Agricultural research: impact on soybeans

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IOWA STATE UNIVERSITY of Science and Technology
Ames, Iowa ......................... January, 1975
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AGRICULTURE AND HOME ECONOMICS EXPERIMENT STATION
IOWA STATE UNIVERSITY of Science and Technology
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By Ruth Steyn
Associate Experiment Station Editor
THE GOLDEN BEAN...  
CINDERELLA CROP... 
POOR MAN'S MEAT

Although the soybean has not displaced King Corn from the midwestern farm scene, its popular nicknames suggest that this ages-old crop, originally imported from China, has captured the imaginations of producers and the general public alike.

U.S. soybean production has grown phenomenally since World War II, fully warranting public enthusiasm for the crop's potential. The versatile soybean, a source of both high-quality protein and edible oils, seems to offer something for everyone. And the dizzying prices that soybeans have commanded recently suggest continued growth in soybean production, exports, and farm profits.

But some disturbing facts underlie this impressive record and the popular acclaim for soybeans:

- Although average soybean yields are about 1.5 times greater today than in the early 1940s, the rate of increase in soybean yields has lagged behind that of other major field crops.
- Recent high prices of soybean meal, if they continue, may eventually trigger increased competition from other protein sources as supplements in animal feeds.
- Expansion in soybean production during the past 20 years was encouraged to a considerable extent by government programs for other crops, reduced oat and hay acreage, and favorable trade policies. As these influences are modified, the soybean production picture may well change.
- Growth in world exports of soybean meal has exceeded that of soybean oil substantially.

If soybeans are to retain their newly won prominence in American agriculture, substantial efforts are needed to increase supplies, reduce production costs, and bolster their competitive position. Our beans must compete in domestic and foreign markets with other protein and edible oil products. And, they
must compete with other crops for the farmer's productive resources—land, labor, capital, and management know-how.

The fundamental reason for growing crops is to capture and transform radiant energy from the sun into stored chemical energy of food and fiber useful to man or his domestic animals. Plant species that do this efficiently with economic levels of management inputs and that yield products desired by man become important commercial crops. Plant species lacking these characteristics don't survive long in commercial agriculture.

The many facets of crop production form three basic, interacting components:

The biological potential of a crop, which can be modified by plant breeding and genetic manipulation;

The growth environment in which a crop's biological potential is expressed and which man tries to manage so as to exploit the full biological potential;

The utilization of a crop, which depends on its cost and suitability as food or feed, the presence of competing products, and the availability of transportation and processing facilities to deliver the crop to consumers in usable forms.

Over the years, scientists at the Iowa Agriculture and Home Economics Experiment Station have conducted studies related to all three components of soybean production—biological potential, growth environment, and utilization. Their research has helped Iowa farmers to incorporate soybeans into their farming operations and to meet increasing consumer demand. In 1950, for example, soybeans were grown on about 9 percent of Iowa's harvested acreage and accounted for 3.5 percent of farm cash receipts. In 1973, soybeans occupied 30 percent of the acreage and accounted for 19.5 percent of cash receipts.

The increase in Iowa's soybean acreage since 1950 was not accompanied by a corresponding decrease in corn acreage. Rather, much of the land now in soybeans was previously in oats, other small grains, or hay and pasture. Most of Iowa's land suitable for corn or soybeans is now in production. And, for several reasons, Iowa farmers probably won't shift major acreages of corn to soybeans in the near future.
Future increases in the supply of soybeans, at reasonable prices, depend upon increasing yields per acre and reducing the costs of soybean production. Failing this, soybean prices will remain high or even increase, as long as demand continues to grow. But eventually, growth in demand will slacken in poor countries if soybeans are priced out of the human food market and replaced by higher-yielding, but less nutritious cereals. And even in developed countries, excessive soybean prices, reflected in higher meat prices, eventually may dampen the growth in meat consumption and encourage development of substitutes for soybean meal.

The soybean, quite obviously, yields products useful and desired by man. But the benefits of the Golden Bean will be denied to many in the future unless we can improve its biological potential, learn to manage its growth environment more effectively, and upgrade soybean marketing and processing techniques.

Many current and past research projects at the Iowa Experiment Station have focused on these problems. Let's take a look at some of these studies to see how research contributes to the role of soybeans in American agriculture—with benefits for both producers and consumers.
Crossing soybeans is a delicate, tedious operation.
BREEDING SOYBEANS

The biological potential of any organism resides in its array of genes, the discrete chemical units that transmit heritable traits from one generation to the next. Genes are linked together into long, linear structures, the chromosomes. Each species has a characteristic number of chromosomes, which generally occur in pairs, with each member of the pair containing genes controlling the same traits.

Most soybeans, for example, have 40 chromosomes, symbolized as 20N to indicate that there are 20 paired chromosomes, a total of 40. The sex cells or gametes have half the total number of chromosomes. When male and female gametes come together during fertilization, the chromosome number is restored to its full complement of 2N.

Some plant traits, such as flower and pubescence color in soybeans, are controlled by a single gene pair. In such simple cases, we often observe the trait as an either-or phenomenon. The soybean flower is either white or purple; its pubescence, the hairy growth on leaves and stem, is either tawny or gray.

Many traits, however, are controlled by more than one gene pair. In soybeans, important "polygenic" traits include yield, height, days to flowering, percentage of protein, maturity, and many others. Complicated traits such as these typically exhibit a wide range of possible values, rather than the either-or behavior of simple traits. The basic reason for this is that the many genes that collectively influence yield, for example, can exist in a large number of different combinations.

What Does a Plant Breeder Do?

Basically, plant breeders try to assemble, within one variety or line, combinations of genes that result in increased yields, improved disease resistance, or other useful characteristics such as a different plant height or chemical composition. When the trait involved is simple, the breeder's job is relatively simple.
When the trait is complicated, the job becomes very time-consuming and expensive.

Plant-breeding programs typically have four basic stages. The first involves mating or crossing different parent lines to produce new gene combinations in the hybrid progeny. Next, progeny are inbred for several generations to obtain true-breeding lines. Then these lines are tested for those traits in which the breeder is interested. Finally, lines are selected on the basis of the tests, the seed is increased, and a new variety is released.

The testing part of a breeding program may concentrate on yield, on pest resistance, on various physical or physiological traits, or on combinations of these. Decisions on which traits to test for, how to test for them, and how to use test results in selecting lines for additional work are integral parts of a breeding program.

A certain aura of magic and mystery surrounds plant breeders, especially when they bring forth a new variety with better disease resistance, improved yield, or an unusually colored flower. Actually though, breeders painstakingly imitate what Nature has been doing for thousands of years; that is, mating

Vine-like wild soybeans, collected in the Orient, may contain valuable genetic traits useful in improving modern varieties (shown in background).
plants with diverse genotypes and then selecting and propagating offspring with certain traits.

Of course, under natural conditions, the parents are chosen randomly, essentially by chance, and matings are carried out by airborne or insect-borne pollen. Plant breeders, in contrast, deliberately choose which parents to use in their breeding programs and control the matings. Breeders also deliberately select which offspring to keep on the basis of specific traits such as yield, color, leaf shape, seed composition, etc. But under natural conditions, overall competitive success in a given environment determines which offspring survive and produce the next generation.

Genetic Diversity

If the basic objective of soybean breeders is to assemble superior combinations of genes, their basic raw material is the collection of genes found in the total soybean population scattered throughout the world. Within this worldwide reservoir of genes or germ plasm is contained a vast diversity of soybean traits that have evolved during biological history. Until quite recently, however, breeders have tapped only a minor portion of the soybean's genetic reservoir, a natural resource as valuable to agriculture as iron ore is to steelmaking.

Because soybeans are not native to the United States, all our varieties are derived from plant introductions that originated in eastern Asia, the soybean's home land. Records indicate that just five of the early plant introductions became the principal varieties during the time soybean production was getting started in the Midwest. These same varieties also were used by the first soybean breeders as parents for crossing and selection of higher-yielding varieties. As a result of this trend, many of the commercial soybean varieties and brands available today are really variations on the same theme, their ancestry can be traced back to a very small number of plant introductions.

In recent years, an estimated 50 to 60 percent of the soybean acreage in the North Central Region of the United States was planted to only five varieties. Three of these varieties have Richland as an ancestor, and all have Mandarin. During 1972, about two-thirds of Iowa's soybean acreage was planted to just
three varieties—Corsoy, Wayne, and Amsoy—that share Mandarin as a common ancestor. The common ancestry and genetic uniformity of current soybean varieties have two important consequences, one short-term, and the other long-term.

The immediate hazard of excessive crop uniformity is potential vulnerability to new strains of disease pathogens or insect pests. When a new race of southern corn leaf blight appeared in the late 1960s, nearly all commercial corn hybrids had the same blight-susceptible cytoplasm, derived from their maternal parents. The leaf blight fungus, faced with acre upon acre of susceptible corn, spread rapidly and caused widespread damage wherever weather conditions were favorable.

The corn leaf blight situation was unusual in that susceptible hybrids had a common cytoplasm, rather than common genes within the nucleus. Nonetheless, the unfortunate experience with corn leaf blight illustrates how crop uniformity, whether stemming from a common cytoplasm or shared genes, may favor the spread and increase of pest populations.

