Soil Fertility
AND
SMALL GRAIN PRODUCTION

UNIVERSITY OF MISSOURI COLLEGE OF AGRICULTURE
AGRICULTURAL EXPERIMENT STATION
J. H. LONGWELL, *Director*
BULLETIN 657 COLUMBIA, MISSOURI JULY, 1955

TABLE OF CONTENTS

FOREWORD

Small grains have long composed a large part of man's diet in bread, cereal, porridge and other forms. The carbohydrate content (mainly starch) in the endosperm of the seeds, which serves as energy food for man and animals as well as for the sprouting grain, does not represent soil fertility removal in large quantities. But that starch is laid down, late in the plant's physiological processes only as reserve energy food for the living, high protein germ that is produced early as a guarantee of the survival of the plant species. The plant's struggle for survival is thus one of creating the proteins, and all the enzymes and other items associated with them, in the germ, first. Then comes the creation of the carbohydrates. But in our measure of yield it is the carbohydrates, or the starch, that stand out as major as they make up most of the size of the kernel.

The increase of bushels of grain calls for the laying down of more germs, then, or the multiplication of the living reproductive cells, early in the season of the plant's life. This calls for a balanced array of all the soil fertility elements during most of its early growth period. It is a call especially for the nitrogen, which is added biosynthetically to the carbohydrate starter compounds and makes the differences between fuel values and life-maintaining values, or between carbohydrates and proteins, respectively. Because we can now add nitrogen as fertilizer to the soil, we are in a position to increase the yields of small grain by helping the crop in its laying down of more germs. It is the plant's struggle for more protein, for more reproduction and more grain, which we can now undergird as we use more nitrogen and learn more about the other fertility requirements in the soil to make this creative process multiply the seed many fold.

In the light of the experience of using nitrogen for growing more forages and more corn, the research in fertilizing the small grains should be remunerative for these food and feed values in both quantity and quality. Fitting, as winter cereals do, into the climatic setting with less alternate wetting and drying of the fertile surface soil to hinder plant nutrition, we may well emphasize the small grains as the major crops for greater certainty under the dry weather handicap Missouri occasionally experiences, especially in summer. There is the suggestion that the wise use of soil fertility under soil-test guidance and extended small grain production may let this state make greater use of her potentialities in food production.

Dr. Wm. A. Albrecht, Chairman
Department of Soils

Soil Fertility and Small Grain Production

G. E. Smith, Wm. J. Upchurch, J. A. Roth, Melton Brown

INTRODUCTION

Missouri is at the junction of the corn and wheat growing areas. In years when summer rainfall is high, interest in corn production increases, primarily because of higher returns per acre from this crop. But when the precipitation is low and summer temperatures are above average, wheat and other small grains are more dependable crops. On the shallow prairie soils, in the southern two-thirds of the state, properly treated winter barley may produce more nutrients per acre than corn. Small grains make most of their growth during the fall and spring when effective soil moisture is usually ample.

Drouth Stimulates Interest

The center of wheat production in the United States is in areas of less than 30 inches of annual rainfall. Corn requires warm summer temperatures but ample and regular rainfall for optimum production on soils of little depth. The drouth conditions experienced in parts of the state in 1952-53 and 1954 have stimulated interest in small grain production as forage and pasture crops, as well as grain. The addition of sufficient plant nutrients to eliminate soil fertility as a factor in production has greatly increased both winter survival and economic yields.

Wheat was the first crop that regularly received additions of commercial plant nutrients. As crop removal and erosion have lowered soil fertility levels, the use of chemical fertilizers has become a necessary practice to produce profitable yields and good quality of all small grains. Except on the highly fertile alluvial soils, most wheat, barley, and a large percentage of the oats now produced receive fertilizers. The use of these treatments has done much to halt soil depletion and to change possible shortages of these grains to surpluses.

Increased use of nitrogen in recent years has shown spectacular effects on small grains. However, the greater use of this element has focused attention on the low level of other minerals in many soils. The addition of other minerals must now be increased to balance these larger applications of nitrogen.

Can Make Up Lost Fertility

The continuous removal of more nutrients in crops than are returned in animal manures and fertilizers is resulting in a loss of soil minerals and a gradual decline in soil fertility. The length of time required for yields to drop to levels that fail to pay production costs will depend on the initial fertility of the soil and the management practices employed.

Experimental work started within recent years has shown that where adequate and balanced supplies of nutrients are added in fertilizers, the fertility differences in many soil types may be largely eliminated in favorable seasons. Yields on many soils with fertility levels below average can be raised above those obtained when these soils were first cultivated.

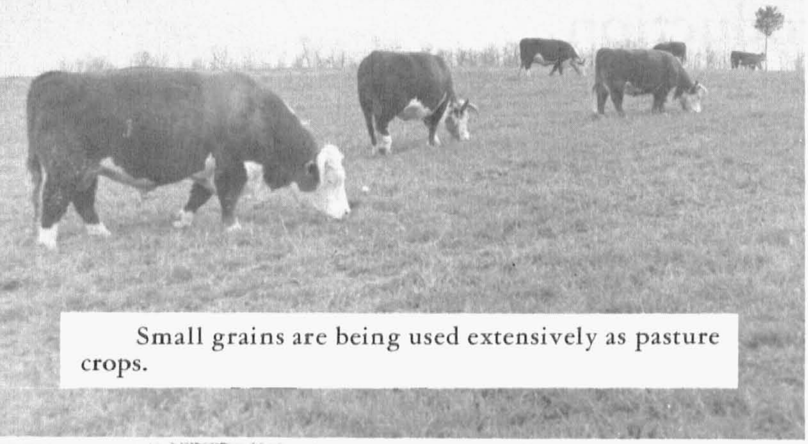
Fertilization the Big Factor

A realization of the potentialities for increasing yields by adequate fertilization has overshadowed much of the older experimental work in soil management. It has now placed the emphasis on the soil nutrient requirements of crops. Soil management is rapidly becoming the practice of nutrient addition and maintenance rather than one of emphasizing cultural or other production factors.

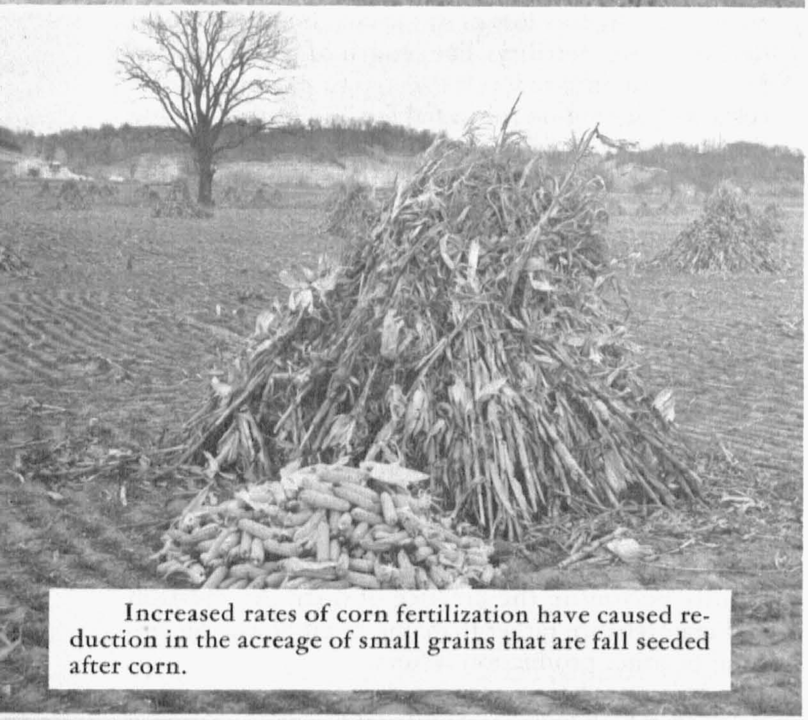
It is now being granted that the management practices which have increased yields most in the past have been those which have stimulated the breakdown of the organic matter and the depletion of the soil fertility. The lower the initial fertility reserves, the more rapidly the yields approached the level of no profit. On deep soils of high fertility, this decline is less apparent and may be confused with weather variations.

Small Grains Have Wide Adaptation

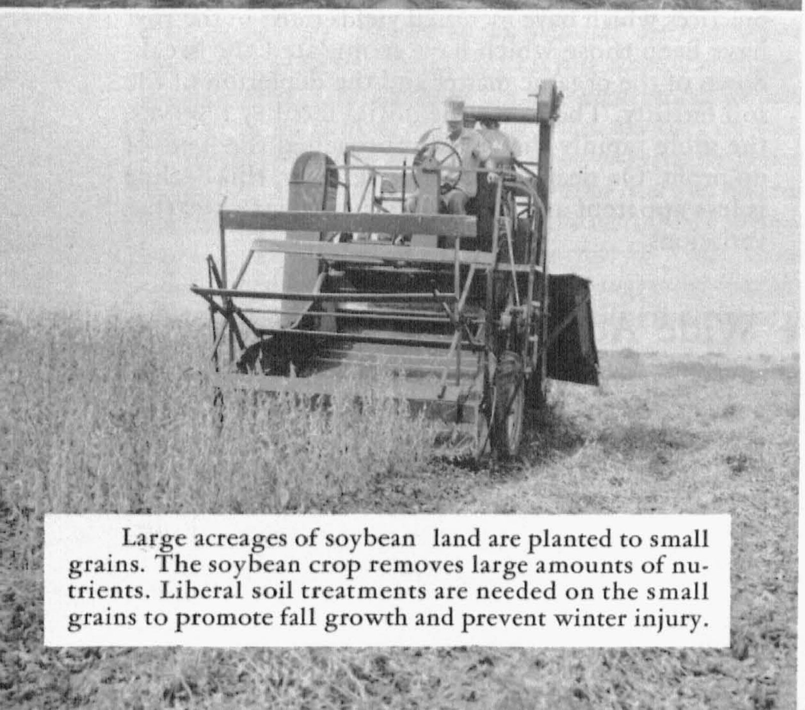
Most Missouri farms produce small grains. Aside from their value as cash crops and as feed grains, they serve as pasture or nurse crops in shifting from cultivated crops to hay and sod crops. However, the place of small grains in soil management systems has undergone radical changes in recent years. The old four—or three—year systems of corn, oats, wheat, clover, or corn, wheat, clover have almost disappeared. The re-



Small grains are being used extensively as pasture crops.



Increased rates of corn fertilization have caused reduction in the acreage of small grains that are fall seeded after corn.



Large acreages of soybean land are planted to small grains. The soybean crop removes large amounts of nutrients. Liberal soil treatments are needed on the small grains to promote fall growth and prevent winter injury.

placement of horses by tractors has reduced the need for oats. The introduction of lespedeza has reduced the acreage of oat stubble that is plowed early for wheat. The heavy fertilization and thick planting of corn, with little being cut and shocked, has made the practice of planting wheat after corn difficult, except in some seasons.

The increase in production of soybeans has resulted in an increase in planting of wheat after this crop. Emphasis on grass and livestock farming has increased the planting of small grain for supplemental pasture and, more recently, for a silage or hay crop. Finally, a realization that crop yields are to a great extent a function of a soil as it supplies available nutrients has brought about soil management practices that will produce high yields on soil previously thought incapable of grain crop production.

Use as Silage Crops

Shortages of summer rainfall during the past few seasons have focused attention on small grains as feed and as silage crops in place of corn. Government acreage restrictions have increased costs of producing wheat because of less efficient use and higher overhead on machinery. Labor, machinery, and other costs make highly efficient farm operations necessary for maximum return from small grain production. All of these factors are influencing soil management practices in the production of small grain. A thorough understanding of the nutrient requirements of these small grains, of the plant food removal of previous crops, and of the composition of their crop residues, is essential if small grain production is to be efficient and to insure a satisfactory stand of legumes or grasses planted with the small grains.

Average Yields of Small Grains Are Low

Despite improved varieties, better farm equipment and increased use of soil treatments, the state average yields of small grains in Missouri have been too low to return a significant margin of profit. The decline in soil fertility through crop removal and erosion has tended to offset improved production practices. The average yields for the principal small grain crops in Missouri from 1901 through 1954 are given in Table 1.

