on bloat scores, as described in 1957. Severe cases of bloat were treated by the same general method previously found successful, but a new therapeutic agent was tested.

Dr. L. R. Brown (Brown et al., 1959) collected samples of blood from animals with varying degrees of bloat and analyzed them in the laboratory for various components. Samples of rumen ingesta were collected periodically throughout the trials for bacteriological studies. At the beginning and close of each trial series of samples were collected before and at various times after feeding the antibiotics; these were assayed for antibiotic activity in order to determine the rate of disappearance of the antibiotic from the rumen. Other trials to determine the effect of adding pectin to the rumen contents and to investigate the pectin esterase and pectin content of the forage at various stages of growth were being carried out at the time of writing.
2. The effect of feeding antibiotics in rotation or in combination on the severity of bloat

At a meeting of Doctors N. L. Jacobson, Paul A. Hartman and the author, held early in March, 1959, the idea of circumventing the short duration of effective prevention of bloat by antibiotics, observed in earlier trials, was discussed. Two possible methods of sustaining the effectiveness of antibiotics were proposed--feeding several antibiotics in succession and then repeating them when resistance had diminished, or feeding them in combinations with the hope that synergistic combinations might extend the duration of effectiveness. The decision was to test both methods, and the Handbook of Toxicology (Spector, 1957) was used as a basis of comparison of various antibiotics which might be useful in rotation or in combination. Antibiotics tested were chosen on the basis of commercial availability, activity against Gram-positive organisms, lack of cross-resistance to one another, and chemical structure. Compounds with peptide bonds or containing amino-nitrogen were eliminated because of possible inactivation due to hydrolysis of peptide bonds by rumen microorganisms. Design of the experiments carried out through August 15 is shown in Figure 7. Trials after August 15 are not described.

Following allocation of the animals to the three groups, antibiotics were fed to two of the groups at the levels and
Figure 7. Experimental design; 1959 alfalfa pasture trials
for the periods indicated in Figure 7. Experimental periods were not fixed, but each antibiotic or combination of antibiotics (combiotics) was fed until it was proven ineffective, or if initially effective, until serious cases of bloat occurred in that group.

Results of the trials are presented in Figures 8, 9, 10 and 11. They indicate that antibiotics can be successfully fed in rotation or in combination. Penicillin and erythromycin fed in combination controlled bloat more effectively and for a longer period of time (26 days in one trial, 23 days in another) than did the same antibiotics fed in rotation. Novobiocin and spontin, included separately in one of the trials, may have exerted an additional preventive effect, but due to their low efficiency and short effect when fed individually, it appears that the effectiveness of the combiotics was mainly due to penicillin and erythromycin. Combiotics continued to provide some protection after the 26- and 23-day periods of maximum effect; however, the effect was diminishing and prevention was not complete. With regard to duration of effectiveness when fed individually, erythromycin and penicillin controlled bloat the longest (about 10 days) at the lowest levels (35 and 70 mg.); tylosin was effective about as long at an intermediate level (105 mg.) but bloat was declining in the control group toward the end and this may have obscured the true effect of
Figure 8. Effect of feeding antibiotics in combination upon bloat severity; 1959 alfalfa pasture trials
Figure 9. Effect of feeding antibiotics in rotation upon bloat severity; 1959 alfalfa pasture trials
Figure 10. Effect of feeding neomycin or oxytetracycline upon bloat severity; 1959 alfalfa pasture trials
Figure 11. Effect of feeding tylosin or chloramphenicol upon bloat severity; 1959 alfalfa pasture trials
the tylosin. Chloramphenicol was effective about 7 days at a rather high level (140 mg.) during a time of less serious bloat. Novobiocin was effective at a relatively low level (70 mg.) for about 5 days. Oxytetracycline reduced bloat somewhat for about 8 days at the 140 mg. level. Neomycin (70 mg.) fed to one group reduced bloat somewhat for about 8 days, but when fed to another group subsequently at the same level used previously, no preventive effect was found. Spontin may have reduced bloat somewhat, but only at the high level of 210 mg. These results indicate that feeding antibiotics in rotation may sustain prevention longer than feeding combiotics if a sufficient number of effective antibiotics are used. This suggests in turn that different combinations could be fed in rotation to give increased protection. Cost considerations suggest rotational feeding as the more practical, while overall effectiveness obtained and the difficulty of preparing several different feeds for bloat control, each with a single antibiotic, indicate that combiotic-feeding may be the more practical approach to bloat control.