The second consequence of genetic uniformity relates to the long-term prospect of developing higher-yielding soybean varieties or uncovering other desirable traits. In the short run, when two good varieties such as Corsoy and Wayne are crossed, there is a reasonable chance of getting offspring as good as or better than either parent. But if crossing and selection among related varieties is continued generation after generation, genetic diversity among the parents may narrow to the point that yield improvement from breeding becomes minimal. In effect, many of the possible gene combinations have been tried before, and finding superior new ones becomes less likely.

On the other hand, if "exotic" germ plasm is brought in by crossing an unrelated, but unadapted, plant introduction with a good commercial variety, very few offspring will outyield the commercial variety. And, the chances of finding the few superior progeny are small. In addition, shattering problems, lodging susceptibility, and other undesirable traits may be introduced with the exotic germ plasm. Despite these disadvantages, primitive exotic strains of soybeans represent a genetic goldmine that breeders can explore for valuable traits such as disease resistance, better oil quality, and higher photosynthetic efficiency.
Because of the need to increase the genetic diversity of commercial soybean varieties and to locate new sources of useful traits, Experiment Station breeders are engaged in long-term studies on the use of exotic germ plasm in soybean breeding. They have worked out efficient techniques for evaluating soybean lines (plant introductions) from China, Korea, and Japan for their potential as parental stocks. Various procedures for incorporating exotic soybean lines into breeding populations are being tested to determine efficient methods of developing more genetically diverse soybean varieties in the future.

In 1973, the Iowa Experiment Station released four soybean breeding populations containing from 25 to 100 percent exotic germ plasm. The plant introductions used as parents in developing these populations are not ancestors of any current varieties. Although these breeding populations are not new varieties, they are the raw material from which genetically diverse varieties may be selected. Release of these populations will help soybean breeders throughout the United States to integrate new germ plasm into their programs.

Research on soybean introductions and methods of incorporating exotic germ plasm will not produce superior varieties this year, or next. But Experiment Station scientists are confident that, eventually, they can obtain superior varieties whose ancestries differ significantly from those of current varieties.

Soybeans are grown throughout the year at the Iowa Station's nursery in Isabella, Puerto Rico.
Small-scale planters and harvesters, developed at the Experiment Station, save time and labor in testing experimental soybean lines.

Speeding Up the Soybean Breeding Program

Development of higher-yielding varieties is the main objective of the Experiment Station soybean breeding program. Although other traits, such as disease resistance, lodging resistance, oil quality, and seedling emergence, are taken into account, much of the present breeding program involves testing and selection based on yield alone.

Extensive testing and replication are necessary to obtain a reliable measure of the yield potential of experimental soybean
lines. In the past, this has severely limited the number of lines that could be evaluated, which, in turn, reduced the likelihood of finding new higher-yielding varieties.

In 1969, Experiment Station scientists started a winter nursery in Puerto Rico where soybeans can be grown year-around. Today, crossings of soybean parent lines, increase of progeny seed, and preliminary selections of promising lines are carried out several times a year in Puerto Rico. Although final testing of new soybean lines still must be done in Iowa, use of the winter nursery probably will reduce the average time for development of new varieties from 15 years to 5 years. Iowa breeders also have worked on mechanizing their breeding programs as much as possible. They have developed new small-scale planting and harvesting equipment suitable for handling many small batches of experimental seed.

The increased efficiency made possible by mechanization and the winter nursery has permitted expansion of the variety development program to a scale never before possible. Station scientists now evaluate nearly 10 times as many experimental soybean lines as they did just a few years ago. By looking at so many more lines, breeders greatly increase their chances of finding the few superior offspring that may become the successful commercial varieties of tomorrow.

**Variety Development Since World War II**

Although future development of superior soybean varieties looks especially promising to Experiment Station breeders, the past has not been without its successes. Since 1945, soybean breeders at the Iowa Experiment Station have originated 15 named varieties. These varieties and those developed by breeders in other states have played a key role in the steady increase of Iowa soybean yields from about 17 bushels per acre during the 1930s to 36 bushels per acre in 1972.

Soybean varieties are adapted to rather long belts east and west but to fairly short distances north and south. This is because of their response to day length and temperature, which control the initiation of flowering. Soybeans grown in Iowa range from early maturing, group I varieties to later-maturing, group IV varieties.
# SOYBEAN VARIETIES ORIGINATED AT THE IOWA EXPERIMENT STATION

<table>
<thead>
<tr>
<th>Name</th>
<th>Year</th>
<th>Maturity</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>HAWKEYE</td>
<td>1947</td>
<td>II</td>
<td>Good lodging resistance, upright growth, sparse branching. Yields 12-15% more than Richland, the older variety that Hawkeye largely replaced in northern Iowa.</td>
</tr>
<tr>
<td>ADAMS</td>
<td>1949</td>
<td>late II</td>
<td>Slightly superior to Lincoln in yield, lodging resistance, and percentage oil in central and southern Iowa. Slightly outyields Hawkeye in central Iowa.</td>
</tr>
<tr>
<td>BLACKHAWK</td>
<td>1951 I</td>
<td>I</td>
<td>Good lodging resistance, upright growth, sparse branching. Outyields older varieties by 5-10% in Iowa's northern two tiers of counties.</td>
</tr>
<tr>
<td>KIM</td>
<td>1956</td>
<td>late II</td>
<td>Two large-seeded varieties with superior yield and shattering resistance compared with older large-seeded varieties. Kanrich has a yellow seed coat and yellow hilum favored by processors.</td>
</tr>
<tr>
<td>KANRICH</td>
<td>1956</td>
<td>late II</td>
<td></td>
</tr>
<tr>
<td>FORD</td>
<td>1959</td>
<td>III</td>
<td>Medium height and usually erect. Outyields Adams and Lincoln by about 8% in central and southern Iowa and lodges less.</td>
</tr>
<tr>
<td>AMSOY</td>
<td>1965</td>
<td>II</td>
<td>Upright, narrow growth habit with small pointed leaves giving an &quot;open&quot; canopy. Yields at least 11% more than older varieties of similar maturity.</td>
</tr>
<tr>
<td>HARK</td>
<td>1966</td>
<td>I</td>
<td>Upright, narrow growth habit. Outyields older varieties like Blackhawk and Chippewa by more than 11%. Lodges less, is slightly taller, and has a higher protein content than the varieties it replaced.</td>
</tr>
<tr>
<td>DISOY</td>
<td>1967</td>
<td>I</td>
<td>Three large-seeded, yellow soybean varieties that mature earlier and outyield Kanrich by 7-14%.</td>
</tr>
<tr>
<td>MAGNA</td>
<td>1967</td>
<td>II</td>
<td>Fairly broad growth habit with pointed leaves similar to Amsoy. Yields 12-15% more than older varieties such as Hawkeye, Harosoy, and Blackhawk. Similar to older varieties in height, lodging resistance, and chemical composition.</td>
</tr>
<tr>
<td>PRIZE</td>
<td>1967</td>
<td>II</td>
<td>Fairly broad growth habit with pointed leaves similar to Amsoy. Yields 12-15% more than older varieties such as Hawkeye, Harosoy, and Blackhawk. Similar to older varieties in height, lodging resistance, and chemical composition.</td>
</tr>
<tr>
<td>CORSOY</td>
<td>1967</td>
<td>II</td>
<td>Fairly broad growth habit with pointed leaves similar to Amsoy. Yields 12-15% more than older varieties such as Hawkeye, Harosoy, and Blackhawk. Similar to older varieties in height, lodging resistance, and chemical composition.</td>
</tr>
<tr>
<td>PROVAR</td>
<td>1969</td>
<td>II</td>
<td>A special-purpose soybean with 7-10% more protein than other common varieties. Yields about 5% less than Amsoy and Corsoy.</td>
</tr>
<tr>
<td>WIRTH</td>
<td>1970</td>
<td>I</td>
<td>Best adapted to extreme northern Iowa where it outyields Chippewa 64 by about 7%. Matures several days earlier and yields slightly less than Hark.</td>
</tr>
<tr>
<td>RAMPAGE</td>
<td>1970</td>
<td>I</td>
<td>Yields about the same as Hark in northern and central Iowa. In other states, outyields Hark by more than 1-1/2 bushels per acre. Is more likely to lodge, but less likely to develop iron-deficiency chlorosis than Hark.</td>
</tr>
</tbody>
</table>
Hawkeye, released in 1947, was the first soybean variety developed at the Iowa Experiment Station by hybridization or crossing of known varieties. With group II maturity, Hawkeye was best adapted to central and northern Iowa where it yielded 12 to 15 percent more than Richland, a common variety in Iowa during the 1940s. Widely adaptable and generally superior, Hawkeye was the leading variety in midwestern soybean production for about 10 years.

During the mid-1960s, the Experiment Station released Amsoy and Corsoy, also of group II maturity and adapted to the same general area as Hawkeye. These recent varieties outyielded Hawkeye and other older varieties by 10 to 15 percent. Both Amsoy and Corsoy have a more upright growth habit, more "open" leaf canopy, and "thinner" profile than Hawkeye. These characteristics are advantageous for yield increases in narrow-row culture.

Adams, released by the Iowa Experiment Station in 1949, and Ford, released a decade later, were both adapted to central and southern Iowa. These varieties matured slightly earlier, lodged less, and outyielded Lincoln, a variety developed in the early 1940s in Illinois and widely grown in Iowa during the 1940s and 1950s. Ford, which matured a few days later than Adams, averaged 2.5 to 3.5 bushels per acre more than Adams.

Experiment Station breeders have originated four varieties of group I maturity that are best adapted to northern Iowa. Blackhawk, released in 1951, had good lodging resistance and yielded 5 to 10 percent more than other early maturing varieties available at that time. Hark was released 15 years later and surpassed Blackhawk in yield, lodging resistance, and protein content.