There was little change in the average yield of wheat from 1901 through 1945. There was an average yield of only 14. 8 bushels in the 10-year period 1931 to 1940. The average yield was only 14.0 bushels from 1940 to 1945. But from 1946 to 1950 the average yield

TABLE 1 -- AVERAGE YIELDS OF SMALL GRAINS IN MISSOURI
(Bu. per Acre)

	Wheat	Oats	Barley	Rye
1901-1910	14.2	20.5	----	----
1911-1920	14.1	23.0	----	----
1921-1930	13.7	20.3	18.6	9.2
1931-1940	14.8	22.8	19.8	10.7
1941-1950	16.1	24.8	20.7	12.3
1941-1945	14.0	22.5	19.0	11.4
1946-1950	18.2	27.0	22.3	13.1
1951-1954	23.9	27.6	26.0	12.3

climbed to 18.2 bushels and for the period from 1951 to 1954 the average figure rose to 23.9 bushels. Yields of oats and barley have shown the same trends with substantial increases occurring only since 1946.

Improved varieties of wheat (and other small grains) are consistently producing three to five bushels more per acre than older varieties.* On the majority of soils in the state the addition of starter fertilizers at the time of planting will consistently increase yields from 7 to 10 bushels per acre. Better machinery enables the crop to be planted and harvested with less hazard. Despite these improvements, most of which are practices followed by progressive farmers, average yields have not made spectacular improvements except during the past 10 years. Part of this increase may be attributed to better growing seasons. However, it is of interest that total fertilizer consumption in the state has increased over 10 times— from less than 75,000 tons to more than 750,000 tons—during this period. It appears that these increases in small grain yields since 1945 have been closely associated with more soil fertility treatments.

Production of small grains requires about the same operations and about the same time per acre whether the yield is 15 bushels or 45 bushels. Most of the costs of land preparation, seeding, and harvesting are approximately the same, except for the cost of fertilizer and extra costs of hauling grain and storing it (Table 2). When proper plant nutrients are provided

TABLE 2 -- COST OF PRODUCING WHEAT PER ACRE*
(Based on 1954 figures)

Operation	Low	High
Plowing	$ 1.75	$ 3.00
Discing (twice)	2.00	3.00
Harrowing	0.50	1.00
Drilling	1.50	4.50
Combining	3.50	5.00
Seed	2.50	4.00
Interest and taxes	4.25	14.50
	$16.00	$33.00

*Part of figures taken from Nebraska Bulletin 413; remainder from the Missouri Agricultural Experiment Station.

for deficient soils, profitable responses in yield and improved quality can be expected. Experiments have shown that the most practical means of improving the yields and quality are the provision of the best crop varieties and the proper nutritional balance for optimum growth. When soil fertility is eliminated as a factor in production, weather and other production hazards are mininized.

*See Missouri Bulletins 501, 508, 532.

Seasonal Factors in Nutrient Availability

Small grains make most of their growth during the cooler seasons of the year. Wheat, barley and rye are planted in the fall when temperatures are declining. Most of the growth is made in the spring when temperatures are relatively low and the surface soil contains adequate moisture. Oats are a cool weather crop. They are planted as early as possible in the spring to permit maximum growth before running into the retarding influence of high temperatures normally experienced in mid-June. Yields will frequently be higher if oats are seeded early in a relatively poor seedbed rather than later when the soil is drier and the length of time for growth at lower temperatures is reduced. Central Missouri is about as far south as spring oats will regularly produce satisfactory yields of grain. In the extreme southern counties, some winter varieties are sufficiently hardy, with adequate fertilization, to withstand the winters and may give yields far superior to spring varieties.

In unfertilized soils, a major portion of the nitrogen, phosphorus, and some other elements absorbed by plants is made available from the breakdown of organic matter by soil organisms. The rate of breakdown is reduced if temperatures are low, or the soil is extremely wet or dry. The addition of readily available plant nutrients as fertilizers at the time of planting will usually speed early growth of these crops. Under adverse weather conditions an ample supply of available nutrients will promote growth and root development. This reduces loss from low winter temperatures and increases yields. For spring oats, an adequate supply of these nutrients early in growth may hasten maturity as much as a week and permit harvest before the crop is damaged by excessive June temperatures.

Early Plowing Increases Availability of Nutrients

For many years where fall seeded small grain has followed small grain it has been a common practice to plow in July or early August. As a general rule, the earlier the plowing the higher the yields. This early breaking of the soil increases the rate of organic mat-

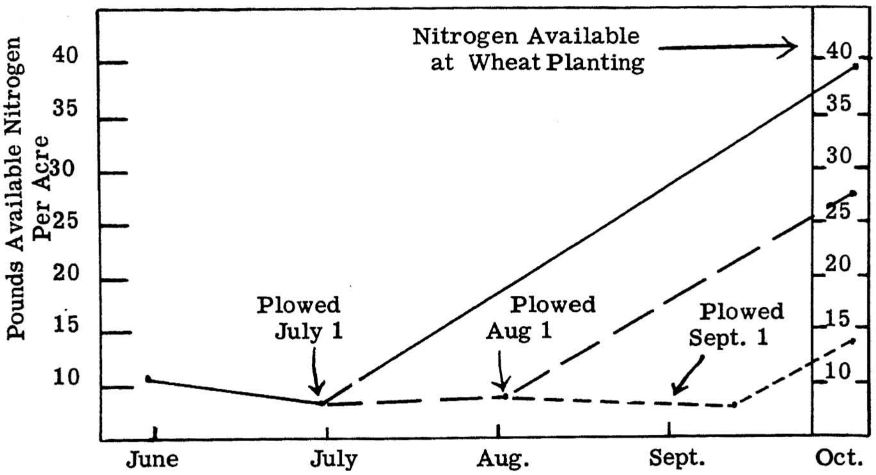


Fig. 1—Early plowing for fall seeded grains releases nitrogen from soil organic matter. When land is prepared late or when wheat follows soybeans or lespedeza the fertilizer applied at time of planting should contain more nitrogen.

ter decomposition and raises the amount of available nutrients at the time of seeding (Figure 1).

Recently, early plowing has not been practiced to as great an extent. The big increases in acreages of lespedeza and soybeans have resulted in small grains being planted after these crops. Seedings are made after lespedeza has been pastured and has produced seed or after soybeans have been harvested for grain. Although these crops are legumes, the levels of available nitrogen and minerals in the soil at their maturity are comparatively low. The fact that the small grains follow these crops so closely has probably been one factor in the failure of the small grains to produce the increased yields which could be expected from the better varieties, the use of more fertilizers, and the other improved factors of production.

When early plowing was the common practice, the weed growth was suppressed and both the nutrients and the moisture that would have been used by the weeds remained available for the grain crop. However, this benefit was offset on rolling land by increased erosion. This has directed interest toward cropping sequences which keep the land covered as much as possible and permit the addition of adequate amounts of fertilizers at the time of planting to replace fertility that early plowing would have made available from the soil.

Cropping systems have removed more nutrients than have been added in crop residues, manures, and fertilizers. These losses, added to those from erosion, have resulted in a decline in the soil's organic matter and in its productivity. As soil nutrient reserves declined, the benefits of early plowing became less noticeable. With a decline in organic matter, less nutrients were made available by early plowing and less stimulation of the young small grain resulted. All of these factors point to the necessity for the addition of adequate fertility through chemical fertilizers if maximum yields are to be obtained.

Nutrient Requirements

The nutrient content of small grain crops will vary considerably, depending on the supply available in the soil. Crops grown on soils of high organic matter content normally have a higher protein content than those grown on soils of low fertility. The amount of nitrogen and minerals found in crops grown on soils of average fertility will vary little unless the nutrient supply is not in proper balance. When one element is present in excess of other elements, the plant usually absorbs a greater percentage of it.

The chemical analyses given in Table 3 show that the highest concentrations of nitrogen and phosphorus are in the grains. Most of the potassium is in the vegetative portion. Without sufficient nitrogen, the plants fail to produce sufficient vegetative growth. Stooling is reduced and yields are low. If phosphorus is not available in adequate amounts, cell division is

TABLE 3 -- NUTRIENT CONTENTS OF SMALL GRAIN CROPS

Crop	Yield	Part of Crop	N (lb.)	P_2O_5 (lb.)	K_2O (lb.)
Wheat	35 bu.	Grain	41	19	10
	1.5 T.	Straw	18	5	24
		Total	59	24	34
Oats	60 bu.	Grain	42	18	12
	1.5 T.	Straw	18	6	42
		Total	60	24	54
Barley	50 bu.	Grain	44	19	13
	1.25 T.	Straw	19	6	38
		Total	63	25	51
Rye	30 bu.	Grain	33	7	9
	1.5 T	Straw	15	4	26
		Total	48	11	35

retarded, plants are small, starches are not formed, shriveled grain is produced and maturity is delayed. A deficiency of potassium prevents the movement of carbohydrates to the seed, and reduces grain production.

When only the grain is harvested, nitrogen and phosphorus are the elements removed in greatest amounts. The removal of straw takes off large quantities of potassium. Unless this potassium is replaced, soil levels of it will drop, and soils that now contain a sufficient supply of this element will have it depleted so that other nutrients will show little benefit.

Small Grains Are "Weak" Feeders

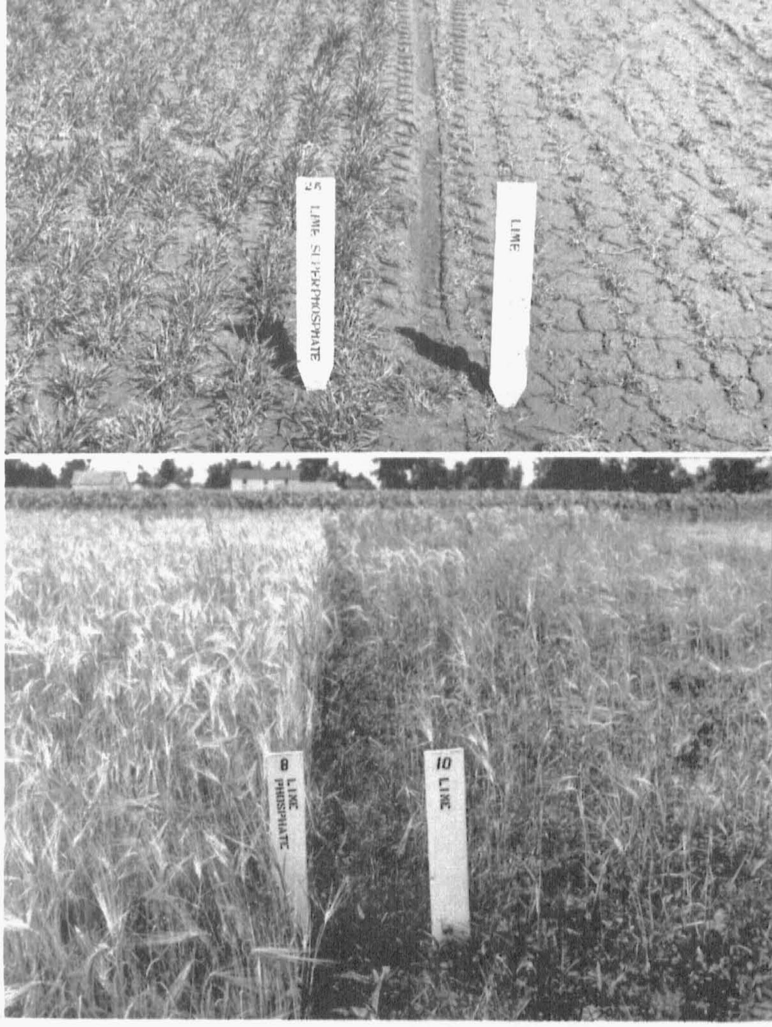
It is well known that some plants can make satisfactory growth on soils where other crops are failures. Some crops can use more of the less available soil minerals or the less soluble fertilizer compounds. This difference in growth characteristics is usually reflected in the plant's chemical composition. Plants producing satisfactory bulk on poor soils usually have lower protein and lower mineral contents. However, laboratory measurements of the power of roots of different plants to extract essential nutrients from the less soluble soil minerals or fertilizer compounds show that the small grains are what might be considered the "weakest" feeders of most field crops in terms of both the degree of acidity and the exchange capacities of their roots (Table 4).

TABLE 4 -- NUTRIENT EXCHANGE CAPACITY OF PLANT ROOTS*

Crop	Ultimate pH	Cation Exchange Capacity**
Soybeans	3.26	58.9
Red Clover	3.37	47.5
Alfalfa	3.42	48.0
Timothy	3.78	22.6
Corn	3.68	26.0
Spring Oats	3.78	22.8
Rye	4.12	15.1
Barley	4.25	12.3
Wheat	4.70	9.0

*Data from M. Drake-Mass. State College.
**Milliequivalents per 100 grams of roots.