Penicillin (70 mg.) reduced bloat somewhat when it was added to the diet after being withheld for periods of up to 17 days, but the effectiveness was considerably less and of shorter duration than when the antibiotic was first adminis-
tered. During 1958, withdrawal of erythromycin for periods up to 26 days failed to renew its effectiveness. Mangan et al., (1959) found that cattle regained their sensitivity to penicillin after about two months. Plate counts taken periodically during the trials under discussion revealed the appearance of resistant strains of bacteria in the rumen ingesta. These also appeared sporadically in the control animals, indicating that there was some transfer of resistant organisms from treated to control groups, probably my mouth through the common water supply used or via the forage. The resistant strains tended to persist for some time, in both treated and control animals.

Assays were carried out to determine the rate of disappearance of the various antibiotics from the rumen after feeding. The results obtained with penicillin were rather surprising—in spite of the known high sensitivity of the procedure used, less than 10 per cent of the antibiotic administered (35-70 mg.) was recovered one-half hour after it was consumed in the grain. Recovery was more complete when a higher dose (140 mg.) was administered. Assays for the other antibiotics used were underway at the time of this writing.

3. The effect of bloat on blood composition

Brown et al., (1959) continued the studies on blood com-
position begun in 1958 and found that although the differences in blood composition associated with bloat were greater in 1958, all phosphorus components measured were higher in bloated animals both years. Of the blood components studied, the differences in plasma inorganic phosphorus levels between bloated and non-bloated animals were the most significant ($P<.005$).

4. The use of oils in bloat therapy

The successful use of lard oil in bloat therapy has been mentioned previously. However, there is some doubt as to whether the lard oil ever will be available commercially for the treatment of bloat. Moreover, the chemical composition of the lard oil has never been revealed. Therefore, it was deemed advisable to attempt to develop a product equal or superior to lard oil as a treatment for bloat. On March 17, 1959, at a meeting of Doctors N. L. Jacobson, R. S. Allen and the author, it was decided that the author would prepare an emulsified oil for field trials during the bloat season. Soybean oil was chosen because of its availability in the midwest, low cost and palatability, but it was conceded that other oils might be equally effective, as pointed out by Reid and Johns (1957). Search of the literature revealed several emulsifiers which might serve the purpose, but the one chosen was adapted from a formula by Bennett (1947).
Bennett's original formula was used in the first batch made in early May. The amount of each ingredient used in the test-batches was one one-hundredth of the amount he suggested. Casein (3.8 gm.) was soaked in 75 ml. of water and finally dissolved with 2.9 gm. of anhydrous sodium carbonate; 220 ml. of denatured alcohol was added, together with 7.6 gm. of gum gamboge and sufficient water to bring the total volume to 725 ml. Bennett suggested adding one part, by volume, of the emulsifier to five parts of a petroleum oil with a specific gravity of 0.891 (a representative sample of crude soybean oil had a specific gravity of 0.914) to obtain an emulsion with lard-like consistency. It was found in the present trials that in order to produce an emulsified soybean oil miscible with water it was necessary to mix one part of the emulsifier with no more than two parts of the crude soybean oil. Apparently the lecithin content of crude soybean oil is important for successful emulsification, because when the lecithin was allowed to settle and the relatively pure oil was used the emulsion was incomplete.

Before field testing, several changes were made in the original procedure. At first the oil and emulsifier were passed through a hand-homogenizer but since there appeared to be no differences in stability of this product as compared to one where the emulsifier and oil were merely shaken together, this latter procedure was substituted for the more
lengthy homogenization. Gamboge, a rather strong cathartic, was eliminated from the emulsifier with no apparent ill effects upon the characteristics of the emulsifier, and 95 per cent ethanol was used in place of the denatured alcohol recommended. Thus, the emulsifier tested in the field contained no toxic compounds.