The most recent soybean varieties developed at the Iowa Experiment Station are Wirth and Rampage. These two early maturing, group I varieties were released in 1970. Wirth is best adapted to extreme northern Iowa where it outyields Chippewa 64 by 7 percent. Rampage has not proved superior to Hark in northern and central Iowa, but yields slightly more than Hark in other states.

In 1956, the Experiment Station released Kim and Kanrich,
which produce seeds 60 to 70 percent larger than those of
common soybeans. Large-seeded soybeans generally are used as
whole beans for direct human consumption or are processed
into human food products. Three other yellow, large-seeded
varieties—Disoy, Magna, and Prize—were released by the Iowa
Experiment Station in 1967. These varieties mature earlier and
yield 7 to 14 percent more than Kanrich. The differing maturities
of Disoy, Magna, and Prize permit reasonably good adaptation
over a wide geographical region.

Provar, released in 1969, is another special-purpose soybean.
It has 7 to 10 percent more protein than common varieties such
as Amsoy and Corsoy. Provar, as well as the large-seeded
varieties, yields somewhat less than common varieties of similar
maturity. Because of this, most farmers only grow these spe-
cialty varieties for a premium under contract to a specified
purchaser.

Today, many of the older soybean varieties are of historical
interest only. But the names of these now-discarded varieties
form a litany describing the slow but steady progress of breeders
in improving the biological potential of soybeans. This record of
past achievements gives hope for the continued improvement of
soybeans in the future.

Physiological Approach to Breeding High-Yielding Soybeans

Plant physiologists are cooperating with soybean breeders
at the Iowa Experiment Station to determine the most important
morphological and physiological traits that influence soybean
yields. If these were known, then plant breeders could try to
develop ideal varieties or "ideotypes" possessing these char-
acteristics. This work, like so much else in scientific crop
production, starts from a recognition of the basic rationale for
growing crops; that is, the conversion of solar energy into
stored chemical energy in a form usable by man or his domestic
animals.

Interception of Light Energy: A narrow band of upper, outer
leaves intercepts most of the available sunlight in many soybean
varieties. In effect, these relatively few leaves intercept more
sunlight than they can use in photosynthesis. At the same time,
however, this type of canopy shades the lower and inner leaves so that they receive less light than they can use in photosynthesis. Thus, some of the available light energy is "wasted" and not used efficiently in converting light energy into dry matter. A restructuring of the canopy so that the lower and inner leaves can intercept more light should increase photosynthetic efficiency in soybean plants.

Canopies into which light penetrates more deeply and evenly are called "open." Those in which light is largely intercepted by the outer, upper leaves are called "closed." Among today's common varieties, Hark, Amsoy, and Corsoy tend to have more open canopies than other varieties. In some instances, these open varieties outyield closed-canopy ones in normal 40-inch rows. But the superior performance of open-canopy types is most evident in narrow, 12- to 20-inch rows.

Two important characteristics that partly determine canopy shape and openness are leaflet angle and leaflet size. Varieties with relatively smaller, more erect leaflets (i.e., oriented more-or-less parallel to the sun's rays) form more "open" canopies. Experiment Station scientists believe that selection on the basis of leaflet size and angle might be useful in developing open-canopy varieties specifically adapted to narrow-row culture.

*Experiment Station scientists measure the photosynthetic rate of different soybean lines using small chambers like these.*
**Net Photosynthetic Rate:** Leaves of crop species differ in the efficiency with which they use intercepted light to carry out photosynthesis, the basic process in which carbon dioxide and water are combined in the presence of light energy to form sugars. On the average, soybean leaves are only two-thirds as efficient as corn leaves in "fixing" carbon dioxide.

There is some evidence that increasing photosynthesis in soybeans could increase yields. For example, when the photosynthetic rate of field-grown soybeans was increased by supplying supplemental light or carbon dioxide, yields increased 17 to 37 percent. Other things being equal, it seems likely that varieties with higher net photosynthetic rates (NPR) would yield more than varieties with lower NPR.

Before scientists try to develop varieties with higher NPR, they must know if lines differ in this trait. In one study, Experiment Station scientists found that the NPR of leaves from 20 soybean varieties and lines differed by as much as 30 percent. Furthermore, the average yields of eight common varieties, as indicated by their performance in the Iowa soybean yield tests, are proportional to their NPR. Among these varieties, a 20 to 25 percent increase in NPR corresponds to a 10 to 15 percent increase in yield.

More recently, the inheritance of NPR has been studied by crossing lines with high and low NPR and testing the progeny. Although this work is still in progress, the early results indicate that NPR is reasonably heritable. This means that much of the variability in NPR is due to genetic differences, not environmental or cultural ones. Thus, it may be possible to increase yields by selection for higher NPR.

Unfortunately, direct measurement of photosynthetic rates is too cumbersome and time-consuming to be useful in a breeding program. But Experiment Station scientists have found that specific leaf weight (weight per unit area) and leaf thickness are related to net photosynthesis. Varieties with high specific leaf weight and thick leaves tend to have a high NPR. Selection for specific leaf weight or leaf thickness in a breeding program might be a practical method to indirectly select for higher NPR.

**Distribution of Photosynthate:** Northern varieties of soy-
beans have an indeterminate growth habit in which vegetative growth continues long after flowering begins. In these varieties, there is strong competition between the vegetative and reproductive or bean-producing parts of the soybean plant for photosynthate, the sugar formed in photosynthesis. Yields might increase if this competition were decreased and more photosynthate were channeled into the beans, rather than new leaves and stems.

Studies conducted several years ago seem to support this idea. Experiment Station scientists sprayed soybeans with an antigrowth hormone that retarded vegetative growth after flower-
Terminal bud on left is from a determinate soybean, which does not increase in height after flowering; that on right is from an indeterminate soybean, in which new vegetative growth continues after flowering. By manipulating the terminal growth habit of soybeans, scientists hope to reduce lodging and the competition between vegetative and reproductive growth.

ing had begun. This treatment made more sugar available for pod and seed set and increased yields by 5 to 15 percent.

Scientists also have studied control of vegetative growth by genetic means. Three major genetically determined growth habits in soybeans are known. The fully indeterminate type, in which vegetative growth continues long after flowering, is found in northern varieties. The fully determinate type, in which little new vegetative growth begins after flowering, is found in southern varieties. The semideterminate type, which is in between the other two, produces some new vegetative growth after flowering.

The semideterminate growth habit was discovered a few years ago by scientists in Illinois. Since then, Iowa scientists have been studying what happens when the semideterminate gene is introduced into northern varieties. They speculate that the semideterminate trait might increase yields by reducing the competition between vegetative and reproductive growth for available sugar.

To test this idea, Experiment Station scientists have developed about 300 isolines, pairs of lines differing only in that one is indeterminate and the other is semideterminate. Thorough
testing of these isolines, which will take several years, is now in progress. The results of this research should indicate whether incorporation of the semideterminate trait into northern commercial varieties is desirable.

Better Seedling Emergence

Unless soybeans get off to a good start soon after planting, they may never fully recover. Good germination and emergence are necessary for the crop to establish a vigorous stand that can survive adverse environmental conditions and yield well.

Seed that is diseased or has been stored improperly often germinates and emerges poorly. Temperature and planting depth also influence emergence, but the effects of these factors seem to vary among varieties.

After germination, the hypocotyl (portion of the plant between the cotyledons and primary root) grows upward and pulls the cotyledons or seed leaves toward the soil surface. Obviously, the deeper the seed is planted, the more the hypocotyl must elongate before the seedling emerges.
Scientists at the Experiment Station discovered that hypocotyl elongation in varieties such as Amsoy, Ford, and Beeson is much less at 77 degrees F. than at 68 or 86 degrees. In contrast, hypocotyl elongation in Hawkeye and Wayne is not inhibited at 77 degrees. When a short-hypocotyl variety like Amsoy is planted fairly deep (3 inches or more) and the soil temperature is between 70 and 82 degrees, the percentage emergence may be very poor. Under these conditions, Amsoy seedlings do not elongate enough to reach the soil surface and emerge. Generally, long-hypocotyl varieties such as Hawkeye will emerge fairly well even when planted deep, regardless of the temperature.

Scientists have devised a relatively simple laboratory test for ranking soybeans by their ability to emerge from 4 inches at 77 degrees. Experiment Station breeders use this test to screen experimental lines and eliminate those that emerge poorly. The emergence test also is performed on all entries in the annual soybean yield test. The emergence scores of commercial varieties can help farmers to decide which varieties are best for them.

**Lodging-Resistant Soybeans**

Soybean yields sometimes are reduced 25 to 30 percent by excessive lodging, when plants fall over in the field. Lodging not only disrupts the crop canopy, which reduces photosynthesis, but also makes harvesting difficult. At high seeding rates, competition between individual soybean plants leads to increased height, reduced branching, weaker stems, and increased lodging. Thus, lower seeding rates can partly offset yield losses due to lodging.

The long-term solution to lodging problems, however, lies in development of varieties with greater lodging resistance. Some breeders think that shorter, possibly semidwarf, soybean varieties would lodge less and have higher yield potential, much like semidwarf wheat. One possible way to produce shorter varieties is substitution of the semideterminate or determinate growth habit, in which post-flowering vegetative growth is greatly reduced, for the indeterminate growth habit typical of most northern varieties.
But unlike wheat and other cereals, the harvestable soybean seed is distributed all along the plant. If selection for shorter plants results in fewer pod-bearing nodes per plant, then shorter varieties, although less likely to lodge, might not yield any better than today's varieties. Because of this possibility, Experiment Station breeders trying to develop shorter, lodging-resistant soybeans are also concerned about two other traits that would maintain or increase the number of pod sites per plant.