This difference in plants as feeders also appears to vary with the time when the most growth is made and with the amount of root surface. Crops that make most of their growth during the warm season appear to have the highest feeding power. It is possible that soil organisms may be an important intermediate factor, making these nutrients available for the growing crop. However, regardless of the mechanism of nutrient mobilization, it is necessary that an adequate supply of nutrients be available at the proper time if small grains are to absorb a sufficient quantity of them for optimum yields.



When soils do not supply nutrients required by wheat or barley, plants are stunted and may winter-kill. Supplies of nutrients at seeding time promote fall growth, reduce "heaving" and increase stand. Superphosphate on deficient soil increased wheat yields (top) 15 bushels per acre. On barley (bottom), it made the difference between crop failure and a 40-bushel yield.

Much work has been done in the study of cultural practices and the proper place of small grains in cropping systems to give optimum yields. Results have pointed largely to practices that would provide maximum nutrient availability and proper soil environmental conditions for these crops.

Soil Management For Improving Yields

Cropping Systems and Yields of Small Grain

On most farms where a regular rotation or cropping sequence is now practiced, corn is usually followed by oats or soybeans and then wheat, barley, or rye, any one of which serves as a nurse crop for grasses

Rotations furnish soil cover but cannot maintain soil productivity when crops are removed. Wheat in these three pictures was of the same variety and planted the same day on plots that had been in the same 6-year rotation for 66 years (Sanborn Field). Pictures were taken the same day. The top plot, which has never received treatment, produced 11.6 bushels per acre in 1954. The area in the center picture receives 6 tons of manure, annually. Its yield in 1954 was 30 bushels per acre. Grain in the lower picture has received treatments according to soil test. It produced 44 bushels per acre in 1954.

and legumes. With the heavy fertilization of corn and thicker planting, it is so difficult to seed small grain after corn in the fall that this sequence is rapidly disappearing. In other cases, the small grain is grown in a two-year system alternating with red clover, or it is alternated with lespedeza in a one-year rotation. A rotation of lesser use is the cropping system of an early variety of soybeans followed in the same year by winter barley or by an early variety of wheat.

Experiments have been conducted comparing these various cropping systems and soil treatments on different soil types. Many Missouri soils are low in nitrogen, phosphorus and calcium. Potassium levels are highly variable. Magnesium is usually adequate, although soil tests show the need of this element is becoming more evident. Most of the experiments described in this publication were conducted on limed soils with starter fertilizers containing phosphorus and potassium. It is now known that in many cases the amount of phosphorus added was not sufficient for optimum growth. More recent investigations show that nitrogen was probably a limiting element.

Wheat yields for a 10-year period on Putnam silt loam are given in Table 5. The average yield of 34.6 bushels per acre when wheat followed oats (summer plowed) in a rotation with corn and sweet clover was the highest obtained. Yields of 31.3 and 30.3 bushels per acre were obtained when wheat followed corn and soybeans, respectively. When wheat was grown with red clover in a two-year rotation, the yield was reduced to 27.8 bushels. Yields of wheat following lespedeza in a one-year sequence were reduced substantially. Plowing the lespedeza land increased yields from 15.4 to 22.1 bushels.

TABLE 5 -- YIELDS OF WHEAT IN ROTATION - 10 YEAR AVERAGES PUTNAM SILT LOAM

Rotation	Yield per Acre
Corn, Oats, Wheat, Sweet Clover (seed) 4 years	34.6 bu.
Corn, Wheat, Red Clover	31.3 bu.
Corn, Oats + Lespedeza, Wheat + Lespedeza, Timothy + Lespedeza, Lespedeza and Timothy for Hay	22.0 bu.
Corn, Oats + Soybeans (hay), Wheat + Soybeans (under)	30.3 bu.
Wheat + Lespedeza (disced for wheat)	15.4 bu.
Wheat + Lespedeza (plowed for wheat)	22.1 bu.
Wheat + Red Clover (2 year rotation)	26.8 bu.
Wheat - continuous (No legume - summer plowed)	22.3 bu.

Soil Treatment: Calcium Limestone, 0-20-10 @ 200 lb. with wheat, 150 with corn and 125 with oats.

Although the fertilizer applied to the wheat was the same in all crop sequences, it is now known that the amounts of nutrients available to the crop were too small for optimum yields. The lower yields of grain following lespedeza were due to lesser amounts of nutrients being available to the wheat than when the ground was plowed early or where a better seed bed could be prepared. More recent experiments indicate that where soil nutrient reserves are raised to high levels, and where adequate nutrients are provided, the depressing effect of lespedeza ahead of the small grain crop is not evident.

Most oats are seeded after corn or lespedeza. Table 6 gives average yields of oats in different rotations for a 10-year period of experimental trials. Where oats followed corn in the various rotations, the yields varied from 45.6 to 49.0 bushels per acre. This difference of 3.6 bushels is small and probably not significant. Where oats followed lespedeza in a one-year cropping system the yield was 39.1 bushels. Again the removal of nutrients by this legume crop or the trashy seed bed apparently was responsible for the reduction in yields.

TABLE 6 -- YIELD OF OATS IN ROTATION - 10 YEAR AVERAGE PUTNAM SILT LOAM

Rotation	Bu. per Acre
Corn, Oats, Wheat, Sweet Clover (seed); 4 years	48.0
Corn, Oats + Lespedeza, Wheat + Lespedeza, Timothy + Lespedeza, Lespedeza and Timothy for Hay	49.8
Corn, Oats + Soybeans (hay); Wheat + Soybeans (under)	45.6
Corn, Oats + Sweet Clover (under); 2 years	47.3
Oats + Lespedeza; one year	39.1

Soil Treatment: Calcium limestone, 0-20-10 @ 125 lb. with Oats, 150 with Corn and 200 with Wheat.

Farm Manure On Wheat

Farm manure is a valuable source of nutrients and will increase yields on most soils of the state. However, manure is deficient in phosphorus. A ton of average unleached barnyard manure will contain about 10 pounds of nitrogen, 5 pounds of phosphate and 10 pounds of potash. If the soil nutrient levels of phosphorus are raised and a starter fertilizer containing adequate phosphate is applied at the time of seeding, the top dressing of a small grain with manure will furnish sufficient nitrogen and potash to improve crop yields greatly.

In long-time experiments, applications of 3 tons of manure per acre have increased wheat yields 3 bushels per acre for each ton applied. Where 6 tons were applied per acre, the increase was 2 bushels per ton. Manure is deficient in phosphorus, which should be added to provide a balanced treatment. Few farms have enough manure to cover all land so other fertilizer materials are needed.

In experiments conducted on Sanborn Field for over 60 years, the application of manure at 3 tons per acre has increased yields of wheat about 3 bushels for each ton of manure applied (Table 7). When the applications have been 6 tons per acre, the increases for both wheat and oats have been about 2 bushels of grain for each ton of manure. Increases from manure have been less than those from chemical fertilizers (possibly because of a phosphorus deficiency) but the practice has been profitable. However, with only an average increase of 2 bushels per ton when 6 tons were applied per acre, the amount of improvement in yield of small grains from manure applications was limited. Few farms produce enough manure for more than a fraction of the grain crop acreage. Although the use of manure on wheat is desirable, there is evidence that it

TABLE 7 -- MANURE INCREASES YIELD OF WHEAT (Sanborn Field)

Cropping System	Soil Treatment	6-Yr. Av.	Yield - 1954
Continuous Wheat	None	8.9 bu.	15.4 bu.
Continuous Wheat	3 T. Manure	17.0	31.1
Continuous Wheat	6 T. Manure	18.8	36.6
3-Year Rotation	None	11.0*	12.1**
3-Year Rotation	6 T. Manure	21.9*	27.5**
4-Year Rotation	None	20.5†	21.4**
4-Year Rotation	6 T. Manure	21.4†	25.7
6-Year Rotation	None	14.3†	11.6
6-Year Rotation	3 T. Manure	20.0	30.4
Continuous Wheat	Full Mineral Treat.	29.1	40.7
3-Year Rotation	Rull Mineral Treat.	----	41.5

*21 year average
**1953
†10 year average

may be used more efficiently on corn.

The necessity for supplying available phosphorus in addition to that supplied in manure is shown in Table 8.

Sweet clover appears to have made more nutrients available to the wheat than 8 tons of manure. The mixed fertilizer increased the yield more than 3 bushels per acre when applied with the manure, but only a fraction of a bushel when sweet clover was grown in the rotation.

Starter Fertilizers for Wheat

Numerous experiments have been conducted in testing various fertilizer ratios applied to wheat in different cropping systems. The results in Tables 9 and 10 are typical. These were obtained on a Putnam silt loam originally showing a lime requirement of 3 tons, a low amount of phosphorus, a medium supply of organic matter, and a high supply of potassium.

TABLE 8 -- MANURE, SWEET CLOVER FERTILIZERS AND YIELDS OF WHEAT GROWN IN ROTATION WITH CORN
(Sanborn Field)

Soil Treatment	Wheat (9-yr. av.)
None	15.6 bu.
0-12-12 @ 400 lb.	17.4
8 tons manure	17.7
8 tons manure 0-12-12 @ 400 lb.	20.8
Sweet clover	19.8
0-12-12 @ 400 lb. and Sweet Clover	20.2

The differences in yield response to small variations in the fertilizer ratios ranged from 2.2 bushels where the lespedeza crop was cut for hay (Table 9) to slightly more than 6 bushels where wheat followed corn or soybeans. In these latter cropping sequences, the highest yields were obtained where the nitrogen in the mixture was increased. When the averages of all of the treatments are considered, the highest yields were obtained with maximum nutrient additions.

Where the entire crop of lespedeza was turned under, or where manure was added, the yields were about 23 bushels per acre. An average yield of only 7.4 bushels was obtained when lespedeza was harvested for hay and the land prepared for seeding with no more tillage than that by a field cultivator. It is evident that earlier seedbed preparation and the higher nutrient levels that result from the breakdown of or-

TABLE 9 -- STARTER FERTILIZERS ON WHEAT IN DIFFERENT CROPPING SYSTEMS
(Putnam Silt Loam - 4 year average - Yield: Bu. per acre)

Fertilizer Ratio*	Continuous wheat + Lespedeza (Hay) Plowed Aug. 20	Continuous wheat & Lespedeza (under) Plowed Aug. 20 - Lime	Continuous wheat & Lespedeza (under) 5 T. Manure in Spring Plowed Aug. 1, Lime	Continuous wheat No Legume Plowed Aug. 1	Continuous wheat No Legume Straw under	Wheat & Lespedeza - 1 yr. Lespedeza, Hay & Seed Field Cultivator	Wheat and Lespedeza Lespedeza, Hay & Seed Field Cultivator - 5000 lb. Lime	Soybeans-Wheat & Lespedeza Hay and Seed. Spring plowed for beans.	Kafir, Wheat & Sweet Clover (Under) Lime 5000 Plowed, May 1 - Kafir	Corn, Wheat & Sweet Clover (under) Lime 5000 Plowed, May 1– Corn	Corn, Wheat, and Red Clover Hay and Seed	Average all Plots
0-20-0	25.8	23.1	23.8	17.0	16.1	6.0	6.2	15.3	14.0	16.0	19.5	16.5
0-10-10	27.0	20.8	24.8	17.0	16.9	7.8	7.7	17.1	16.1	16.0	20.5	17.4
0-20-10	26.9	23.5	24.7	17.0	17.0	7.1	7.0	18.5	16.4	17.2	19.0	17.6
0-20-20	----	22.7	24.7	17.0	16.8	6.8	8.0	18.6	15.0	15.7	21.3	16.7
10-20-20	27.6	24.3	25.6	19.3	18.8	6.6	10.0	19.8	19.1	18.0	24.9	19.4
10-20-20	----	25.6	26.6	21.1	19.5	7.5	9.4	19.0	18.1	19.6	22.3	18.9
No Fertilizer	20.2	14.1	18.5	10.6	12.6	3.8	3.6	9.2	10.4	13.1	15.6	12.0
2-12-6	25.4	22.9	23.6	17.6	18.0	8.2	8.7	17.6	15.3	16.3	19.8	17.5
0-12-4	25.8	21.5	24.8	17.7	17.8	8.4	8.0	16.6	15.0	16.0	18.6	17.2
4-12-4	26.9	23.2	23.9	17.1	17.5	7.3	8.5	18.6	16.0	18.5	18.8	17.7
4-12-8	26.6	22.8	27.9	20.1	19.0	8.0	7.6	19.1	16.8	17.0	19.5	18.6
8-12-8	26.4	24.7	28.0	20.5	22.0	8.1	9.7	21.4	18.0	19.2	19.7	19.7
Av. all Treatment	25.8	23.2	25.3	18.3	18.1	7.4	8.3	18.3	17.3	17.2	20.4	15.9
Maximum Difference Between Fertilizers	1.2	3.9	5.4	4.1	5.9	2.4	3.8	6.1	5.1	3.6	6.3	7.7

*All fertilizers applied @ 150 pounds per acre with grain drill at time of seeding.

ganic matter in the soil (which is possible when the land is prepared early) are more influential on crop yields than are small differences in fertilizer composition.