The emulsified soybean oil which was tested in the field (ISU Bloat Mix No. 4) was made as follows: 3.8 gm. of casein was soaked in water for several hours, being stirred constantly with a magnetic stirrer; 2.9 gm. of anhydrous sodium carbonate was added to dissolve the casein; 220 ml. of 95 per cent ethanol was added, together with sufficient water to bring the total volume to 725 ml. One part of this emulsifier was mixed with two parts (by volume) of crude soybean oil. The resulting emulsion was not particularly stable, but when shaken it re-emulsified readily and remained emulsified for sufficient time to permit its use. Batches of ISU Bloat Mix No. 4 were mixed periodically as needed, so rancidity was not a problem; it is recognized that under conditions of commercial production it would probably be necessary to add an anti-oxidant to prevent deterioration of the oil during prolonged periods of storage between manufacturing and use.

Table 23 shows the results of the field tests with ISU
Table 23. Response of serious cases of bloat to treatment with anti-foaming agents; 1956, 1957, 1958 and 1959 alfalfa pasture and soilage\textsuperscript{a} bloat trials

<table>
<thead>
<tr>
<th>Bloat Level (mg. agent)</th>
<th>Number of animals</th>
<th>Other severity\textsuperscript{b}</th>
<th>Treated</th>
<th>Recovered</th>
<th>Died</th>
<th>Total</th>
<th>Treated</th>
<th>Recovered</th>
<th>Died</th>
<th>Total</th>
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<tbody>
<tr>
<td>3</td>
<td>100</td>
<td>Lard oil c, d, e, f</td>
<td>5</td>
<td>5</td>
<td>1</td>
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<td>150</td>
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<td>8</td>
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</table>

\textsuperscript{a}Data from Brown (1959).
\textsuperscript{b}See Table 3 for scale used in evaluating bloat.
\textsuperscript{c}1956 data.
\textsuperscript{d}1957 data.
\textsuperscript{e}1958 data.
\textsuperscript{f}1959 data.
Table 23. (Continued)

<table>
<thead>
<tr>
<th>Bloat severity\textsuperscript{b} (mg. agent)</th>
<th>Number of animals</th>
<th>Other treat.</th>
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<tbody>
<tr>
<td></td>
<td>Treated</td>
<td>Recovered</td>
</tr>
<tr>
<td>I.S.U. Bloat Mix No. 4\textsuperscript{f}</td>
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<td></td>
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<tr>
<td>3</td>
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<td></td>
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<tr>
<td>350</td>
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<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>95</strong></td>
<td><strong>90</strong></td>
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</table>
Bloat Mix No. 4, together with some other anti-foaming agents used in 1959 and those used in the other years. Of 95 cases with a bloat severity of 3 or higher at the time of treatment with ISU Bloat Mix No. 4, 90 recovered, 4 required extra treatment (additional oil) to deflate and 1 died. The animal that died did so during treatment; insufficient time had elapsed for the oil to exert its full effect.

Treatment was chiefly by stomach tube. Almost invariably the animals began to belch and pass large amounts of free gas through a stomach tube immediately following administration of the oil and usually were completely deflated and ready to return to pasture within 15 to 40 minutes. Un-emulsified soybean oil was also used in several cases and seemed to be moderately effective on the basis of the few cases in which it was used. However, recovery was less rapid than with the emulsified oils. A comparison of ISU Bloat Mix No. 4 with lard oil is not feasible even though the total number of cases treated with each is about the same. A greater proportion of the cases treated with lard oil were in the higher degrees of bloat (4 and 5) than was the case with ISU Bloat Mix No. 4. Warner and Woods (1959) used lard oil to treat 72 cases of bloat in sheep scored 3 or higher (on a scale comparable to that in Table 3), while ISU Bloat Mix No. 4 was used in 38 such cases at the rate of 1 to 1½ ounces per animal. They concluded that the two oils were
equally and immediately effective; after treatment with either of the oils the sheep deflated completely in 30 minutes or less.