One of these traits is internode length—the length of the stem between successive nodes. Obviously, if the average internode length were reduced along with the height of the plant, the total number of nodes on shorter plants could equal that on taller ones.

A second trait that might be bred into shorter plants is racemes, long flowering side-shoots with pod sites all along their length. Shorter plants with racemes, even if they had fewer nodes, could have the same number of pod sites as taller varieties without racemes.

**Breeding for Disease Resistance**

Soybeans once were considered a "safe" crop with few disease problems. As soybean production intensified, however, several diseases increased to levels that can cause severe damage. Although breeders already have had some success in developing resistant varieties, much more work is needed if diseases and insects are not to limit the productivity of soybeans in the future.

Scientists at the Iowa Experiment Station have studied several important soybean diseases including brown stem rot, downy mildew, bacterial blight, rhizoctonia root rot, pythium rot, and soybean mosaic virus. Part of this research involves screening soybean varieties and plant introductions for resistance. Often, resistance is found in lines that have poor agronomic characteristics, for example, in unadapted plant introductions. In such instances, the resistance is of little practical value until the resistance genes are transferred by hybridization and selection into varieties that perform well.

Resistance to plant diseases sometimes is controlled by one or a few genes. Usually, there are few difficulties in trans-
A variety of diseases can infect midwestern soybeans.

ferring this type of “oligogenic” resistance into agronomically acceptable varieties. The breeder’s job is much more difficult, however, when resistance is controlled by the joint action of many genes, each with only a small effect.

In matings between a line with this type of “polygenic” resistance and a nonresistant, agronomically good variety, the probability is low that all the genes necessary for maximum resistance will be transferred to any one offspring. Furthermore, the few progeny that do show good resistance may lack some of the desirable characteristics present in the agronomically good parent. For these reasons, many years may elapse between discovery of a source of disease resistance and release of a good commercial variety incorporating that resistance.

Downy Mildew: Plant pathologists at the Experiment Station have identified and worked out techniques for classifying the different races of the fungus that causes downy mildew. These races differentially infect different soybean varieties. For example, Pridesoy is quite resistant to race 2 and susceptible to race 8, whereas Harosoy is susceptible to both races.
There are 22 known races of the downy mildew fungus in the United States, but only races 8 and 2 occur commonly in Iowa. Many soybean varieties grown in Iowa are susceptible to one or both races. In contrast, many southern varieties are resistant to these races, but susceptible to race 10, found predominantly in the south.

It might be possible to transfer the "specific" resistance to races 2 and (or) 8, found in southern varieties, to northern varieties. Such an approach, however, might result in some other race of the fungus becoming prominent in Iowa after introduction of soybean varieties resistant to races 2 and 8. Indeed, this approach could lead to a repetition of the boom and bust pattern of resistance that has occurred with other crop diseases such as oat crown and stem rusts, potato blight, and wheat stem rust.

A more promising strategy is to locate sources of "general" resistance that is effective against many, if not all, known downy mildew races. Because general resistance works against all races of a pathogen, it is unlikely to foster population increases of any one race. Experiment Station scientists have found this type of general resistance to downy mildew in seven soybean introductions and a few named varieties, including Mendota and Kanrich. Some of these lines now are being used in development of commercial varieties resistant to downy mildew.

Brown Stem Rot: Today, brown stem rot (BSR) is probably the most serious disease threat facing soybean growers in the Midwest. The disease is caused by a soil-borne fungus that invades the roots and lower stem and grows upward, gradually obstructing a plant's vascular system. Although BSR often shows no external symptoms, it causes a brown discoloration inside the stems of infected plants.

The incidence of BSR in Iowa increased steadily during the early and mid-1960s. Surveys by Experiment Station scientists indicated that fewer than 10 percent of Iowa's soybean fields were infected in 1960, but 50 to 60 percent of the fields were infected in 1966. In other studies, scientists found that bean yields in fields with infected plants ranged from 4 to 20 percent less than yields in fields with healthy plants.
The most prominent symptom of brown stem rot is rotting and discoloration inside the lower stem. A healthy stem is on the right. Plant in center, mildly infected with BSR, will have 5 to 10 percent yield reduction compared to healthy soybean on left. Heavy infection, as in plant on right, may cut yields by 20 percent or more.

Although BSR can be controlled by crop rotations, the increased acreage of soybeans often makes rotation impractical or not long enough. Because of this, the Iowa Experiment Station began a breeding program in the late 1960s to develop resistant varieties. Several soybean introductions with partial resistance to BSR are being used in this program.

All soybean varieties currently grown in Iowa are susceptible to BSR. But a few varieties, like Corsoy and Harosoy, usually are infected later in the season than others and may be useful in lessening damage from the disease. Surveys show that the incidence of BSR in northern Iowa has decreased in areas where Corsoy was grown for several years.

Recent studies at the Iowa Experiment Station suggest that resistance to BSR may be associated with the presence of soybean mosaic virus. BSR-susceptible plants, inoculated with both soybean mosaic virus and BSR, develop much less stem browning than do plants inoculated with BSR alone. Also, scientists found that soybean mosaic virus was present in leaf extracts from soybean lines partly resistant to BSR, but absent from BSR-susceptible varieties.
Although Experiment Station scientists don’t fully understand this unusual interaction between soybean mosaic virus and BSR, their observations may be important for soybean breeders. After many years of breeding, testing, and selecting for BSR-resistant lines, no commercial varieties have been developed. Possibly, the interaction of soybean mosaic virus and BSR has contributed to the difficulties encountered in developing BSR-resistant varieties.

Station scientists currently are studying the use of soybean blends as a means of reducing BSR damage. Fields are planted to a mixture of a high-yielding commercial variety and a resistant line that does not yield as well as most common varieties. Preliminary results indicate that blends outyield susceptible commercial varieties on infested land. On uninfested land, blends and commercial varieties yield about the same. If the blend technique proves successful after more thorough testing, the lengthy process of incorporating resistance genes into high-yielding, agronomically good varieties would be unnecessary.

**Chlorosis Resistance**

In recent years, soybeans in some parts of Iowa have suffered from iron-deficiency chlorosis, characterized by inter-veinal yellowing of the leaves and stunting of plant growth. This condition, which can lead to significant yield losses, occurs mostly on some high-lime soils in north-central Iowa.

Although scientists have recognized lime-induced, iron-deficiency chlorosis for many years, it became a production problem only during the last 10 years. Many of the common high-yielding varieties (Hark, Wayne, Corsoy) introduced during this period are quite susceptible to iron deficiency, because they absorb and utilize iron poorly on high-lime soils. In contrast, older varieties like Hawkeye use iron fairly efficiently even on high-lime soils.

Soybean breeders at the Experiment Station are trying to combine the genes for efficient iron uptake and utilization, found in older varieties, with the high-yield characteristics of today’s varieties. They are evaluating more than 800 experimental lines for iron-deficiency symptoms on high-lime soils.
Lines showing fewer symptoms will be yield-tested in the next stage of the project.

The symptoms of iron deficiency and the associated yield reductions are alleviated by proper application of iron. Thus, farmers can overcome this problem while other varieties are being developed.

**Chromosome Mapping of Soybeans**

The Iowa Experiment Station and the U.S. Department of Agriculture are cooperating in a research program on soybean cytogenetics, the study of chromosomes and chromosome patterns by microscopic and genetic techniques. Each soybean chromosome contains many different genes linked together into one long molecule. One objective of cytogenetic research is to identify and classify linked genes in their linear order on the chromosomes. This is like mapping the chromosomes by discovering which genes occur on the same chromosome and how far apart they are.

The importance of chromosome mapping for practical plant breeding is that linked genes, and the traits they condition, are more likely to remain together during mating than are genes on different chromosomes. Although genes on the same chromosome sometimes are separated during mating, the chances of this happening are greater when the genes are relatively far apart than when they are closer together.

Aneuploid soybeans that contain one more or one less chromosome than the normal 40 are being developed at the Experiment Station. By carefully testing such abnormal plants,
scientists can locate specific genes on specific chromosomes; that is, the extra one or missing one. Aneuploids have been used successfully in the chromosome mapping of several crops, but only recently has this technique been tried with soybeans.

Scientists hope to identify linkage groups containing genes for easily recognizable traits, such as pubescence color, and genes for disease resistance. If such linkage groups are found, then the easily recognizable traits could be used to detect resistant lines, eliminating the need for elaborate testing procedures involving inoculation with the disease-causing organisms. This approach could save considerable time and money in the development of resistant varieties, especially in the early stages when many experimental lines must be screened. Before their release, however, resistant varieties still would be tested directly for resistance by exposure to the pathogen.

Information about linkage groups involving desirable and undesirable traits also can help breeders. For example, assume that a breeder was trying to develop varieties resistant to pod blight and that a soybean line, maybe a plant introduction, was crossed with an adapted, high-yielding variety that had good emergence. But suppose all the progeny with good blight resistance also showed poor emergence. If it became clear that resistance and emergence were linked, the breeder would need to use special techniques to break up the linkage so that the desirable resistance gene could be transferred to progeny without simultaneously transferring the gene conditioning poor emergence. Alternatively, the breeder might look for another source of blight resistance in a soybean line that also has good emergence. If such a line were used as a parent, then the linkage of resistance and emergence would not cause problems.
GROWING SOYBEANS

Even the best soybean varieties will not yield well with poor management. Row spacing, tillage, fertilization, weeds, pests, and harvesting are all aspects of the soybean's growth environment that farmers must manage, and manage well, to achieve high yields.