More than 100 experiments have been conducted on various soil types over the state in recent years where different fertilizer ratios have been applied with wheat and barley. Results were similar to those shown in Tables 9 and 10. These results tell us that past soil

TABLE 10 -- RESPONSE OF BARLEY AND WHEAT TO STARTER FERTILIZERS ON PUTNAM SILT LOAM, FOLLOWING LESPEDEZA CUT FOR HAY; PLOWED AUGUST 20
(6 Year Average)

Fertilizer*	Barley	Wheat
0-20-0	40.7 bu.	30.5 bu.
0-10-10	37.4	31.2
0-20-10	38.4	31.4
10-20-10	43.8	32.7
0-0-0	26.7	25.4
2-12-6	40.0	30.6
0-12-4	36.9	31.1
4-12-4	40.2	31.7
4-12-8	40.5	31.5
8-12-8	40.7	32.2

*Applied @ 150 lb. per acre at time of seeding.

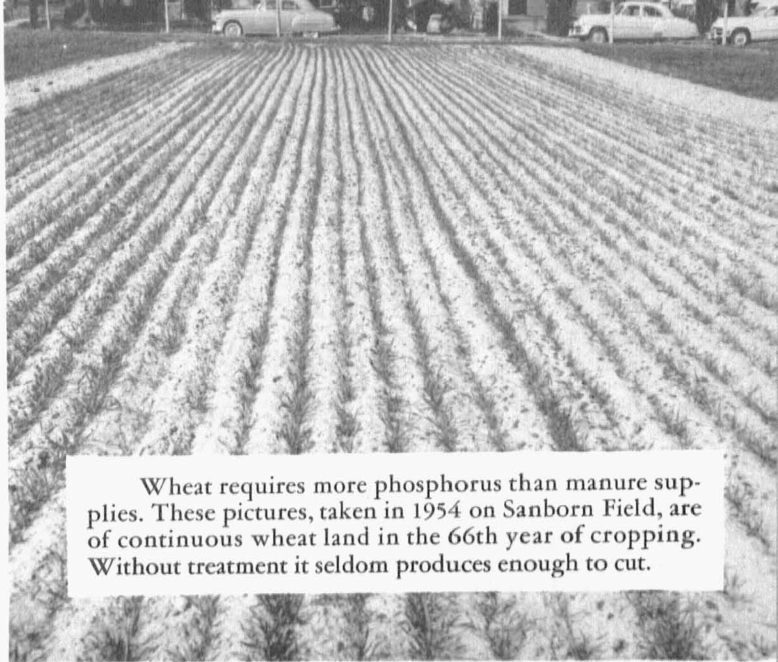
management factors, such as the time of cultural operations, the liming, the removal of legumes for hay, the applications of manure, the depth of surface soil and other factors are more influential in raising the yields of the following small grains than are small differences in fertilizer ratios.

Sources of Phosphorus

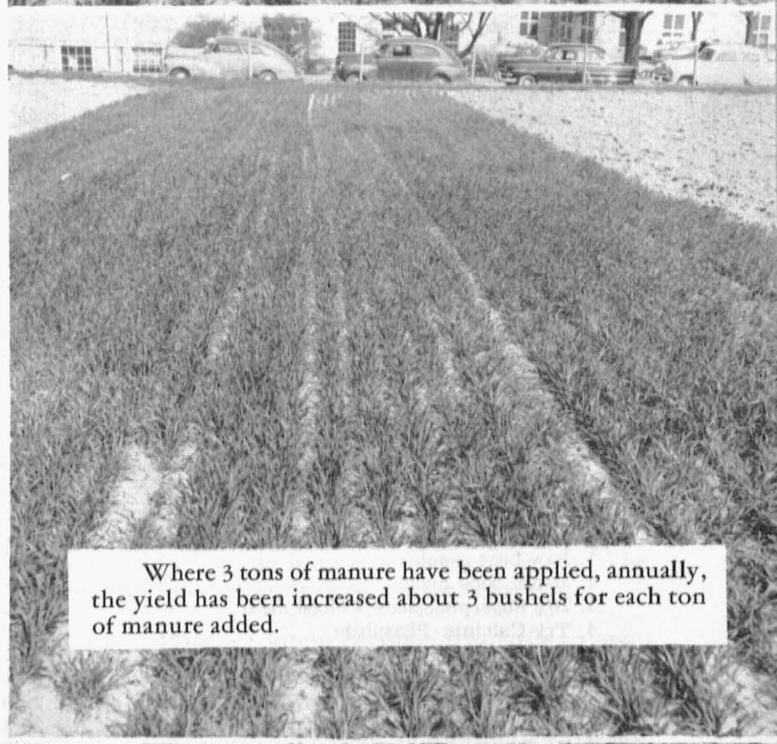
Most Missouri soils contain inadequate supplies of available phosphorus for small grains. The addition of an available phosphate fertilizer at the time of seeding will give a profitable response on most soils (exceptions include some alluvial bottoms and the better prairie types of Northwest Missouri). In many cases, nitrogen is the limiting element for growth on these soils. Consequently the addition of phosphorus will be of little benefit until the soil's content of available nitrogen is increased.

Wheat was the first crop to be fertilized extensively in the state. Prior to 1940 the wheat crop probably received more than 75 percent of the fertilizer used. Superphosphate was frequently the only fertilizer material applied. It was not until after potash levels dropped and synthetic nitrogen became available that mixed fertilizer came into more general use.

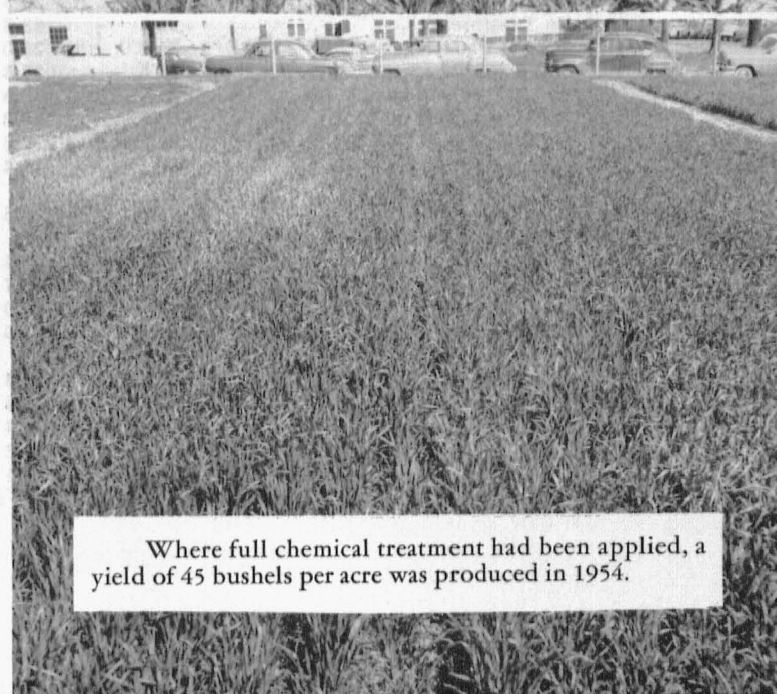
A wide variety of phosphates are available. These materials were compared at the same rate of phosphorus addition on wheat and on barley for a 10-year period on both limed and unlimed soils. Each of the treatments applied at the time of seeding each year



Wheat requires more phosphorus than manure supplies. These pictures, taken in 1954 on Sanborn Field, are of continuous wheat land in the 66th year of cropping. Without treatment it seldom produces enough to cut.



Where 3 tons of manure have been applied, annually, the yield has been increased about 3 bushels for each ton of manure added.



Where full chemical treatment had been applied, a yield of 45 bushels per acre was produced in 1954.

supplied 30 pounds of P_2O_5, except for additional treatments using 60 pounds of P_2O_5 from 20 percent superphosphate and 120 pounds of P_2O_5 from rock phosphate. The yields given in Tables 11 and 12 are averages of three replications.

Although it is now realized that either the rate of phosphorus addition or the amount in the soil was not adequate for optimum yields, the data show crop

TABLE 11 -- EFFECT OF DIFFERENT PHOSPHATE FERTILIZERS ON YIELD OF BARLEY
(1-year rotation - Barley, Lespedeza (hay) plowed for Barley)

	No Lime			Limed		
	Av. first 5 years	Av. last 4 years	Av. 9 years	Av. first 5 years	Av. last 4 years	Av. 9 years
1. Raw bone meal	40.6 bu.	39.4 bu.	40.0 bu.	38.3 bu.	47.4 bu.	42.3 bu.
2. Steam bone meal	36.2	41.1	38.4	36.5	44.1	39.9
3. 20% Superphosphate : blood meal	42.3	42.4	42.3	45.0	48.8	46.7
4. Tri-Calcium phosphate	37.7	37.6	37.6	35.5	44.8	39.6
5. Di-Calcium phosphate	42.4	41.3	41.9	40.3	46.0	42.8
6. Mono-Calcium phosphate	44.2	41.8	43.1	42.9	47.0	44.7
7. Fused phosphate	42.7	40.9	41.9	42.9	45.6	44.1
8. Calcium Meta phosphate	43.5	38.1	40.8	41.2	46.2	43.4
9. No treatment	32.0	29.5	30.9	35.5	39.1	37.1
10. Sodium phosphate	42.1	35.8	39.3	46.5	45.1	45.9
11. 20% Superphosphate at 150 lb.	40.4	38.3	39.5	46.6	47.1	46.8
12. 20% Superphosphate at 300 lb.	41.7	41.7	41.7	47.1	47.5	47.3
13. Rock phosphate 90 lb.	34.6	34.8	34.7	36.9	43.4	39.8
14. Rock phosphate 400 lb.	36.5	36.7	36.6	39.0	43.5	41.0
15. 38% Superphosphate less than 10 mesh	43.3	40.9	42.2	47.2	46.3	46.8
16. 38% Superphosphate larger than 10 mesh	41.9	38.8	40.5	42.8	44.6	43.6
17. 45% Superphosphate	45.4	39.0	42.6	46.6	44.0	45.4
18. No treatment	32.4	33.3	32.8	36.4	41.6	38.7
19. Basic slag	41.2	38.2	39.8	44.4	44.7	44.5
20. Ammonium phosphate	41.4	37.9	39.9	44.3	47.0	45.5
21. 20% Superphosphate + ammonium sulfate	41.1	37.3	39.4	48.0	47.1	47.6
22. 20% Superphosphate + potash	41.9	38.6	40.4	49.4	46.5	48.1
23. No treatment	32.6	29.5	31.2	38.2	38.3	38.2
Average for all	39.9	38.0	39.0	42.2	45.0	43.5
Average no treatment	32.3	30.8	31.6	36.7	39.7	38.0

All plots except where noted received 30 lb P_2O_5 per acre annually at seeding.