Brown (1959) used n-decyl alcohol to treat 5 cases of bloat scored a 4; the alcohol was effective in both 25- and 100-ml. doses. Di-decyl tetraphenyl succinic anhydride, an anti-foamer prepared by Dr. R. S. Allen, was injected intraruminally in two cases scored 3 and one scored 4; with the 5- and 10-ml. doses employed the animals recovered, but the effect was very slow compared to similar cases when the ISU Bloat Mix No. 4 or the lard oil was used. Corn lecithin, a highly surface-active compound was emulsified with the same emulsifier and method used for the soybean oil and 200 ml. was administered to an animal scored a 3. Some free gas was obtained using a stomach tube, but ISU Bloat Mix No. 4 had to be administered to deflate the animal completely and the lecithin was not tried again.

Results of the trials on cattle and sheep with lard oil and the ISU Bloat Mix No. 4 have led the author and his co-workers to conclude that both are very effective in relieving bloat, probably by breaking foam and releasing gas. For maximum effectiveness the oils should be introduced into the rumen through a stomach tube and the tube maintained in place to allow the gas to escape. If a stomach tube cannot
be inserted because of extreme intraruminal pressure, the oil can be injected with a hypodermic syringe. As soon as possible a stomach tube should be introduced, or where the bloat is scored as a 5, the trocar and cannula can be used to allow free gas to escape following administration of the anti-foaming agent.

5. Miscellaneous observations

In cases which were not reached in time for treatment as outlined previously the knife was found more effective than the trocar and cannula. In 1956, 1957 and 1958 the procedure used was to cut a large hole in the animal's side and remove the ingesta, but this procedure required extensive treatment by the veterinarian to repair the damage caused. In 1959, the procedure followed was to make an incision the size of the knife blade and then to turn the blade within the incision to allow gas and foam to escape. By periodically rotating the blade in this manner and/or manipulating the incision with the fingers, sufficient free gas and foam escaped that three animals treated in this manner recovered with no other veterinary assistance than an injection of antibiotics to prevent peritonitis. The temporary fistulas thus created soon closed without further assistance and the animals usually began to eat and bloat again within a few days.
During all four years of the pasture trials described herein it had been observed that animals would not bloat during the first day they were turned on a new plot of alfalfa. It was thought that this might be due either to a tendency to graze grass and weeds first or to the necessity of filling the rumen with lush, tender plants following the grazing of the coarser stems on grazed-over plots. The latter hypothesis seemed more likely since it is known that after eating hay for some time animals must graze legumes for a day or two before they will bloat; also, the forage grazed in the 1959 trials was relatively pure alfalfa, with little contamination by weeds and grasses. To test the latter hypothesis the animals were allowed to graze one plot several times until they bloated; they were then switched at the next grazing to a new plot, upon which they continued to bloat. This procedure was repeated once more with the same results, and it was concluded that the hypothesis tested is the correct one.
IV. GENERAL DISCUSSION

...Though I am very well inclined to your undertaking in general, and think that the various improvements in husbandry cannot be too soon, or too universally communicated to the industrious husbandman, you will not take it ill if I remark that your collection of papers has some conjectures, which, in my opinion, must rather puzzle than help the plain country farmer....

---P.H., 1764 (Beddows, 1959)

The intensive research efforts of recent years have resulted in considerable success in unravelling the mysteries of the entity known as pasture bloat. The important role of stable foam formation as a prerequisite of bloat is at last generally recognized, and this has in turn suggested logical approaches to successful prophylaxis and therapy. It has raised additional questions, however, about the biological, chemical and physical factors involved.

A. Etiology

Stable foam formation is now generally conceded to be a necessary prerequisite to the occurrence of pasture bloat, mainly on the basis of the successful use of anti-foaming agents in treating and preventing bloat. Observations on the characteristics of rumen ingesta during bloat have tended to support this view, and several workers, including the present author, have observed that the seriousness of bloat is closely related to the amount of stable froth present;
as the proportion of froth increases with a concomitant decrease in free gas, the severity of bloat becomes more pronounced. Eructation sometimes occurs in relatively advanced cases, but eventually this avenue of escape of free gas is blocked, aggravating the condition still further. Some confusion remains concerning the mechanism by which eructation is inhibited, and the importance of gaseous diffusion to and from the blood stream as a source of ruminal gases or route of escape for those gases has not been ascertained.