Research on soybean genetics and breeding is intertwined with research on various management problems at the Iowa Experiment Station. The ultimate goal is to develop crop varieties and management techniques that can be integrated into economically viable, efficient production systems. The immediate objective of agronomists and soybean producers, however, is to maximize yields of the available varieties by management of the environment.

A Good Start Is Important

Although high-quality seed won't guarantee record-breaking yields, it does get a soybean crop off to a good start in its season-long confrontation with weeds, pests, and unfavorable weather. Techniques to distinguish between high- and low-quality seed, before planting, can help farmers avoid the risk of poor field emergence and stand failure.

Scientists at the Iowa Experiment Station have developed a seed "stress test" that does a better job of predicting field performance than the standard germination test. The stress test is most useful for evaluating carry-over seed that has been stored more than a year. Because of subtle changes that occur in seed during extended storage, carry-over seed may lack vigor even though it looks all right and performs well in germination tests.

Research on the physiology and biochemistry of soybean seed is aimed at pinpointing the differences between low- and high-quality seed. Experiment Station scientists have studied
seedling growth, respiration, and chemical composition of different quality seed during germination. They hope that a better understanding of seed dormancy and the germination process will lead to superior methods for identifying high-quality seed and predicting seedling vigor.

Size is one of the more obvious differences among seeds that is known to affect performance. Although small seed often emerges faster than intermediate or large seed, its overall percentage emergence is less. In addition, Experiment Station scientists have found that, even when thinned to equal stands, soybeans from small seed produce an average 5 bushels less per acre than those grown from intermediate or large seed.

Even high-quality seed can be infected by soil-borne fungi that cause seed decay or pre-emergence and postemergence seedling blight. These damping-off fungi, including Pythium sp. and Fusarium oxysporum, are present in most soils most of the time and tend to cause problems whenever soybean seed does not germinate or emerge quickly. Infection by damping-off fungi is most likely when the soil is dry, which retards germination, or when the soil is wet and cold, which retards growth of young seedlings but promotes growth of the fungi.

Experiment Station scientists are testing many fungicides as soybean seed treatments to protect seed against infection from

Soybean stands are much better in plots planted with fungicide-treated seed (left) than in control plots planted with untreated seed (right).
both soil-borne and seed-borne fungi. The results so far suggest that seed treatment can insure adequate stands even when weather conditions favor disease development. The weather is hard to predict, and the only remedy for extensive damage is replanting. Thus, effective seed treatment may be relatively inexpensive insurance against poor stands or the need for replanting.

**Row Spacing Makes a Big Difference**

An important management decision facing Iowa soybean producers is how far apart to space soybean rows. This may seem trivial to city folk for it's difficult to imagine that a few inches one way or the other could influence bean yields very much. Scientists at the Iowa and other state experiment stations, however, have amassed abundant evidence that soybeans grown in narrow rows yield substantially more than those grown in typical wide rows. In Iowa tests, yields range between 10 to 40 percent greater in 12- to 20-inch rows than in the 30- to 40-inch rows, favored by most producers.

The yield increase associated with narrow-row culture is largely due to increased light interception and photosynthesis that allow more pods and seeds to develop to maturity, rather than aborting. In wide rows, much of the sunlight strikes the soil between rows and is wasted during early pod and seed set, a crucial period when 70 to 75 percent of the flowers may abort and never form pods. Station scientists have found, for example, that soybeans planted in 10-inch rows intercept 98 percent of the available light at beginning of pod set, while those planted in 40-inch rows intercept only about 87 percent of the light.

Although nearly all soybean varieties yield more in narrow rows than in wide ones, the response to narrow-row culture varies among varieties. As mentioned earlier, more erect, open-canopy varieties, in which light penetrates deeply and evenly, are especially suited to narrow rows. With an open-canopy variety planted in narrow rows, essentially all the available light is intercepted, and the light is distributed in a way to permit its most efficient utilization in photosynthesis.

Despite the evidence favoring narrow rows, only about 30 percent of Iowa's soybean acreage was planted in row-spacings
Some soybean producers are using uneven row spacings, a combination of wide and narrow widths, that leave room for field equipment and still result in higher yields than uniform 40-inch rows. Two different planting patterns are shown.

less than 34.5 inches in 1972. And only 3 percent was planted in spacings less than 28.5 inches.

Scientists have been scratching their heads for years about farmers' reluctance to switch to narrow rows. Inconvenience, extra equipment costs, and concern about weed control seem to explain the lack of enthusiasm for a practice known to boost yields dramatically. Possibly, recent increases in acreages and prices of soybeans will stimulate greater adoption of narrow rows than 10 years of scientific advice has.
Soybean Nutrition

Scientists studying plant nutrition attempt to answer two basic questions: (1) How much of which nutrients does a crop need, under particular environmental conditions, to grow and yield well? (2) What does it take to meet these needs?

To answer the first question, scientists at the Experiment Station have studied the uptake of the major nutrients—nitrogen, phosphorus, and potassium—and their distribution among the different parts of the soybean plant throughout the growing season. This research indicates the total amount of these nutrients used, at what periods in the plant’s growth cycle absorption of nutrients is greatest, and how nutrients are translocated from one part of the plant to another.

Another way of trying to answer the question of what a plant needs to yield well is to develop equations relating yield to plant composition. This is done by growing plants with different amounts of added fertilizer, so that nutrient levels in the plants vary, and then measuring yield and chemical composition of the plants. From these data, scientists can determine the relationship between yield and the percentages of various nutrients in the plant.

One use of such yield-plant composition relationships is to calculate the estimated maximum yield and the plant’s chemical composition associated with this yield. From information like this, scientists can see how different nutritional conditions within plants are reflected in yields. Also, this type of information helps scientists to recognize nutritional imbalances that may cause lower yields.

Having some idea of the nutritional condition associated with healthy, high-yielding soybeans, however, is only half the battle. Producers must know how to build up and maintain soil fertility so that soybeans get the necessary nutrients; that is, what fertilizer additions are necessary for optimum mineral nutrition of their beans.

Potassium and Phosphorus Fertilization: The yield response of soybeans to direct fertilization with potassium and phosphorus has varied considerably from experiment to experiment. Nonetheless, when soils test low in available phosphorus or potas-
sium, profitable yield responses usually are obtained by adding these nutrients.

There are several possible reasons that yield responses to fertilization sometimes are inconsistent. First, the applied fertilizer may be unavailable to plant roots because of weather conditions or the timing and method of application. Experiment Station scientists have conducted numerous studies to determine which application methods assure efficient use of fertilizers by crops. Techniques that increase the percentage of applied fertilizer actually taken up by a crop have obvious economic benefits for producers. They are also important in reducing possible environmental problems due to movement of nutrients from agricultural land into streams and lakes.

A second cause for failure to obtain response to fertilization is deficiency of elements other than those applied. In several studies at the Experiment Station, lack of response by soybeans to phosphorus was attributed to the low potassium content of the soil. When the potassium deficiency was corrected, phosphorus fertilization increased yields. Deficiency of other elements such as magnesium, sulfur, and various micro-elements also may limit the yield response to applied fertilizers.

Responses to fertilization also vary because of genetic differences. In one study, yield increases due to phosphorus applications differed up to 20 percent among several soybean lines. Station scientists also found large differences among these same lines in the number and fresh weight of root nodules after phosphorus and potassium applications.

Genetic variation among soybean varieties in response to fertilization complicates the interpretation of fertilizer experiments. But this genetic variation, like that in other plant traits, may be useful to soybean breeders in developing superior varieties that use soil nutrients more efficiently or respond particularly well to fertilization.

Recently, Experiment Station scientists have extended earlier studies on the effect of potassium and phosphorus fertilization on yields of corn and soybeans grown in sequence. They found that corn generally is more responsive to these nutrients than are soybeans and responds best to direct fertilization. In contrast, soybeans respond as well or better to carry-over or residual
nutrients as to direct fertilization. This research suggests that, on soils of low fertility, applying sufficient potassium and phosphorus to the corn crop for the corn-soybean cropping cycle is as satisfactory as direct fertilization of each crop. On soils of medium or higher fertility, however, crop response to fertilization usually is small, and there is little if any difference in response to directly applied and residual nutrients.

_Nitrogen Fertilization—A Wasted Effort?_ Probably no aspect of soybean nutrition has been the subject of more attention, and frustration, than has nitrogen fertilization. The large yield increases that have come from added nitrogen in corn and other nonlegume crops have not occurred in soybeans.

The dilemma posed by this seeming indifference to nitrogen by a crop that contains 4 to 5 times as much nitrogen per bushel as corn has long stimulated scientists to ask why. At present, there are two main explanations of why nitrogen fertilization does not increase soybean yields.

The first centers around the soybean's dual mechanism for obtaining nitrogen—(a) uptake of nitrate from the soil and (b) nitrogen fixation in root nodules formed by bacteria _Rhizobium japonicum_ that infect soybean roots. Research at several state experiment stations shows that nitrogen fixation supplies 30 to 60 percent of the total nitrogen required by a typical soybean crop in the Midwest. But, under conditions of nitrogen stress, when less soil nitrogen is available, nitrogen fixation increases to meet the crop's needs.