TABLE 12 -- EFFECT OF DIFFERENT PHOSPHATE FERTILIZERS ON YIELD OF WHEAT
(1 year rotation wheat-lespedeza (hay) limed for wheat)

	No Lime			Limed		
Material	Av. first 5 years	Av. 2nd 5 years	Av. 10 years	Av. first 5 years	Av. 2nd 5 years	Av. 10 years
1. Raw bone meal	28.0	27.9	28.0	27.3	34.8	31.0
2. Steam bone meal	28.6	28.7	28.6	24.8	33.2	29.0
3. 20% Superphosphate + blood meal	30.8	31.0	30.9	30.1	34.4	32.3
4. Tri-Calcium-Phosphate	27.1	28.0	27.5	23.7	32.3	28.0
5. Di-Calcium-Phosphate	27.5	30.1	28.8	28.7	34.6	31.7
6. Mono-Calcium-Phosphate	28.3	29.2	28.8	28.5	33.7	31.1
7. Fused Phosphate	30.4	29.6	30.0	28.7	33.3	31.0
8. Calcium Meta Phosphate	28.6	29.3	29.0	29.5	33.8	31.7
9. No Treatment	22.7	23.3	23.0	20.5	29.2	24.9
10. Sodium Phosphate	29.2	26.0	27.6	27.8	32.7	30.3
11. 20% Superphosphate 150 lb.	28.4	27.8	28.1	29.8	34.4	32.1
12. 20% Superphosphate 300 lb.	30.7	30.5	30.6	32.0	35.3	33.7
13. Rock Phosphate 90 lb.	26.2	26.8	26.5	23.7	31.5	27.4
14. Rock Phosphate 400 lb.	27.9	27.6	27.7	24.3	31.8	28.1
15. 38% Superphosphate	31.1	29.4	30.2	31.7	34.3	33.0
16. Less than 10 mesh 38% Superphosphate	30.9	28.6	29.8	29.4	33.8	31.6
17. Larger than 10 mesh 38% Superphosphate	30.1	29.4	29.8	29.5	33.6	31.5
18. No treatment	23.9	25.7	24.8	21.7	30.2	26.0
19. Basic Slag	28.5	27.0	27.8	28.8	31.5	30.1
20. Ammonium Phosphate	28.4	29.0	28.7	29.3	34.1	31.8
21. 20% Superphosphate + ammonia sulphate	26.8	28.4	27.6	28.3	35.7	32.0
22. 20% Superphosphate + potash	30.2	28.5	29.3	33.2	37.5	35.5
23. No treatment	21.8	26.4	24.1	21.8	31.6	26.7
Average	28.1	28.2	28.1	27.5	33.4	30.5
Average no treatment	22.8	25.1	24.0	21.3	30.3	25.9

All plots except those where noted received 30 lb. P_2O_5 per acre annually at seeding.

responses to these phosphate materials. Neither the wheat nor the barley produced high yields from rock phosphate, using an application of 400 pounds per acre annually for 10 years. Tri-calcium phosphate gave less crop response than the superphosphates. The differences between other phosphates were not great, indicating that in Missouri there is no great difference in their efficiency for wheat or barley. The addition of 60 pounds of phosphate as 20 percent superphosphate produced only 1- to 2-bushel higher yields than 30 pounds. The responses when either nitrogen or potash was added to the treatments indicate a deficiency of these elements that may have limited the response to the increased rate of phosphate application.

It is of interest that the yields were higher when the particle size of the phosphate was less than 10 mesh than when the granules were larger.

Calcium metaphosphate (63 percent P_2O_5) gave slightly higher yields on unlimed soil and lower yields on limed soil than did the same quantity of phosphorus from 20 percent superphosphate. This is in agreement with findings that this compound is less available to some crops when soils are neutral or alkaline in reaction.

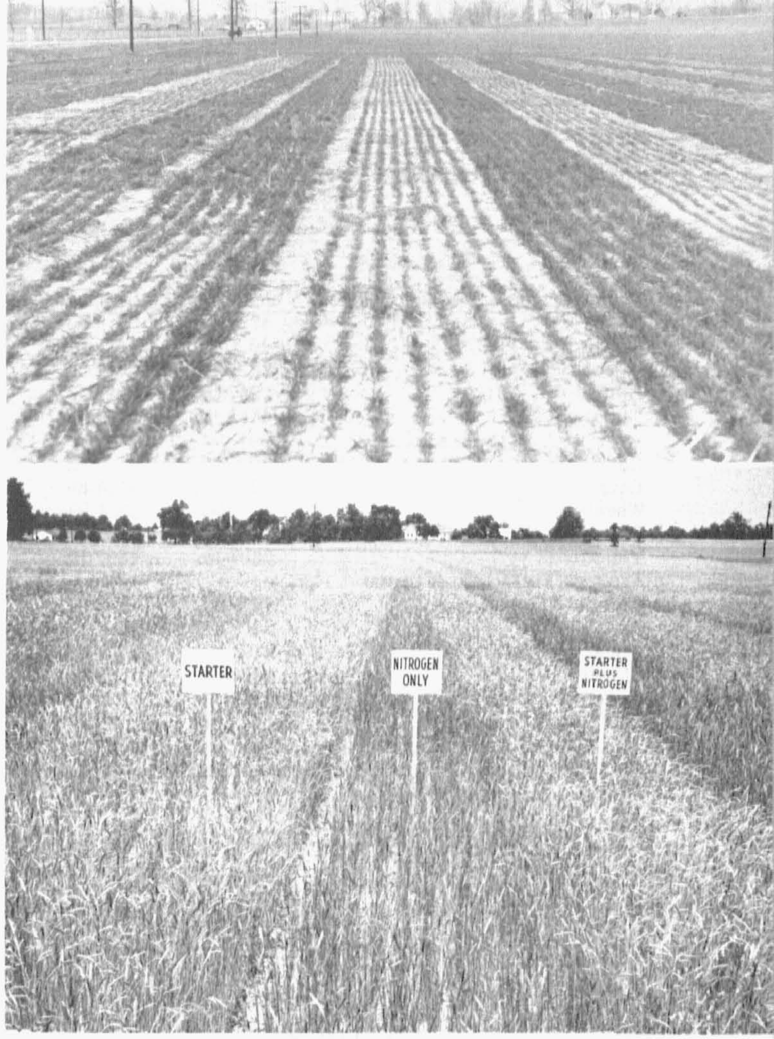
Average yields were higher when the soil was limed. The lime greatly increased the growth of lespedeza and it is probable that the additional fixation of nitrogen by the legume was partially responsible for these higher yields.

When the soil was not limed the yields of both wheat and barley were slightly lower where 20 percent superphosphate had been applied than where the phosphates of higher analysis had been used. However, on the limed soils, the 20 percent superphosphate gave the largest increase. It is suggested that the 20 percent superphosphate may have contained other compounds (sulfur or trace elements) that exerted some benefit through the legumes after the soils were limed to provide the necessary calcium.

These results indicate that under most soil conditions, there will be little difference in the response by small grain to different phosphate fertilizers when the phosphorus is in an available form, as shown by phosphorus availability tests now in use.

Rock Phosphate in Rotation Systems

Rock phosphate cannot be used by small grains as effectively as the more soluble phosphates. However, other plants (particularly legumes) can absorb phosphorus from the pulverized rock form or, by absorbing the calcium from rock phosphate, can leave the phosphorus in the form more available for other crops. When legume residues are returned to the soil, their phosphorus content becomes available to other crops in the rotation.



Field experiments show the needs of individual soils and aid in the interpretation of soil tests. Top: The need for both nitrogen and phosphorus was evident in early spring. The center drill width received only nitrogen. The two on the left received starter fertilizer at time of planting and the heavy strip at right received starter fertilizer and a fall application of nitrogen. Bottom: The same treatments as shown above at time of harvest.

In experiments on Sanborn Field comparing rock phosphate and superphosphate in rotations with corn, small grains, and grass-legume mixtures (Table 13), the yields of oats and wheat were higher during the first two rounds of the rotation where superphosphate was applied. However, in recent years the highest production has been obtained where rock phosphate was the source of phosphorus. The soil has not been limed and since clover yields have been highest where rock phosphate was used, it is suggested that the calcium added in the rock phosphate has aided the clover growth and the phosphorus released through it has been made available to grain crops following.

In experiments where red clover has been grown in a two-year rotation with wheat on Putnam silt loam with fertility above average, the rock phosphate ap-

TABLE 13 -- COMPARISON OF SUPERPHOSPHATE AND ROCK PHOSPHATE
(Sanborn Field)

Average Yield - 1915-1949	Manure,* Super-phosphate	Manure,* Rock Phosphate
Corn	62.1 bu.	62.5 bu.
Oats	40.3 bu.	46.1 bu.
Wheat	28.8 bu.	26.9 bu.
Clover	2947 lb.	3673 lb.
Timothy (2 yr.)	4421 lb.	4515 lb.
Average Yield First 2 Crops		
Corn	40.6 bu.	45.8 bu.
Oats	42.4 bu.	49.4 bu.
Wheat	35.5 bu.	28.4 bu.
Clover	3941 lb.	5201 lb.
Timothy (2 yr.)	5807 lb.	4897 lb.
Average Yield Last 2 Crops		
Corn	78.5 bu.	76.8 bu.
Oats	35.5 bu.	45.8 bu.
Wheat	21.2 bu.	23.8 bu.
Clover	2634 lb.	3087 lb.
Timothy (2 yr.)	1852 lb.	2570 lb.

*Both plots received 8 T. manure before corn and 3 T. on wheat and second grass. Superphosphate applied @ 48 lbs. P_2O_5 on corn and wheat. Rock Phosphate applied @ 1000 lb. per acre each 6 years before corn.

plied at the rate of 1500 pounds per acre once each six years has given yields of wheat only slightly below those obtained from superphosphate (Table 14). When the experiment was started, this soil gave little response to potassium application but after seven years it was evident that potassium deficiency was limiting the yields. After the potassium was added, the yields of wheat with rock phosphate were equivalent to those obtained with superphosphate.

TABLE 14 -- YIELDS OF WHEAT AND RED CLOVER IN 2 YEAR ROTATION RECEIVING VARIOUS SOIL TREATMENT

Soil Treatment	Wheat	Red Clover
	7-year average 1939-1945	
2 tons limestone	15.6 bu.	2573* lb.
2 tons limestone 100 lb. 0-38-0	21.7	2366
2 tons limestone 1500 lb. rock phosphate	20.7	2655
1500 lb. rock phosphate	22.7	2885
100 lb. 0-38-0 500 lb. fine lime with clover	26.8	3082
	6-year average 1946-1951	
2 tons limestone	20.9	2186* lb.
2 tons limestone 100 lb. 0-40-0	27.3	2758
2 tons limestone 100 lb. 0-40-40	31.8	3098
2 tons limestone 1500 lb. rock phosphate 0-0-40 with wheat	30.2	3270
1500 lb. rock phosphate 100 lb. 0-0-40 with wheat	30.2	3406
100 lb. 0-40-40 500 lb. fine lime with wheat	31.6	3411

*In some seasons the clover hay was from 1/4 to 1/3 weeds.

It is also of interest that yields were slightly higher where rock phosphate was used alone than where limestone was added. Apparently two applications (3000 pounds) of rock phosphate alone furnished a sufficient supply of both calcium and phosphorus to the clover in this cropping system to be almost equal to the separate treatments of limestone and superphosphate.

This fertility practice of using clover in a two-year rotation with wheat is not advised since it is seldom practical to keep this much clover in a cropping system. In fact, after 13 years it was necessary to abandon it because of the inroads of biennial species of weeds in all plots. Although there are soils and cropping systems where rock phosphate may supply adequate phosphorus for small grains, it is advisable to also use a starter that contains considerable phosphorus in a quickly available form to provide adequate quantities of this element early in growth. This is particularly true when increased amounts of nitrogen fertilizer are added.

Potassium on Small Grains

On a large portion of the soils in Missouri, crops of small grains will show little response to potash fertilizers unless they have been limed and legumes have been removed for hay or unless heavy applications of nitrogen have been made. The silt minerals serving as reserve fertility in many of the acid soils will break down and supply sufficient potassium to balance the levels of other nutrients before the more common deficiencies of phosphorus, calcium, and nitrogen are corrected. After liming, the rate of potash breakdown from soil minerals is reduced.

Legumes remove more potassium than do grains. The higher yields obtained from additional phosphate and nitrogen magnify the need for potassium. In experiments on many soils where fertilizers were applied in the row, potassium fertilizer did not give response until from five to 10 years after liming. However, symptoms of potassium deficiency developed after this period and other fertilizer elements failed to give their expected responses.

Table 15 shows typical responses by small grains to treatments made to a soil requiring only lime, phosphorus, and nitrogen or where soil tests showed an adequate level of potassium. In rotations where red clover, soybeans or lespedeza were grown and removed for hay, the response to potassium was significant after two or three rounds of the rotation (1945-1949). Where sweet clover was used as the legume and was turned under as a green manure crop, the potassium level of the soil remained higher and the addition of this element in the starter fertilizer had little effect.