Successful measurement of foam characteristics important in the bloat syndrome has recently been accomplished by Mangan (1959). He has devised a technique for measuring the dynamic stability and strength of a foam, as well as the foaming ability of the foam system. Use of foam volume measurements to evaluate the foaming ability of frothy ingesta has proven unsatisfactory, due to the nature of the foam system involved; as ingesta become frothy, liquid is replaced by gas (indicated by lowered specific gravity) and there is less total precursor available for foam genesis per unit volume of ingesta. Dynamic foam stability and foam strength measurements therefore assume added importance and the apparatus of Mangan is being modified by the author and his co-workers for further research on this important phase of etiology.
Various biological, physical and chemical factors have been implicated in the genesis of foam. Surface tension of the ruminant ingesta has been associated by some with froth formation, and in the present studies surface tension has consistently increased with increasing severity of bloat. Viscosity relationships have been stressed by some workers and pH by others. Depression in salivary secretion may result from the ingestion of lush legumes; some workers have found that lack of saliva leads to increased viscosity of the ingesta and perhaps to foam formation. Two effects of pH of the ruminal contents may be important; the state of ionization of charged groups in the molecules of foam precursors depends on pH, and when the state of ionization is changed the surface tension of solutions containing such molecules is changed also. Also, salivary bicarbonate may be converted to carbon dioxide at low pH. Optimum pH values for stable ruminal foam formation have been found by Mangan (1959) to correspond with the pH of red clover cytoplasmic protein; in the present study, however, pH of ingesta has not been correlated in a consistent manner with bloat. Mangan (1959) suggests four prerequisites for foam formation: a) the active foaming agents must be present in solution in the rumen in the required concentration for a sufficient time for foam to be formed; b) pH values, salt concentration and perhaps other factors must be suitable within the rumen for stable foam formation; c) sufficient gas must be gener-
ated by fermentation or by release from salivary bicarbonate; and d) anti-foaming agents from the forage consumed must be sufficiently inactivated or diluted to permit the foam to persist.

Variations in individual susceptibility to bloat have been discussed by several authors. In the studies described herein wide variation in susceptibility was observed, but it is felt that this is largely a matter of degree since all of the animals in the herd have been observed to bloat to a lesser or greater degree when conditions were optimal for bloat. Identical twin studies indicate that heredity is an important factor in determining susceptibility and one sound approach to the problem of bloat may lie in a breeding program with selection on the basis of low susceptibility to bloat. This would admittedly require much time and care to avoid the loss of other desirable characteristics, but nevertheless offers some promise.

With respect to plant characteristics associated with bloat, breeding may ultimately provide a plant which will not cause bloat, but since the plant factor or factors related to bloat are still unknown, no sound plant breeding program can yet be designed. Johns (1958b) suggests that the chemical components of the plant are important in bloat in three ways: a) they are the source of the substrates for
fermentation leading to gas production (dry matter, organic acids, carbohydrates, non-stable nitrogenous compounds); b) they add foaming agents (saponins, proteins, pectic substances) and anti-foaming agents (chloroplastic lipid) to the rumen fluid; and c) they may be the source of toxic compounds. Saponins are foaming agents but their main effect in bloat seems to be due to their other physiological properties. The phosphorus content of the soil, forage, rumen ingesta and blood seems to be involved in the etiology of bloat but the nature of this involvement is still obscure. Lack of phosphorus in the soil has been suggested by Cooper as a cause of unbalanced ratios of nitrogen and calcium to phosphorus in the forage, leading in turn to the formation of unstable nitrogenous compounds in the rumen (precursors of gas), adverse ionic effects on surface tension and state of emulsion of the ingesta, shortage of phosphorus-containing compounds necessary for proper nervous function (depressed eructation and loss of tone of the rumen musculature), and formation of certain toxic compounds, both within the plant and the animal. This theory has been supported by some findings, but the work of the author and his colleagues, as well as that of others, has indicated that phosphorus fertilization, instead of preventing bloat, increases the incidence and severity of bloat, probably by causing the plant to grow faster. During this period of rapid plant growth, nitrogen
content of the plant is increased, but the author found that ratios of calcium and nitrogen to phosphorus were well within levels defined as optimal. In further opposition to Cooper's theory, Brown (1959) found that the phosphorus content of blood fractions increases during bloat, and Lienert (1950) suggests that it is the presence of large amounts of phosphate in the plant and phosphatase in the rumen fluid which leads to increased gas production and bloat. Further work is certainly needed to clear up the contradictions involved but it does appear that phosphorus may be associated with bloat.