Conversely, when soil nitrogen is increased by fertilization, nitrogen fixation decreases so that the total amount of nitrogen in the crop and the yields remain about the same. Scientists have concluded that soil nitrogen, whether residual or directly applied, supplants nitrogen fixation and does not supplement it.

This trade-off between nitrogen obtained from fixation and that obtained from the soil seems to explain why nitrogen fertilization doesn't increase soybean yields. Fertilized beans really aren't getting any more nitrogen than unfertilized ones. If this explanation is correct, there are several possible ways to circumvent the situation and, perhaps, increase yields.

Scientists are studying the nitrogen-fixing bacteria to see if the efficiency of nitrogen fixation can be increased. They hope
that better strains of rhizobia and improved inoculation techniques will get more "free" nitrogen from the air into soybeans.

The many different strains of rhizobia can be classified into about 200 groups or serotypes on the basis of their reaction with antibodies. In research at the University of Minnesota, soybean plots inoculated with different serotypes produced yields differing by as much as 50 percent. Field studies by USDA's Agricultural Research Service also indicate that some rhizobia are better nitrogen fixers than others.

"Nodules (top) and roots (bottom) from soybeans treated with different amounts of fertilizer nitrogen illustrate the "trade-off" between nitrogen fixation and uptake of soil nitrate. Nodule numbers and nitrogen fixation decrease as soil nitrate increases."
Surveys by Experiment Station scientists show that one serotype forms about two-thirds of the soybean nodules in Iowa. Research now in progress will determine if soybean yields are increased by introduction of rhizobium strains different from the ones that happen to predominate in Iowa now.

The nodules on soybean roots are formed by rhizobia residing in the soil and by rhizobia introduced (inoculated) at the time of planting. Experiment Station scientists have found, however, that inoculated rhizobia don't form many nodules unless they greatly outnumber the rhizobia present in the soil. Current procedures using preinoculated seed or inoculated peat supply so few bacteria that only 10 percent or fewer of the nodules are formed by the introduced strain in many Iowa fields.

Recently, Experiment Station scientists developed a new liquid-inoculation technique in which 40 to 90 percent of the nodules are formed by the introduced strain. If superior strains of rhizobia are found, this improved inoculation technique should make it possible to successfully introduce these strains into Iowa soybean fields.

Another aspect of rhizobia that scientists are investigating is their tolerance of soil nitrate. Some years ago, Iowa scientists discovered that the fresh weight of nodules per soybean plant decreased about 40 percent when nitrogen was applied at 150 pounds per acre. But recent evidence suggests some rhizobium strains are less inhibited by nitrate than others. Possibly, fertilization of fields containing nitrate-tolerant strains would lead to a net increase in the nitrogen available to the plants, rather than a trade-off between fixed and soil nitrogen.

Modified techniques of direct fertilization, which don't inhibit nodulation and nitrogen fixation, are another approach to getting more nitrogen into soybeans. These methods include putting nitrogen fertilizer deep enough to avoid the nodules, which form near the top of soybean roots. Another idea is to incorporate corncobs or crop stubble into the surface soil. This ties up topsoil nitrate in decomposition of the organic matter and might permit nodules to form and function.

Obviously, all these ideas for increasing soybean yields assume that, if more nitrogen gets into soybeans, they will be able to use it. But some scientists say that isn't so, and they
Sugar as well as nitrogen is needed for the synthesis of proteins. A poor sugar supply may limit soybean yields, regardless of the source of nitrogen.

propose a different explanation of why applied nitrogen doesn’t increase soybean yields.

In this view, soybeans don’t respond to applied nitrogen because there is not enough sugar available for the crop to use extra nitrogen. Thus, the sugar-producing apparatus or photosynthetic capacity of soybeans primarily limits yields, not an inadequate nitrogen supply.

The argument underlying this explanation is that the uptake and assimilation of nitrogen, either from the soil or by nitrogen
fixation, requires energy. Plants obtain that energy by "burning" sugars formed in photosynthesis. In addition, incorporation of nitrogen into plant material requires an adequate supply of "carbon skeletons," which form the chemical backbone of amino acids and proteins. The carbon skeletons are present in sugars and, by chemical reactions within the plant, are transformed into nitrogen-containing amino acids and proteins. So, lack of response to added nitrogen actually may reflect a limiting supply of sugar.

Among the evidence supporting this view are data from experiments showing that the rate of nitrogen fixation and the yield of field-grown soybeans are increased when photosynthesis is increased artificially. Earlier studies by Experiment Station scientists also suggest that something other than nitrogen itself limits soybean yields. They compared the yield responses to nitrogen fertilization of a normal, nodulating soybean line and a nonnodulating isolate that could obtain nitrogen only by uptake of soil nitrogen.

If the trade-off between applied and fixed nitrogen underlay the lack of yield increases in normal, fertilized soybeans, then a nonnodulating isolate would be expected to outyield its normal isolate at high fertilizer levels. Actually though, Experiment Station scientists observed that yields of the nonnodulating isolate gradually increased, but never surpassed yields of the normal line, as the level of applied nitrogen was increased. These results point to some common factor, most probably a poor sugar supply, as the predominant limitation on yields in both nodulating and nonnodulating soybeans.

Experiment Station scientists recently tested the effect of nitrogen and sugar on nodulation, nitrogen-fixing activity, and yields of field-grown soybeans. As has been found before, nitrogen applied to the soil or to foliage reduced nodulation and nitrogen fixation and did not influence bean yields significantly. But nodulation, nitrogen-fixation and yields all increased when bean leaves were sprayed with sugar solutions. Furthermore, soybeans treated with both sugar and nitrogen had more nodules and greater nitrogen-fixing activity than those treated with nitrogen alone.
These recent studies rather clearly point to an inadequate sugar supply as a major limitation to soybean yields. They also suggest that the apparent inhibitory effect of applied nitrogen on nodulation and the lack of positive yield responses to nitrogen could be overcome by higher sugar levels in soybean plants.

Scientists convinced of this line of reasoning think that substantial yield increases depend on first increasing the soybeans' sugar supply by improving the photosynthetic capability of the crop. Once this is done, then additional nitrogen, supplied directly or indirectly, may lead to higher bean yields.

**Insect Pests—Sporadic Competitors**

Although Iowa soybeans are attacked by many insect pests, yield losses due to insect damage have been relatively low. But insect problems may intensify in the future because of increased acreages of soybeans, their higher market value (which makes a given level of damage more costly), and use of higher-yielding varieties that may be more sensitive to insect damage than today's common varieties.

Experiment Station scientists are studying the bioeconomics of several soybean insects to determine the relationship between pest numbers and yield losses. In this research, scientists develop

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*Pest numbers vary from year to year. Insecticide treatment when a pest population is below the economic injury level costs the farmer more money than the value of the crop saved.*
The leaf-eating green cloverworm usually is the most damaging insect attacking Iowa soybeans.

accurate techniques to sample insect populations, gather information about insect biology, and determine economic-injury levels.

The economic-injury level is the lowest number of insects that can cause a crop loss exceeding in value the cost of control. Without some knowledge of economic-injury levels there is no rational way to decide whether pest control measures are necessary and economically justified.

Use of economic-injury levels as a guide in decisions to use insecticides is analogous to a cost-benefit analysis. The benefit corresponds to the monetary value of potential crop losses that are prevented by treatment. And the economic-injury level is that number of insects that makes the expected cost-benefit ratio for treatment equal to one. When the number of insects present is considerably less than its economic-injury level, the cost of control will exceed expected benefits, and insecticide treatment won't pay off for the farmer.

So far, Experiment Station scientists have studied the green cloverworm most thoroughly. This leaf-eating insect, which is green with white stripes, is present in most Iowa soybean fields nearly every year. Larval population peaks usually occur in mid- and late-August when soybeans can tolerate considerable defoliation without appreciable yield losses. But during the damaging cloverworm outbreaks in 1966, 1968, and 1973, larval populations reached a peak 2 to 3 weeks earlier when soybeans do suffer significant yield losses from defoliation.
Some years ago, Experiment Station scientists measured how much soybean yields are reduced by various degrees of defoliation. Recently, using special feeding cages and measuring devices, they determined how much soybean leaf tissue green cloverworm larvae consume. These two types of information were used to estimate probable yield losses caused by different numbers of green cloverworms at various soybean growth stages. Then, by considering the market value of soybeans, the cost of insecticide treatment, and probable yield losses, Station scientists calculated the economic-injury levels for the green cloverworm throughout the growing season.

They concluded that earlier recommendations called for insecticide treatment when cloverworm populations were below the economic-injury level. Their research showed that soybeans could tolerate 2 to 3 times as many cloverworms before the value of yield losses approached the cost of control. By not spraying at unreasonably low populations of insect pests, farmers can save money and reduce the potential hazards of insecticide residues.

Station scientists also are determining economic-injury levels for the potato leafhopper and the thistle caterpillar, two other insect pests common in Iowa soybean fields. The results of this work will help farmers to decide when treatment for these pests is economically justified.

Green cloverworm populations are fairly low during many years, with only occasional population build-ups or outbreaks.

**Right:** Larvae of parasitic wasp feeding on green cloverworm.  
**Left:** Eggs of small fly, laid on cloverworm, hatch into larvae that eat cloverworms. These and other natural enemies help to keep populations of soybean insects in check.
Experiment Station scientists have observed several natural enemies, including a fungus disease, parasitic fly, and tiny parasitic wasp, that help to keep cloverworms in check much of the time. Studies are under way to relate the presence, abundance, and effectiveness of these and other natural enemies to green cloverworm population levels.