When the experiments were first started, the application of superphosphate with the grains gave good

TABLE 15 -- EFFECT OF STARTER FERTILIZERS ON YIELDS OF SMALL GRAIN. EXPERIMENTS CONDUCTED FOR 14 YEARS -- 1936-1949

Cropping System	Soil Treatment (lb. per acre)	Wheat 1936-40	Wheat 1945-49	Oats 1936-40	Oats 1945-49	Barley 1936-40	Barley 1945-49
Soybeans, Barley	None			29.9	17.8	25.6	19.8
+ Lespedeza, Oats	0-20-0 @ 150			37.3	22.7	35.2	30.0
+ Lespedeza.	0-20-10 @ 150			----	23.9	----	34.6
Corn - Wheat,	0-20-0 @ 150, lime			41.8	25.7	36.0	29.8
Red Clover	0-20-10 @ 150, lime			----	25.9	----	36.8
One year Rotations							
Barley-Soybeans	None	17.3	14.3	27.6	13.6	10.1	8.5
Oats-Lespedeza	0-20-0 @ 150	23.7	19.7	35.4	18.6	17.9	14.9
Wheat-Lespedeza	0-20-10 @ 150	----	24.6	----	16.7	----	16.4
	0-20-0 @ 150, lime	24.9	21.7	43.3	21.2	23.5	15.8
	0-20-10 @ 150, lime	----	26.1	----	21.5	----	25.0
Corn, Oats +	None	17.2	21.4	44.7	24.6		
Soybeans, Wheat +	0-20-0 @ 150	22.9	33.0	51.2	30.9		
Soybeans	0-20-10 @ 150	----	34.2	----	35.6		
	0-20-0 @ 150, lime	24.4	33.1	51.9	29.0		
	0-20-10 @ 150, lime	----	35.9	----	35.6		
Corn, Oats, Wheat,	Lime	27.2	33.7	43.8	30.9		
Sweet Clover	Lime + 0-20-0 @ 150	34.9	37.2	60.7	35.2		
	Lime + 0-20-10 @ 150	34.7	38.8	61.3	39.1		

response. However, after about five years, particularly when straw and legume hay were removed, the effect of phosphate fertilizer became less significant and visible symptoms of potassium deficiency (marginal leaf burning and lodging) were evident. When potassium was added to the fertilizer, both the plant vigor and the yield were noticeably improved.

After the soil tests were developed, they served as a means of determining the level of potassium and other essential elements in the soil. Although availability of potassium will depend on soil moisture, previous crop, type of clay in the soil and many other factors, these tests indicate whether the soil mineral reserves are adequate to prevent potassium from being a limiting element. Soil tests are not yet sufficiently sensitive to suggest the specific mixed starter fertilizers to be used.

Nitrogen—Key to Increased Production

Nitrogen is a constituent of proteins. On many soils there is a struggle by plants to secure sufficient nitrogen to satisfy their need for protein in growth processes. The availability of synthetic nitrogen has lessened the emphasis on soil humus, farm manures, and legumes to supply this all important element. In recent years mixed fertilizers applied when small grains are seeded have contained a higher percentage of nitrogen.

Nitrogen for Small Grains

The availability of chemical nitrogen fertilizers since 1946 has altered the program of soil treatment for small grains on many farms. Experiments with liberal additions of nitrogen have shown this element to be the limiting factor in production on numerous soils.

When small grains are produced on fields having adequate levels of mineral fertility (either naturally or through fertilizer addition) the soil nitrogen available from organic matter or from the residues of decaying legumes is seldom adequate to produce the highest yields. About 2 pounds of nitrogen are required from the soil to produce 1 bushel of wheat. A soil with 3 percent organic matter will release from 30 to 60 pounds of nitrogen during the period of the year when small grains are actually growing, or enough for a yield of 15 to 30 bushels per acre. For a 40-bushel crop on this type of soil, 35 to 50 pounds of additional nitrogen are usually needed. A portion of this may be applied at the time of seeding and the remainder as a top dressing, either late in the fall or early in the spring.

The response by the growing crop to added nitrogen fertilizer will depend on the amount delivered by the soil. Some experiments have shown that the response has been disappointing, when nitrogen in amounts of 30 to 40 pounds per acre was added to soils deficient in other minerals. To obtain satisfactory increases in growth from added nitrogen fertilizers, the minimum soil level (according to Missouri soil

Barley responds to adequate soil fertility. The grain, top left, received minerals but no nitrogen. The heads are erect but poorly filled. On the right, where top-dressed with nitrogen, the yield was increased nearly 25 bushels per acre. Below: These well-filled heads carry sufficient weight to cause some lodging.

tests) should be 125 pounds of phosphate and 200 pounds of potassium. When mineral levels in the soil are adequate, the use of nitrogen has produced average increases in yield of about 1 bushel of wheat for each 3 pounds of nitrogen applied. The data given in Table 16 summarize results from 76 trials where from 33 to 40 pounds of nitrogen per acre were applied as a spring top-dressing for wheat.

Similar results have been obtained with barley and oats. Barley is one of the crops most responsive to adequate fertilization. Although the responses differed widely, depending on the amount of nitrogen delivered by the soil, increases in yield of 20 bushels of barley per acre were common when from 30 to 40 pounds of nitrogen were top-dressed on soils well supplied with minerals. In some areas the application of nitrogen in the fall, as illustrated in Table 17, im-

TABLE 17 -- EFFECT OF FERTILIZERS ON YIELD OF BARLEY, ANDREW COUNTY
(Marshall Silt Loam)

Soil Treatment (lb. per acre)	Yield
None	36.2
0-20-10 @ 150	43.1
0-20-10 @ 150 + 33 N at seeding	69.8
0-20-10 @ 150 + 33 N spring	60.9

proved fall growth, decreased winter killing and produced higher yields than where the same quantity of nitrogen was applied in the spring. For both wheat and barley, liberal quantities of nitrogen in the starter fertilizers, have been been beneficial when soils contained a small amount of available nitrogen at time of seeding. Spring top dressings of additional nitrogen have further increased yields.

Forms of Nitrogen for Small Grains

The supplies of chemical nitrogen fertilizers were not sufficient to meet agricultural demand until the 1954 season and all forms were widely used. Experiments have demonstrated only minor differences in small grain responses to chemical nitrogen from different sources when properly applied. Ammonium nitrate (33½ percent N), Ammonium sulfate (21 percent N), Urea (42 to 45 percent N), sodium nitrate (16 percent N), Cyanamid (21 percent N), and other solid materials have been used regularly with good results. There has been increased interest recently in anhydrous ammonia or a mixture of anhydrous ammonia with solutions of either ammonium nitrate or urea (solution nitrogen) for application to small grain, particularly in the fall.

TABLE 16 -- RESPONSE OF WHEAT TO CHEMICAL NITROGEN
(1946-1953)

		Yield Bu. Per Acre		
No. of Trials	Area of State	No Nitrogen	33-40 lb. Nitrogen	Increase for Nitrogen
9	Dark soils, Northwest and Central Mo.	22.0	33.0	11.0
9	Well-drained bottom soils	14.8	26.1	11.3
11	Heavy bottom soils	10.9	20.5	9.7
16	Gray prairie soils Northeast Mo.	18.3	28.3	10.0
12	Timbered soils of Northeast and Ozark Uplands	19.8	31.9	12.1
11	Light-colored soils Southwest Mo.	20.3	30.0	9.7
8	Southeast Mo.	22.7	34.3	11.6

TABLE 18 -- RESPONSE OF WHEAT TO ANHYDROUS AMMONIA -- 1950

Soil Type	No Nitrogen Bu./A.	Nitrogen Lb./A.	Bu./A.	Difference
Wabash silt loam	15.4	40	29.8	14.4
Marshall silt loam	11.1	40	15.3	4.2
Sandy loam	17.9	40	27.3	9.4
Waukesha silt loam	30.0	32	34.7	4.7
Av. 4 comparisons	18.6	38	26.8	8.2

Anhydrous ammonia was applied late in spring.

Comparison of Anhydrous Ammonia and Ammonium Nitrate

Soil Type	No Nitrogen	Nitrogen (40 lbs. per acre): Ammonium Nitrate	Nitrogen (40 lbs. per acre): Anhydrous Ammonia
Sandy Loam	17.9	28.1	27.3

Anhydrous ammonia is a gas at ordinary temperatures and pressure, but is a liquid containing 82 percent of nitrogen when highly compressed. In the liquid form, it exerts a pressure of almost 200 pounds per square inch at 100° F. and special equipment is required for storage and application. It must be applied by means of special applicators and at a depth of at least 6 inches in moist soil. Application of ammonia should be avoided when soils are excessively wet or dry. The ammonia gas is rapidly adsorbed by moist soil and is a good source of nitrogen for small grain.

If ammonia is applied to growing small grains, considerable mechanical damage may be done to the young plants by the applicators. Running equipment across, rather than with, the drill rows keeps the damage to a minimum. Since fields are usually drilled in the long direction of the field, the application of anhydrous ammonia often has to be made along the short axis with considerable turning. Although a large number of plants may be uprooted by the applicator, the added nitrogen has increased stooling, improved yields, and made the application profitable. In a limited number of experiments, as shown in Table 18, the increases have been about the same as where the same quantity of nitrogen was applied as ammonium nitrate.

In calculating the cost of anhydrous ammonia, both the cost of material and the cost of application should be considered. For example, if the cost of application is \$2.60 per acre and only 40 pounds are applied, this amounts to 5½ cents per pound for applying. If 100 pounds per acre are used, then the cost of application is only 2.6 cents per pound. Costs will be less per pound of nitrogen as the rate per acre is increased.

Increased production of anhydrous ammonia and a lower cost per unit of nitrogen in this form than in some other nitrogen compounds has stimulated interest in preplanting applications for small grains. Results (Table 19) indicate that on silt loam soil in the eastern part of the state the anhydrous ammonia was as satisfactory when applied before planting wheat as it was when applied after the plants started growth, or where solid forms of nitrogen were top-dressed.

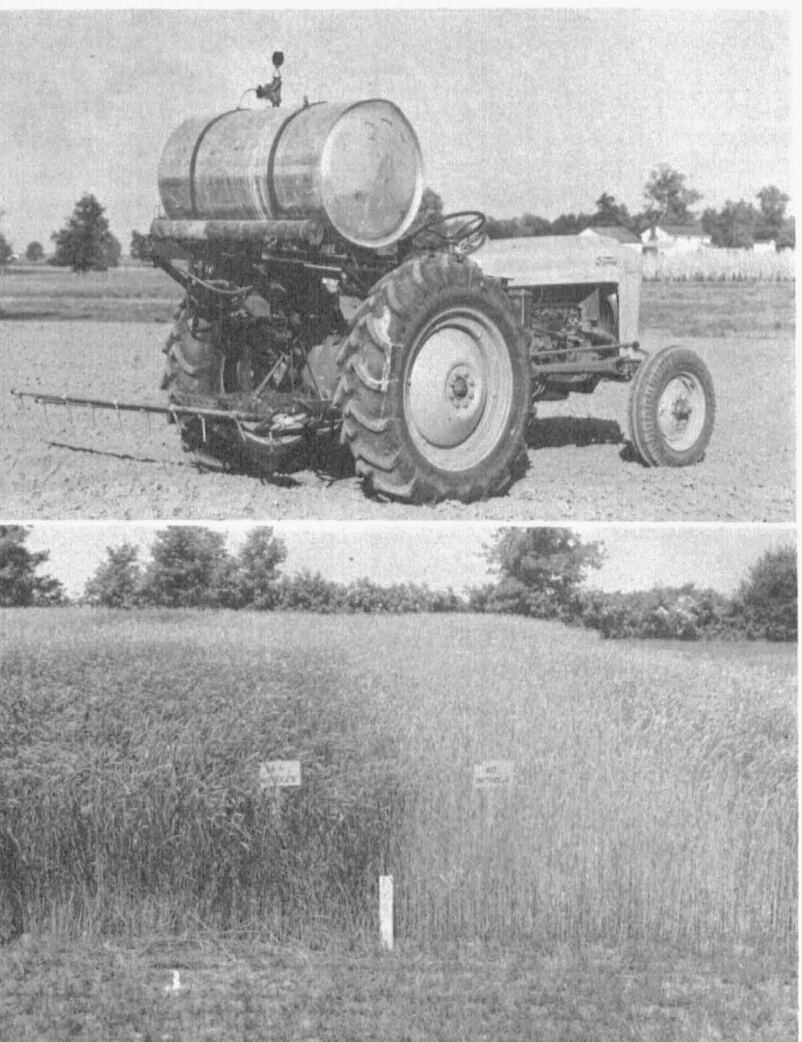
Anhydrous ammonia has given good response on small grains. Applying this material under the soil damages the stand (top picture). However, stooling is increased and response is about the same as from the solid forms of nitrogen. There is a trend to ammonia application before seeding. This pre-planting application has given good results except on the most sandy soils. The lower picture shows the fall growth of barley where ammonia was applied before planting at 20-inch spacing.