The physical nature of the plant was long suggested as an important factor; lush, young legumes were thought to cause bloat while the more mature forage was considered safe. However, in the present studies and those of Johns (1954) bloat was obtained occasionally on mature forage and even on hay made from bloat-provoking forage. More recently Conrad et al. (1958) suggested that interactions of certain parts of the plant cell structure may be important in foam genesis.

Certain climatic conditions, particularly damp weather, have traditionally been held responsible for outbreaks of bloat, but the present author and many others found no correlation of specific weather conditions with bloat incidence and severity. It has been observed that when rain follows a period of drought, plant growth is accelerated and bloat
may result. In the present studies animals tended to bloat more in the evening, when the forage was the driest; in other studies the animals sometimes have bloated more in the morning, sometimes more in the evening. In some studies more bloat has been observed when the animals were first turned on the plots, but in the present studies and certain others, it has been observed that the animals must be on the plots for a time before serious bloat occurs. This is probably due to the necessity of replacing the coarser, stemmy material in the rumen with more lush, easily fermented forage.

B. Prophylaxis

New Zealand workers have recommended pasture management—the maintenance of proper balances between legumes and grasses—as the best long-range approach to bloat control. However, bloat occasionally occurs with relatively low proportions of legumes in the pasture mixture, making this method of prevention doubtful at the best. Then too, the legumes are generally better than the grasses from the standpoint of nutrition and yield per acre and the aim of the good manager should be to increase the amount of legume forage he feeds rather than to limit it; he then needs other methods of prevention. One approach which is receiving widespread attention currently because of other advantages it possesses is the practice of zero grazing (feeding soilage); bloat tends
to decrease when the animals are forced to consume the entire plant. Different methods of altering the grazing pattern have been tried with varying degrees of success but these generally require much time and effort on the part of the livestockman in moving fences and driving cattle to and from pasture. Roughage feeding before or during grazing has been advocated by some workers, but the results obtained have been variable. In studies conducted by the author animals were permitted free access to timothy hay with no apparent effect on bloat severity or incidence. Roughage may act as an anti-foamer, either due to its chemical composition or physical nature; it may also slow down microbial attack on the ingested forage, or it may exert an effect on the nervous responses involved in eructation.

Administration of anti-foaming agents is the most logical approach to bloat prophylaxis; however, several problems must be resolved before their use is completely successful. Undesirable side-effects on the animal and lack of palatability can be avoided by choosing the agents with care and by keeping the dosage low. Anti-foaming agents remain active within the rumen only for a period of a few hours, however, so intake must be fairly continuous. In the studies reported herein administration of various oils or similar compounds was effective in preventing bloat as long as the supply of such agents available in the rumen was replenished from time to
time. New Zealand workers suggest spraying oil on the forage to be grazed as the best method of insuring constant intake of anti-foaming agents, but this method seems unduly laborious for satisfactory use in the United States. A more practical method is soilage feeding, as mentioned previously; when bloat occurs under this system, an anti-foamer, such as soybean oil, can be sprinkled over the soilage at the time of feeding and constant intake of the oil is thus assured. Complete control of bloat has been obtained in this manner (Brown, 1959). Adding the anti-foamer to the drinking water may be an alternative, but efficiency depends upon many conditions affecting the intake of treated water, and the method is practical only where the source of water is limited to the treated water.