Populations of most common soybean insects only infrequently reach the economic-injury level in Iowa. But such sporadic pests can be transformed into devastating, perennial pests through destruction of their natural enemy complex by injudicious use of broad-spectrum insecticides. Experiment Station scientists hope to prevent this in Iowa's soybean fields by gearing insecticide recommendations to the lowest effective, economically justified rates; by developing practical sampling methods so that farmers can accurately determine how many insects are present in their fields; and by conserving, even augmenting, the natural enemies that prey upon soybean pests.

Weeds—The Constant Competitors

"Agriculture is a controversy with weeds" may seem like an exaggeration attributable to prejudiced weed specialists overlooking the obvious damage wrought by crop insects and diseases.

But weeds are always present, whereas damaging infestations of insects and diseases often are sporadic. Weed control involves a delicate balance between discouraging weedy species and not harming the crop. And by competing for nutrients, water, and sunlight, weeds can subtly, almost invisibly, drain off a crop's lifeblood and reduce yields significantly.

Twenty years ago, Experiment Station specialists set out to learn just how much weeds reduce soybean yields. From studies conducted over 11 years, they estimated that weeds robbed Iowa farmers of 3 to 4 bushels per acre when typical cultural methods of control were used. Today, the use of herbicides, in addition to cultural practices, has cut these yield losses to an estimated 2 to 2.5 bushels per acre. But with soybeans at $4 to $6 per bushel, the monetary loss due to weeds may be just as great today as it was in the 1950s.
Herbicide evaluation has formed a major portion of the weed research program at the Iowa Experiment Station in recent years. Both experimental herbicides and those already on the market are tested for effectiveness and possible toxicity to soybeans. Data from these experiments provide the basis for recommendations concerning dosages, timing and method of application, and side effects of different herbicides.

Generally speaking, soybean tolerance to herbicides depends on the dosage. Almost any herbicide, applied at high enough rates, will cause crop injury. Because of this, accurate and objective evaluations to determine the dosages that effectively control weeds with minimal crop damage are very important to farmers.

Research on herbicide formulations and application methods also is conducted at the Experiment Station. Improvements in the targeting of herbicide applications, changes in the size of spray droplets, or different formulations may reduce the amount of herbicide needed to get good control. This, of course, would save money for farmers and reduce problems of crop damage.

Soybeans sometimes are damaged by carry-over triazine herbicides applied to corn in previous years. Studies now are going on to pinpoint where and under what conditions significant carry-over occurs. Experiment Station scientists also are testing different tillage systems and certain additives that might stimulate breakdown of triazine herbicides by soil microorganisms, thus reducing carry-over and the risks of soybean damage.

Because weed control is an integral part of the total crop production system, substantial changes in other practices, such as adoption of conservation tillage or narrow rows, may require changes in weed control practices. Conservation or reduced tillage helps to minimize soil erosion and may cut production costs. Growing soybeans in narrow rows often increases yields. But many farmers have rejected these practices partly because they believe effective weed control is not possible with them.

Realizing the benefits of reduced tillage and narrow-row soybeans, Experiment Station scientists are evaluating the effectiveness of different types of standard cultivation equipment, herbicides, and herbicide application methods in conservation tillage systems and narrow-row soybeans. The results of this
research will show farmers how they can reap the benefits of reduced tillage or narrow-row culture, without facing excessive weed problems.

The effectiveness of mechanical and chemical weed control depends to a large extent on timing. Annual weeds are destroyed most easily soon after germination as the young seedlings emerge. Mechanical cultivation too early, before weed seed germination, often aggravates weed problems by creating soil conditions that favor germination and early weed growth. Pre-emergence herbicides, applied to the soil, are effective only if they remain in the same soil area until weed seeds germinate. On the other hand, if control methods are delayed until weeds are well established, pre-emergence herbicides and normal mechanical cultivations are both ineffective.

Experiment Station scientists are trying to improve the efficiency of herbicides by timing their application more closely to the period of maximum weed seed germination. They also are studying the effects of soil moisture, temperature, different tillage methods, and plant hormones on germination of weed seeds, which usually occurs over an extended period during spring and early summer in Iowa. If this "flush of germination" could be concentrated into a shorter period, destruction of weeds by herbicides or cultivation would be easier, more consistent, and probably cheaper.

Harvesting Losses Steal Profits

Soybeans are harvested with combines that gather, thresh, and separate the beans in one operation. Research in Iowa and other states shows that more than 80 percent of harvest losses occur during the gathering operation. Because of this, the gathering unit of the combine has been extensively analyzed to determine the major causes of harvest loss.

Engineers at the Experiment Station have concluded from field and laboratory studies that the cutting mechanism or cutter-bar causes most of the losses attributable to the gathering unit. These losses include shatter loss, stalk loss consisting of stalk pieces that are cut but not collected, and stubble loss. Excess stubble length, due to stalk slippage past the cutterbar, is the
Shatter Loss: Loose or free beans and beans in pods detached from the plant, chargeable to the machine.

Lodging Loss: Beans in pods attached to stalks or branches that slipped under the cutterbar and are abnormally longer than the stubble.

Stalk Loss: Beans in pods attached to stalk pieces that were cut but not collected.

Stubble Loss: Beans in pods attached to the freestanding stubble left by the machine.

Soybeans lost during the gathering operation account for the major part of harvest losses.
primary limitation on combine operating speed and capacity of present machines.

Thorough analysis of harvesting operations provides engineers with the necessary information for designing better machines. But, research results also show farmers how they can lower harvest losses using today's machines. For example, cutting stalks as low as possible minimizes harvest losses. A stubble of 3.5 inches contains about 5 percent of the beans. With a stubble of 6.5 inches, 12 percent of the crop is left in the field.

The moisture content of soybeans at harvest also affects harvest losses, especially those due to shattering. As bean moisture decreases below 14 percent, shatter losses increase considerably. Experiment Station scientists have recorded the lowest harvesting losses when moisture content of the beans is between 13 and 14 percent. Harvesting on damp days or evenings, when shattering is less, also cuts losses.

Narrow-row culture not only increases yields, but also helps to reduce harvest losses. Soybeans grown in narrow rows
at appropriate planting rates generally have slightly higher pods, fewer branches, shorter plants, and less lodging—all of which tend to reduce harvesting losses. In one test with the variety Hark, yield was 20 percent higher, and gathering losses 22 percent lower, in 10-inch rows than in 30-inch rows.

Farmers may lose 6 to 8 bushels of soybeans per acre during harvesting. Such losses can drastically reduce profits because the cost of producing these beans must be paid, whether they are harvested or not. Development of better combines and careful adjustment and operation of present-day machines can reduce harvest losses to 1 to 2 bushels per acre.
What happens to U.S. soybeans?

55% of our soybeans are exported as beans, meal, or oil.
USING SOYBEANS

Most soybeans produced in the United States are crushed and processed into two quite different products, soy oil and high-protein meal. Soybean oil is used primarily in shortening, margarine, and cooking and salad oils. Soybean meal is the most important protein ingredient in livestock feed, supplying about 65 percent of the high-protein concentrates used in poultry, hog, and fed-cattle rations. Use of soy protein in baked goods, beverages, meat products, and other human foods accounts for only 2 percent of the soybean meal consumed domestically.

As producers of soybeans, Iowa farmers look for good prices and strong market demand. As purchasers of soybean meal for livestock production, they look for reasonable meal prices that permit profitable livestock feeding without forcing meat and poultry prices so high that consumer demand weakens. And American consumers, of course, hope for minimum increases in their meat and poultry bills.

Because of the complexity of the soybean marketing situation and the multiple uses of the crop, many factors influence the marketing and utilization of soybeans. Availability of adequate transportation facilities, the quality of soybeans and their products, competition from other products, and long-term trends in market demand all interact to determine the patterns of soybean usage and the economic well-being of the U.S. soybean industry.

Getting the Beans to Market

Although Midwestern farmers historically have faced difficulties in getting their products to market, transportation problems have intensified in recent years. The inability of elevator operators to ship current stocks because of inadequate transportation forces them to curtail grain purchases from farmers. In turn, farmers incur extra storage costs and may have to borrow to meet current expenses. When elevator operators cannot get grain to exporters on time, they pay stiff penalties. And again, part of these higher marketing costs are passed on to farmers as reduced prices for their grain.
Several factors have contributed to the recent crisis in grain transportation. Cash sales of corn and soybeans have increased and are expected to continue upward. Export sales also are up, and more grain is shipped greater distances to seaports, tying up railcars for longer periods. Changes in harvesting techniques have allowed farmers to move huge quantities of grain to market in shorter periods. Also, many miles of branch rail lines have been abandoned.

Last year, Iowa State University research and extension staff completed an initial study of the grain transportation system in the area surrounding Fort Dodge. The purpose of this research was to find what distribution system would yield the highest net income for the study area, located in the heart of Iowa's cash-grain producing region.

Data used in the computerized study included information on the amount of grain expected to be sold outside the area in 1980, prices from markets now served by the area, handling costs, transportation rates, and three different rail line options.
The rail line options included maintaining all existing lines at their 1971 handling capacities, maintaining 46 percent of the track in the area, and maintaining the 27 percent of the track that could handle loaded jumbo hopper cars.