TABLE 19 -- TIME AND SOURCE OF NITROGEN APPLICATION FOR WHEAT
(Weldon Silt Loam -- 1954)

Source (lb. per acre)	Time of Application		
	Before Seeding	December	March
No Fertilizer	10.0 bu.		
Starter only	14.9		
Ammonium Nitrate 30 N	24.0	24.4	22.8
Ammonium Nitrate 60 N	29.4	31.5	32.8
Ammonium Sulfate 30 N	24.9	25.7	21.6
Ammonium Sulfate 60 N	31.5	28.9	31.1
Urea 30 N	25.7		28.3
Urea 60 N	33.0		30.9
Anhydrous ammonia 30 N	31.1	25.7	26.4
Anhydrous ammonia 60 N	34.4	31.4	23.5
Solution 32* 30 N	29.7	27.1	28.3
Solution 32 60 N	30.4	35.3	30.9
Solution 2A** 60 N (surface)	28.9	28.7	26.4
Solution 2A 60 N (disced in)	31.5		
Solution 2A 60 N (deep)	30.5		
L. S. D. - 1% - 5.38:5% - 4.14			

*Products of Allied Chemical and Dye Co. One-half Urea, one-half Ammonium Nitrate.
**41% N - 22% Volatile Ammonia, 65% Ammonium Nitrate and 12.8% water.

Nitrogen materials in solution can be pumped or moved by air pressure, thus reducing labor. Here is an experimental applicator for applying non-pressure solutions on the surface of the soil. Under farm conditions, the application boom can be made longer. The lower picture shows the effect of 66 pounds of nitrogen as non-pressure solution applied on wheat. The yield was increased 20 bushels per acre. When solutions contain ammonia they should be placed in the soil.



Other data indicate that on very sandy soils, where nitrogen may be lost through leaching, the spring applications may give better results.

It appears that where anhydrous ammonia is to be used on small grain, the material should be applied before planting on all except sandy soils. Nitrogen applied at seeding has given good response (see Table 19) and pre-planting applications will eliminate injury to plants.

Solution Nitrogen Materials

A number of solution nitrogen materials are on the market for direct application to the soil. Some contain free ammonia and have the same limitations for application to small grain that were described for anhydrous ammonia. However, these solution materials exert a much lower pressure and can be handled with less expensive equipment.

One solution containing 32 percent nitrogen contains half of it in ammonium nitrate and half in urea. This material can be sprayed on the surface of growing small grain without loss of nitrogen or injury to plants. It has the advantage of eliminating heavy lifting since it can be pumped or moved by air pressure. It does not require pressure equipment for handling. However, the tanks, pumps and sprayers must be made of non-corrosive materials. This solution has given test results equivalent to those from other forms of nitrogen on a number of crops (Table 19).

Experimental results and farmer experience indicate that applications of 30 to 60 pounds of nitrogen from this non-pressure solution may be sprayed on small grains without significant damage to the foliage, if applied before the plants are 6 inches high. If small grain is to be pastured, livestock should not be turned into the field until a rain has washed the material from the leaves. The nitrate adhering to the leaves could be consumed in sufficient quantity to be toxic.

More recently, nitrogen in water solutions that are a mixture of ammonium nitrate and anhydrous ammonia have been used for direct application to the soil. These solutions exert only low pressure (less than 10 pounds at 100° F. and no pressure at from 60 to 70° F.) They have given good results with small grain (Table 19) but they must be applied under the soil to prevent a loss of ammonia.

Satisfactory results have been obtained by applying the material to moist soil at the time of discing the seed bed for small grains.

In some seasons sufficient grain may be shattered to give thick volunteer stands. A grain drill will get fertilizers down to the roots and stimulate growth for fall pasture. Volunteer stands are usually undesirable for grain as germination is too early and stands are too thick.

Time of Applying Nitrogen for Wheat and Barley

Nitrogen may leach from some soils if applied when plants are not growing actively enough to use it. It has been the general practice to make top-dressings of solid materials such as ammonium nitrate, ammonium sulfate, sodium nitrate or urea to small grains in late winter or early spring when growth is starting. This practice is advisable if soils are sandy. However, the soils are soft in many spring seasons and it may be difficult to make the applications until too late for maximum benefit.

Experiments have shown that on soils, where leaching is not a problem, the nitrogen may be applied at any time from seeding until late March or early April. Where soils are particularly low in nitrogen, maximum benefits are frequently obtained when the nitrogen is applied at time of seeding. Particularly good response has been obtained by applying nitrogen at the time of seeding in the fall when the small grain follows soybeans or lespedeza. In most cases late fall top-dressings have been equivalent to those made in the spring (Tables 20 and 21). Where soft ground delays spring application, the fall or winter top-dressings are to be desired.

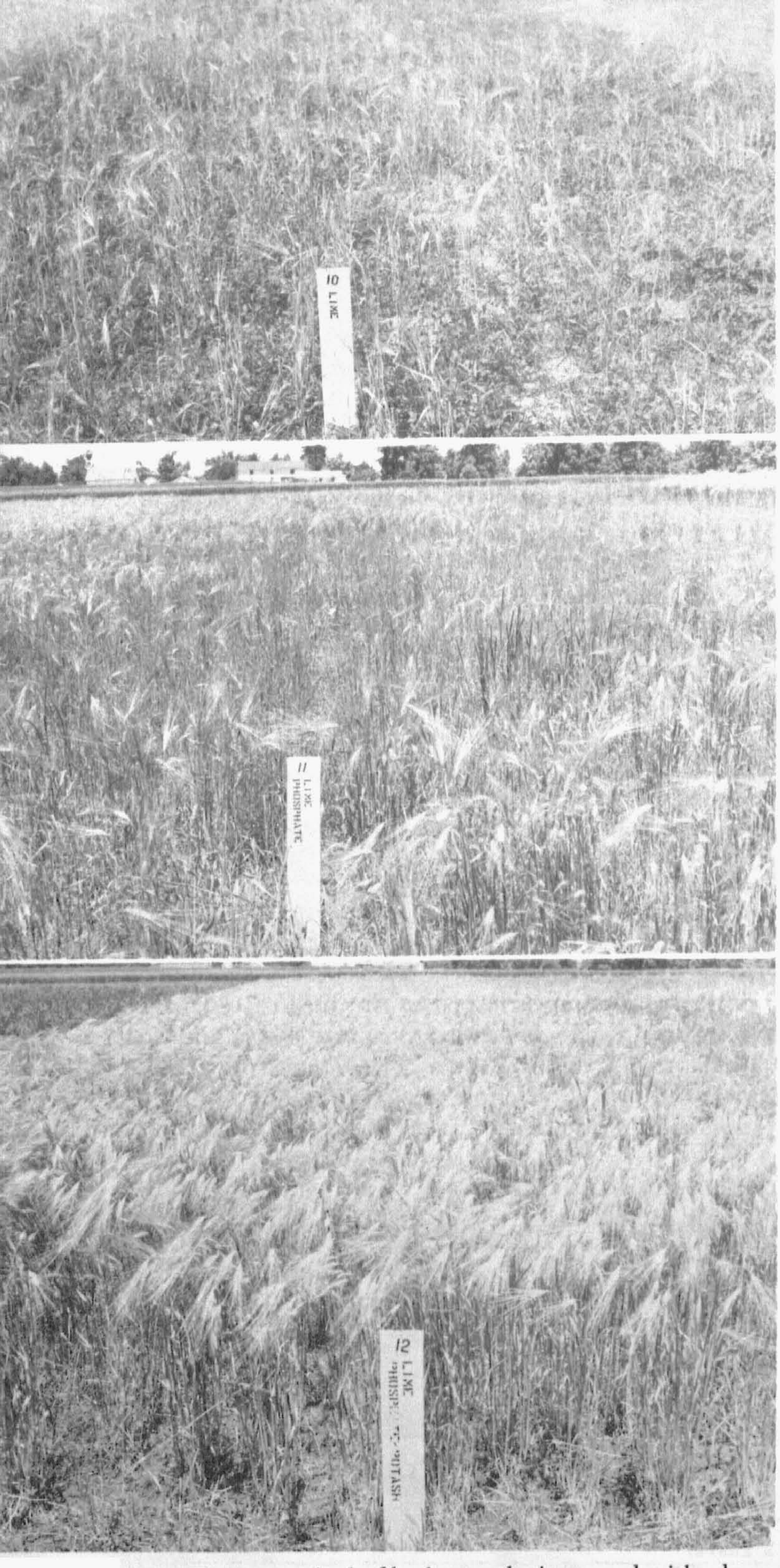
TABLE 20 -- TIME OF APPLYING NITROGEN TO SMALL GRAIN
(Putnam Silt Loam)

Amount and Time (lb. per acre)	Barley Bu. 1950	1951	1952	3-Year Av.	Wheat Bu. 1950	1951	1952	3-Year Av.
No Nitrogen	17.0	43.8	33.0	31.3	18.2	38.4	18.1	24.9
33 N seeding	31.6	71.6	48.2	50.5	30.0	43.6	20.1	34.6
33 N November	27.3	73.8	46.0	49.0	29.0	44.4	23.5	32.3
33 N March	24.2	70.6	44.8	46.5	27.0	47.7	26.9	33.8
33 N seeding 33 N March	25.6	70.1	51.9	49.2	33.0	43.8	26.9	31.6
66 N March	24.9	68.6	44.5	46.0	29.0	44.2	27.4	33.5
33 N May	16.9	45.3	38.5	33.6	24.0	40.5	20.9	28.5

TABLE 21 -- WHEAT YIELDS AS INFLUENCED BY TIME OF NITROGEN APPLICATION
(Average 2 Years)

Soil Treatment (lb. per acre)	Fine Sandy	Sandy Loam	Silt* Loam	Silt Loam	Silt Loam	Sandy Clay	Clay	Clay
None	13.9	23.4	19.1	28.2	23.7	27.4	18.4	21.6
0 - N + Starter	22.0	30.2	28.8	36.2	37.8	36.4	31.5	28.4
33 N Seeding + Starter	27.5	37.0	37.9	37.0	45.1	39.0	35.1	28.8
33 N Spring + Starter	34.0	37.0	40.1	41.4	45.4	38.0	41.4	33.4
66 N Seeding + Starter	33.8	38.8	40.0	40.4	49.3	38.9	35.9	33.2
66 N December + Starter	38.0	40.2	42.4	42.2	50.6	39.6	40.8	35.4
66 N Spring + Starter	34.6	40.7	43.7	42.2	46.4	40.4	41.1	40.2
66 N Spring + 300 3-12-12	35.8	43.0	39.6	43.0	48.2	41.6	40.9	39.6

*Starter fertilizer was 8-24-8 @ 300 lb. per acre on this soil; 300 lb. 12-12-12 on other locations.



Winter survival of barley can be increased with adequate soil treatment. Winter barley plots in these three pictures were planted at the same time. In the top picture, soil was deficient in phosphorus and the crop winter killed. The soil in the center picture was deficient in potassium. Addition of phosphate alone did not bring profitable production. The barley in the lower picture received adequate phosphorus and potassium. Plants were able to withstand the severe winter and produce more than 60 bushels per acre.

When top-dressing is delayed beyond April 1, (Figure 2) the percentage protein in the grain increases but the yield declines. Apparently after some critical physiological period in plant growth (probably cell differentiation for jointing or formation of heads to suggest the shift from vegetative growth to reproductive activities) the plant cannot utilize the added nitrogen for increasing the formation of more grain, but puts it into the filling of the endosperm for more protein there. Seemingly, the added nitrogen is simply translocated to the seed with little effect on vegetative growth or yield.

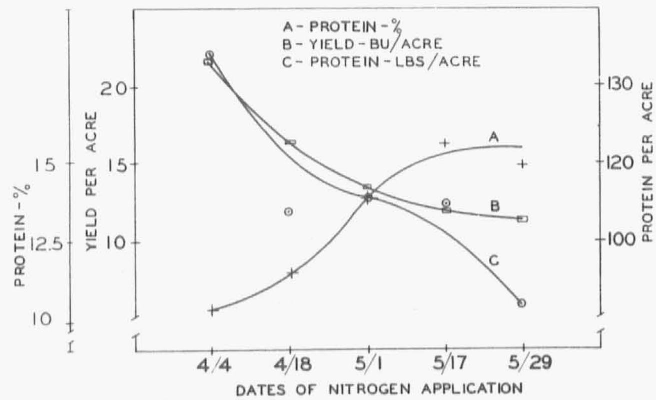


Fig. 2—As the date of nitrogen application on wheat is delayed, the protein as percentage in the grain goes up (curve A). But yields as bushels of grain (curve B) and as pounds of total protein (curve C) per acre both go down. (Data by R. L. Lovvorn and M. F. Miller, Missouri Agricultural Experiment Station.)

It appears that on fall seeded small grain, the nitrogen may be applied with equal effects any time from preplanting until active growth begins in the spring. On sandy soils or those subject to erosion, the starter fertilizer should contain a liberal amount of nitrogen and the top-dressing application should be delayed until spring.