The oils and similar products are generally considered effective preventives by virtue of their anti-foaming action, but indications are that they may also exert a preventive effect by slowing fermentation through a delaying action on microbial attack upon the forage (coating effect). Silicones and detergents may be somewhat effective but are generally considered unreliable. Work is being done at this institution to discover why the anti-foamers become inactive so soon; this should be continued.
Administration of individual antibiotics has been advocated by other workers, but those that are effective at all usually lose their effectiveness after 7 to 10 days of continuous feeding. In the present studies it was discovered that several antibiotics can be fed in rotation or in combinations to sustain the effect far beyond the period of protection afforded by one antibiotic. Additional work is necessary to determine the best sequences and combinations, the minimal levels necessary and the possible side effects on the animals, but this method has been very successful to date and avoids the short duration of control observed in the case of the anti-foamers. The work of the researchers in New Zealand seems to establish that there are no undesirable side-effects on the animals, at least for penicillin, and suggests that the antibiotics may exert their effect by inhibiting certain bacteria responsible for alteration of the chloroplastic lipid, the natural anti-foaming agent contained in the plant. On the other hand, antibiotics may alter certain metabolic pathways of bacteria in such a way as to depress the production of foam precursors. The method of administering the antibiotic is important, since antibiotics can be inactivated relatively quickly under some conditions. This limits their use in salt-mixtures, and may preclude their use in the drinking water until such time that water-stable forms of the antibiotics can be developed. Effective-
ness of administering antibiotics in salt or water is also limited by variations in intake due to various factors.

C. Therapy

Even with the recent advances in prevention by use of the anti-foaming agents and successful use of these same agents in bloat therapy emergency rumenotomy is sometimes still necessary. This procedure has serious disadvantages, particularly if the incision is large. However, in the present study the author found that a knife could be used successfully to make a small hole, large enough to permit the escape of gas and foam but small enough to heal without surgical assistance. Animals relieved in this manner should be examined by a veterinarian as soon as possible, however, and the usual procedure in the present study was to administer antibiotics to avoid peritonitis.

Use of the trocar and cannula may be successful if the free-gas pocket is relatively large, but is probably no more effective than is the use of a stomach tube. If a stomach tube can be introduced, it will permit the escape of the free gas, and then can be used for the introduction of anti-foaming agents; the tube also serves a third purpose, that of permitting the rapid escape of gas released from the foam by the action of anti-foamers. In very serious cases it has been observed that introduction of a stomach tube is impos-
sible, possibly due to an extreme mechanical rigidity of the froth under high pressure or to a constriction of the cardiac end of the esophagus by nervous or mechanical influences. In such cases, anti-foamers can be administered by direct injection through the left paralumbar fossa with a hypodermic syringe and needle. This treatment should be followed as soon as possible with the introduction of a stomach tube or a trocar and cannula to permit the escape of free gas and reduce pressure. Caution is suggested since there is some indication that too rapid release of pressure can be fatal.

Among the various anti-foamers used in bloat therapy, the oils have enjoyed the greatest success to date. Detergents and silicones are generally considered unreliable. New Zealand workers have used peanut oil and other vegetable oils with success, and no undesirable side effects have been observed; other workers also have used vegetable oils. It is felt, however, that water-dispersibility greatly increases the rate of action. One of the principle goals of the present studies was the development of a product which could be used in therapy. It is necessary that such a product be economical, non-irritating, non-toxic and readily dispersible in the rumen fluid. This goal was accomplished, it is felt, with development of ISU Bloat Mix No. 4. It was highly effective and action was rapid in cases of serious bloat of both cattle and sheep.
Some may contend that what has been learned about bloat is insignificant in relation to what remains to be learned, but an objective review of accomplishments to date makes it difficult to be that pessimistic. It is true that more work must be done, but at present we have a working hypothesis about the cause of bloat which has led to successful methods of treatment and prevention. The fact is that bloat can be controlled now, and it will be the task of future workers to develop more universally acceptable prophylactic and therapeutic techniques and eventually to define completely the etiology of bloat.
...The clover husbandry being now, happily for the parts of our country heretofore worn out and sterile, very prevalent, it behoves us to extinguish all prejudices against this great and extensive improvement....