Using various combinations of these factors, the researchers determined the net revenue resulting from 11 different marketing and shipping systems in the area. They concluded that the greatest net revenue would be obtained if there were six large subterminal elevators in the area and all grain were shipped out in 115-car trainloads using the high-capacity 27 percent of the 1971 rail system. If more track were retained, fewer or more subterminals used, or grain moved in smaller shipments, net revenue would be less.

The study also indicated that small country elevators would be needed to collect and store grain, which would move by truck to the subterminals. The researchers calculated that small elevators, even without train-loading facilities, would yield nearly the same net earnings as they do today.

**RAIL LINE OPTION III**

27 PERCENT OF 1971 RAIL SYSTEM
GRAIN FLOW -- ELEVATORS TO SUBTERMINALS
SINGLE, 3-CAR, 115-CAR RATES

Three of the systems analyzed in Experiment Station study of farm commodity transportation in the area surrounding Fort Dodge.
The adverse impact of inadequate grain transportation on domestic farm profits, consumer food costs, and expansion of export sales requires continued efforts to develop more efficient distribution systems. The Experiment Station now is expanding its transportation research to cover all of Iowa.

**Poor Flavor Reduces Use of Soybean Oil**

Soybean oil tends to develop an unpleasant off-flavor caused by oxidation of the linolenic acid contained in all soybeans. Because this oxidation is accelerated at higher temperatures, it has hampered use of soybean oil in products such as salad oil and shortening that are stored for long periods at room temperatures.

Scientists believe that a high concentration of linolenic acid gives soybean oil its poor flavor stability. Most soybean oil contains 7 to 8 percent of this unsaturated fatty acid, whereas corn oil contains only 1 percent or less. As a result, corn oil is more stable, has a longer shelf life, and has a more neutral taste. Most of the other edible oils that compete with soybean oil also are superior in these respects.

Experiment Station scientists are trying to improve the flavor and keeping qualities of soybean oil by developing varieties with less linolenic acid. An extensive survey of soybean varieties and plant introductions revealed only a few lines having less linolenic acid than commonly grown varieties.

To produce more lines with low linolenic acid for their breeding program, Station scientists are using traditional breeding procedures in combination with various mutagenic agents, such as X-rays. Already, they have obtained soybeans with linolenic acid levels 1 to 1.5 percentage points below that of the lowest parental lines.

Although some progress has been made in this work, much remains to be done. It will take several more generations of hybridization and selection of promising offspring to get soybean lines that yield oil with only 2 to 3 percent linolenic acid, the level thought necessary to reduce development of off-flavors appreciably. Then, scientists must cross these lines with agronomically good varieties to transfer the trait for low linolenic acid to commercially acceptable varieties.
Soybeans and Soy Protein in Human Foods

About 40 percent of the total dry-matter content of whole soybeans is protein. The nutritional quality of soy protein, as indicated by its amino acid distribution, is nearly as good as meat proteins. But, the biological inefficiency and high cost of producing animal protein makes meat an unattainable protein source for millions of people. The protein needs of many people, especially in less-developed countries, probably can be met only by a vastly increased use of soybean and other vegetable proteins, which are relatively inexpensive.

Despite their high nutritional value, whole soybeans have formed only a minor portion of human diets except in China and Japan. One reason soybeans have not been accepted widely as a human food is their characteristic off-flavor and odor—often described as "painty" or "beany." Although this beany flavor once was thought to be an inherent property of soybeans, recent studies indicate that the flavor develops when soybeans are disrupted or damaged in the presence of water. An enzyme called lipoxygenase produces the beany flavor, which develops very rapidly and is almost impossible to eliminate or mask.

Direct human consumption of whole soybeans is limited in the United States. But soy protein and soybean oil are used in many food products, and the market is growing rapidly.
Scientists at the Iowa Experiment Station are studying lipoxygenase and possible ways to decrease its activity. They discovered that a relatively simple blanching treatment seems to inactivate the enzyme and prevent formation of the beany flavor. Continued research is aimed at developing a practical blanching process suitable for treating soybeans on a large-scale basis.

Soy protein, prepared by crushing the beans and extracting the oil, can be processed and incorporated into a variety of food products. In the United States, extracted soy protein in various forms (flours, concentrates, and isolates) is used to a much greater extent than whole soybeans in human foods.

One of the fastest growing uses for soy protein is as an extender in meat products. In a recent study at the Experiment Station, the quality of all-beef loaves was compared with that of beef-soy loaves containing 30 percent fortified soy protein concentrate. No attempt was made to mask the soy flavor with tomatoes or spices, and evaluation by a taste panel indicated that a definite soy flavor dominated the taste. Although the beef-soy loaves had lower cooking losses, they were rated somewhat less juicy than all-beef loaves. Chemical analysis indicated that cooked all-beef and beef-soy loaves contained about the same amount of fat, water, and vitamin B1. Except for flavor, the quality of beef loaves containing substantial amounts of soy protein was similar to that of all-beef loaves.

**Soybean Market Trends**

Carry-over stocks of soybeans in the late 1960s climbed to about 25 percent of annual production, causing some economists to predict a significant slowdown in market growth—the 'end of an era' in which U.S. soybean production grew at an average annual rate of about 10 percent. But since then, production has continued upward, largely stimulated by a 50-percent jump in soybean exports during the early 1970s.

What the future holds, no one will bet on too heavily. Despite the uncertainties, analysis of soybean market trends by Iowa economists and others points out some of the problems and the potential facing soybean producers and consumers.

Because the soybean contains two products—high-protein
meal and edible oil—market demand and prices for soybeans reflect the composite influence of demand and prices for these two products. If, as has happened to some extent, growth in demand for oil lags behind that for meal, depressed oil prices tend to force meal prices upward to offset the lower oil prices.

Today, soybean meal is the No. 1 high-protein feed for livestock and poultry, in terms of both quality and dependability of supply. But the top prices commanded by soybean meal in the past year or two translate directly into significant increases in production costs for livestock and poultry. These increases encourage development and use of competing products—including meal from other oilseeds, synthetic amino acids, fish meal, single-cell protein, and recycled animal wastes.

Although the most abundant of the edible fats and oils, soybean oil accounts for only about 16 percent of the total world supply. Strong competition, especially in foreign markets, comes from sunflower oil, peanut oil, rapeseed oil, cottonseed

Iowa soybeans loaded onto Mississippi River barge start their long journey to overseas markets.
oil, palm oil, and animal fats. Soybean oil provides about 60 percent of the domestic supply of edible fats and oils, but its market share overseas is much less. European consumers, in particular, complain that soybean oil has an undesirable taste and does not stand up well to repeated heating, cooking, and reheating.

The relative consumption of soybean meal and oil in domestic markets has pretty much equaled their relative abundance in the crop; that is, about 4.5 pounds of protein meal per pound of oil. This has not been true in European markets. Although western Europe buys about 75 percent of our soybean meal exports, it takes less than 1 percent of our soybean oil exports. Indeed, since the mid-1950s, much of our soybean oil has been exported under the Food for Peace program. These concessional exports have tended to stabilize world oil markets and to support soybean oil prices, thus preventing weak oil prices from putting upward pressure on meal prices.

The growth in foreign demand for U.S. soybeans and soybean meal has stemmed mostly from about 25 years of continual economic expansion in Europe and Japan and a concomitant increase in meat and poultry consumption. Aggressive market-development activities by the soybean industry also have played an important role in expanding foreign sales, which today account for about half the total dollar value of the soybeans produced by U.S. farmers.
Iowa soybean yields have increased an average 3 percent or 0.9 bushels per acre annually since the mid-1960s. Total production has nearly doubled. No one single discovery or practice has produced this steady and substantial progress. Nor, despite wishful thinking, is any single advance likely to produce a sudden "miracle" yield increase in the future. Because many factors interact in our partly natural, partly man-made agroecosystems, advances in one area depend on advances in others:

- The soybean breeders' prize, high-yielding variety will not perform well without good weed control and sufficient nutrients.
- Farmers switching to narrow-row soybeans may be disappointed if they continue to use older, "closed" canopy varieties and do not modify their weed-control practices.
- Techniques to make more nitrogen available may not boost yields much unless the soybean's sugar supply also is increased.
- As farmers grow more beans, diseases probably will take an increased toll unless breeders can incorporate resistance into future varieties.
- Soybean production and use may face a bottleneck if transportation facilities are not improved enough to keep distribution costs reasonable and the flow of beans to consumers steady.

U.S. soybean producers and the general public will benefit if the Golden Bean can retain its position as the nation's No. 1 cash crop and a prime export dollar earner. But to do this, soybean prices must remain competitive with other sources of protein and oil and stay within reach of the economic resources of both foreign and domestic consumers. This is a challenging
goal, requiring a concerted effort to increase soybean yields, reduce production costs, improve the quality of soy products, and assure dependable supplies delivered where and when they are ordered.
THE CHALLENGE AHEAD

American agriculture is undergoing searching scrutiny these days. Public concern about food prices, possible environmental problems stemming from agricultural production, and who will control agriculture in the future has focused the eyes and ears of many on America's farms. The attention, even if sometimes unsettling, is warranted because of the vital, indispensable contribution of agriculture to our economic and social welfare.

The challenge ahead for the Iowa Agriculture and Home Economics Experiment Station is to solve some of the basic problems underlying this public concern. The Experiment Station has a continuing responsibility to conduct research that serves the people of Iowa and the nation by contributing to solutions of current and future biological, physical, social, and economic problems.
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