--Richard Peters, 1804 (Beddows, 1959)

During the years from 1956 through 1959 grazing trials were carried out on alfalfa pasture to investigate etiological factors involved in bloat and to develop effective methods of prophylaxis and therapy.

In 1956, 25 steers were divided randomly into two groups, one of which received a water-dispersible oil (lard oil) in the drinking water. The groups were reversed periodically throughout the summer and the results showed that the oil reduced bloat incidence and severity appreciably. This effect was particularly pronounced during a serious outbreak of bloat; however, it was necessary to increase the percentage of oil in the water from an initial 1 per cent to a level of 2 per cent to circumvent a decrease in water and oil consumption brought about by cold, damp weather. The oil was palatable and apparently had no adverse effects on appetite or well-being of the animals. At the close of the pasture season the same oil was given in the drinking water to animals receiving a high concentrate and low roughage ration. The oil was not so effective in preventing bloat as in the
pasture trials, but little bloat was observed in either treated or control animals.

In 1957, 36 steers were divided into three groups by blocking on bloat scores; each group received various prophylactic agents in dry feed before grazing twice daily, or in water. Soybean oil, lard oil and lecithin mixed with soybean oil greatly reduced bloat for several hours when fed at the rate of 0.25 lb. or more, per animal in the grain at each feeding or at the rate of 2 per cent in the drinking water (lard oil only). Feeding oil or oil-lecithin mixtures increased weight gains appreciably, ranging from 0.07 to 0.75 lb. per animal per day for the various oil treatments. Penicillin (75 mg. per animal daily) reduced bloat for nine days, but subsequently its effectiveness diminished rapidly. Increasing the penicillin to 125 mg. reduced bloat for a period of two days, after which bloat incidence increased sharply. Animals receiving penicillin gained 0.44 lb. per day more than controls.

In 1958, 41 dairy and beef cattle were divided into three groups by blocking on bloat scores. Six of the animals which had been fistulated were used for studies of rumen fluid characteristics and other etiological factors. Soybean oil at the rate of 0.25 lb. per animal prevented bloat for 3 to 4 hours when fed in the grain immediately before grazing.
Increasing the concentration of oil to 0.5 lb. per lb. of grain made the mixture unpalatable and reduced consumption by some individuals, making evaluation difficult. A mixture of oil with ground corn cobs and grain was less effective than a mixture of oil with grain alone; feeding ground or flaked raw soybeans had little or no effect. Erythromycin (75 mg. per animal per day) reduced bloat severity for several days but the effect soon decreased and was not restored when the antibiotic was reintroduced after 26- and 15-day periods. Corn lecithin apparently prevented bloat efficiently, but observations were limited in number. Soybean lecithin mixed with methyl esters of fatty acids gave variable results. Neither gastric mucin, corn distillers' dried solubles nor ad libitum feeding of timothy hay prevented bloat. Phosphate fertilization did not reduce bloat. An in vivo technique involving the fistulated steers indicated that the rate of dry matter digestion in the rumen was slower when the forage fed was more mature or when oil was administered to the animals.

In 1959, approximately the same number of animals and the same procedures were used as in the 1958 trials. Results indicated that the period of effectiveness of antibiotics can be extended considerably by feeding several different antibiotics in rotation or by feeding them in combinations. Those found particularly effective were penicillin, erythromycin and tylosin. Chloramphenicol and novobiocin were
slightly less effective; oxytetracycline, neomycin and spon-
tin were of questionable value. Penicillin and erythromycin
were more effective for a longer period of time when fed
together than when fed in rotation.

Analysis of forage composition and observations of
weather conditions revealed no consistent differences cor-
related with bloat. Determination of rumen fluid charac-
teristics showed that surface tension increases and specific
gravity decreases during froth formation and during bloat.

Two emulsified oils—lard oil and an emulsified oil de-
veloped especially for the purpose—were effective in re-
lieving serious bloat in 181 of 194 cases treated; 8 animals
required further treatment (usually with more of the same
oil) and 5 died. In limited trials, soybean oil appeared
less effective (due to slower action) than the emulsified
oils.
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