Where fall seeded small grain is planted on land plowed in midsummer, a larger amount of nitrogen becomes available from soil organic matter. In these cases a starter fertilizer that will furnish 8 to 12 pounds of nitrogen (300 pounds of 3-12-12 or 4-12-8) may be adequate. If the land is not prepared until just before seeding or where the preceding crop is lespedeza or soybeans, then the starter fertilizer should furnish at least 30 pounds of nitrogen (300 pounds per acre of 10-10-10 or 12-12-12, assuming that phosphorus and potassium are also needed). Frequently it is more economical to use a mixed fertilizer containing a low amount of nitrogen and make a separate application of a nitrogen fertilizer than to use a mixed fertilizer with a high nitrogen content.

Research work now in progress* indicates that the time of nitrogen application and other variations in soil treatments can have a pronounced effect on the composition of grain. The protein and mineral content of the wheat germ (embryo or reproductive portion, high in protein) is affected differently than that of the starchy portion (endosperm) which is the storage tissue used principally in sustaining the germinating seedling, and commonly made into flour or feed. The protein content of the embryo has been influenced less than has the storage tissue by applications of fertilizer nitrogen. Wheat crops that have given the highest yields have not necessarily given the best germination or the most seedling vigor. Some seed from low-yielding experimental areas has produced the most vigorous seedlings.

It appears that to perpetuate the species, the plants from the embryo as a primary process early in the plant's life. The endosperm of starch or storage tissue, which is the bulk and common measure of yields, is laid down as a secondary process coming late in the plant's growth period. The addition of phosphate fertilizers has not affected grain composition, but the addition of large amounts of nitrogen reduced the phosphorus content of the embryo.

The effects of these soil treatments on grain composition and seedling emergence have not been noted to any extent in the field. Rates of seeding are usually two times the amount required. This increased rate of planting compensates for the many unknowns in seed quality. But research results are pointing to the changes that can be effected by soil fertility in the makeup of grain. Soil treatment effects show the need for additional experimental work on soil factors affecting the formation of the seed, its vigor in guaranteeing the next crop, and the food quality of the products manufactured from grains.

Residual Effects of Nitrogen

Corn receives the heaviest applications of nitrogen applied to most crops. When these applications are made according to soil tests, a considerable portion of the nitrogen will remain in some soils after the corn is harvested. (When nutrient additions have been less than that removed by the corn, these residual effects have been negligible). In experiments conducted on Putnam silt loam, where 66 pounds of nitrogen per acre were applied for corn following different legumes (Table 22), the average increase in yield during three years from the wheat, unfertilized and following the corn in the rotation, has been 2.9 bushels per acre. At current prices, this residual effect on the wheat is sufficient to pay for most of the nitrogen applied to the

*Robert L. Fox, Ph.D. Thesis, University of Missouri.

TABLE 22 -- EFFECT OF RESIDUAL NITROGEN APPLIED TO CORN ON THE FOLLOWING WHEAT CROP
(3 Year Average)*

Rotation: Corn, Wheat, Legume	Putnam Silt Loam — Nitrogen Applied to Corn	
Legume	None	66
Red Clover	18.6 bu.	21.6 bu.
Sweet Clover	18.1	21.9
Lespedeza	15.7	18.2
Soybeans	17.6	19.2
Average	17.5	20.4

*200 pounds per acre of 0-20-20 applied when wheat was seeded.

previous corn crop. In a rotation of corn, wheat, and timothy with different amounts of nitrogen applied to corn, the heavier applications have given striking residual effects. These are shown in Table 23.

TABLE 23 -- RESIDUAL EFFECT OF NITROGEN APPLIED TO CORN ON THE YIELD OF WHEAT
Rotation: Corn, Wheat, Timothy - 3 year average

Nitrogen Applied to Corn	Yield of Wheat
0 lb.	16.4 bu.
33	16.8
66	17.5
132	18.4
200	22.4

In one year (1951) the yield of wheat was 5.3 bushels per acre higher following the 200 pound application than where 132 pounds were applied and 12.3 bushels greater than where no nitrogen had been applied to corn.

The residual effect of nitrogen, applied to corn, on the following oat crop will depend on the amount of nitrogen added, the type of soil, the amount of residues returned, and the season. When the spring weather is cold and wet, and when the nitrogen in soil organic matter is not released, then the effect of the added fertilizer nitrogen on the oats may be striking.

This rye field shows the residual effect of fertilizer applied in watermelon hills the previous year. Applications of fertilizer to rebuild nutrient reserves will increase crop yields for more than one season. The carry-over effect on small grain from the previous year's treatment may be sufficient to repay the entire cost.

In one experiment on Marshall silt loam, shown in Table 24, the yield of oats was increased 7.8 bushels by 66 pounds of nitrogen applied to the previous corn crop. It was further increased to 10.7 bushels when 130 pounds of nitrogen were applied.

TABLE 24 -- RESIDUAL EFFECT OF NITROGEN APPLIED TO CORN ON THE FOLLOWING OAT CROP

Marshall Silt Loam 1952
(8-24-8 @ 100 lb.) applied to oats

Fertilizer Applied to Corn	Yield of Oats
No fertilizer	40.8
200 lb. 8-24-8	40.0
200 lb. 8-24-8, 66 lb. N	48.6
200 lb. 8-24-8, 130 lb. N	51.5

In other trials on Marshall silt loam (open subsoil) and Putnam silt loam (heavy subsoil), nitrogen applied to the corn was not all used by the corn crop (Table 25). Where 100 pounds of nitrogen were applied to the corn, the yield of oats that followed the next year on the Putnam silt loam was increased more than 6 bushels per acre and on Marshall silt loam more than 10 bushels. Yields of oats were further increased when additional nitrogen was applied.

TABLE 25 -- YIELD OF OATS FOLLOWING CORN AS INFLUENCED BY NITROGEN APPLIED TO CORN

Nitrogen Applied to Corn	Putnam Silt Loam Oats	Marshall Silt Loam Oats
0	28.9 bu.	40.8 bu.
30	28.6	----
60	----	48.6
100	35.6	51.5
200	46.9	----
300	58.1	----

In one season on the Putnam soil where oats followed the application of 100 pounds of nitrogen on corn, the yield was increased by 11.1 bushels. Where 200 pounds of nitrogen were applied the yield was increased by 18 bushels. Where 300 pounds of nitrogen were plowed down for corn the residual nitrogen increased oat yields by 29.2 bushels.

The residual effect of nitrogen will be the greatest on soils with a high percentage of clay in the subsoil. If stands of corn are thick and a large amount of residue is returned, it will probably be profitable to make additional nitrogen applications to the oat crop.

Oats Respond to Adequate Soil Fertility

Oats have received comparatively little fertilizer because the returns from such soil treatments have been larger on other crops in the cropping sequence. The response to direct applications of fertilizers by oats is similar to that by the other grains which normally have a higher value per bushel. If best yields are to be obtained, liberal supplies of nutrients must be supplied. When price relationships are favorable, the application of mixed fertilizers when drilling the oats is profitable.

The results given in Table 26 were obtained on a soil low in both calcium and phosphorus but containing adequate potassium. The addition of 30 pounds of phosphate (150 pounds of 20 percent superphosphate) increased the yields from 7 to 10 bushels per acre over a 10-year period. In most areas, the nitrogen was the element which was limiting the yields since when corn preceded the oats or where either soybeans or lespedeza were removed the amount of nitrogen remaining in the soil for the oats was inadequate.

In 44 trials on various soils, the addition of 33 pounds of nitrogen per acre increased the yields of oats more than 21 bushels per acre (Table 27).

Early seeding is essential to prevent a reduction in oats yields by hot weather in June. Top: Seedbeds have often been prepared hastily by discing corn fields in early spring. While oats seldom receive fertilizer, they would respond profitably to it. The oats crop in the lower picture was planted after corn and received 150 pounds of 0-20-20 fertilizer at seeding. On the left, where 66 pounds of nitrogen was broadcast immediately after seeding, the yield was increased more than 30 bushels per acre.

TABLE 26 -- EFFECT OF FERTILIZERS AND LIME ON YIELD OF OATS
(Putnam Silt Loam 9-year average)

Cropping Systems	No Fertilizer	0-20-0 @ 150 lb.	0-20-20 @ 150 lb.	Lime 0-20-0 @ 150 lb.	Lime 0-20-20 @ 150 lb.
Oats + Lespedeza	13.1	23.4	22.6	28.0	28.4
Soybeans, Barley + Lespedeza, Oats + Lespedeza	18.7	26.1	28.1	30.0	28.3
Corn, Oats + Lespedeza, Wheat + Lespedeza Timothy + Lespedeza	26.5	35.2	33.8	40.7	41.9
Corn, Oats, + Soybeans, Wheat + Soybeans	28.7	35.1	35.5	40.9	40.2
Corn, Oats, Wheat, Sweet Clover	33.9*	----	----	41.7	42.6

*Received lime.

TABLE 27 -- RESPONSE OF OATS TO CHEMICAL NITROGEN (1946-1950)

No. of Trials	Area of State	Yield in Bu./A. No* Nitrogen	Yield in Bu./A. 33 lb.* Nitrogen	Increase Bu./Acre
23	Dark upland soils of Central & North Mo.	41.6	62.1	20.5
14	Light colored soils Northeast & South Mo.	33.2	51.6	18.4
7	Bottom soils	44.9	77.4	32.5
44	Average	39.4	61.2	21.8

*A portion of the soils received starter fertilizers, at the same rate on both treatments.

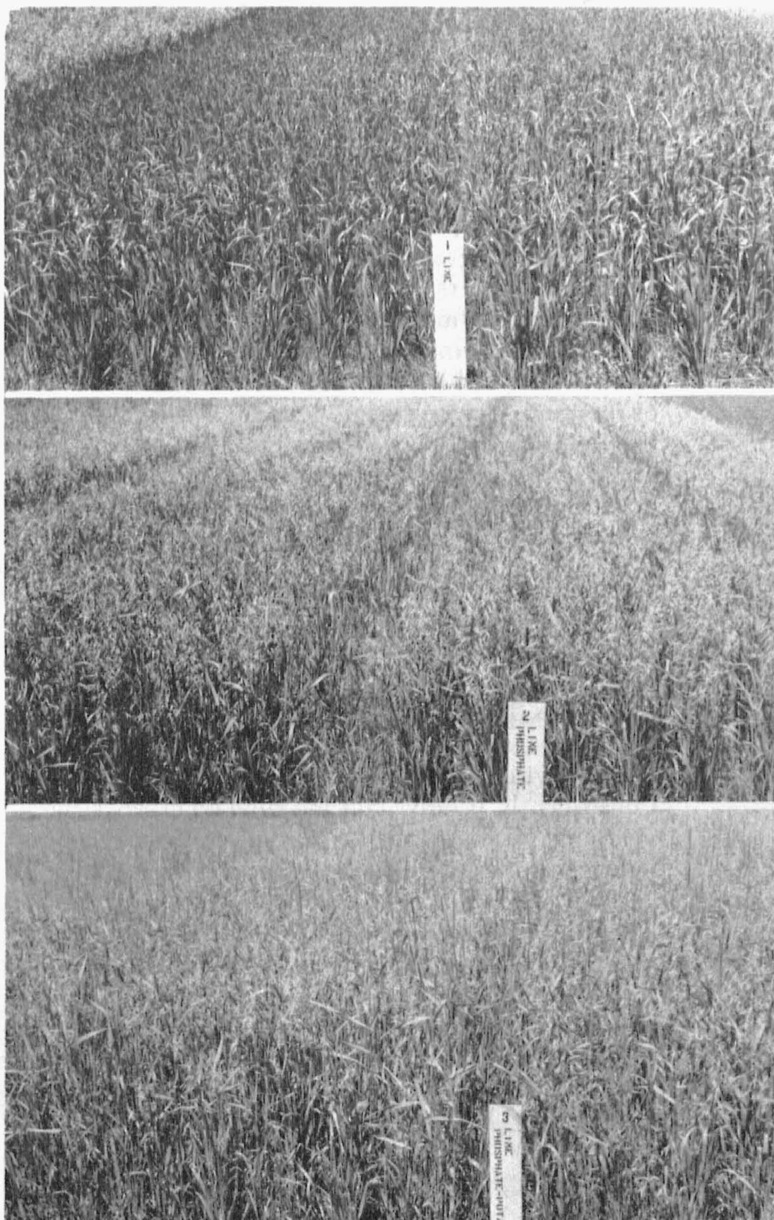
Oats contain about ⅔ pound of nitrogen per bushel (30 pounds) of grain. If the analysis of the entire crop is considered (grain and straw) the nitrogen content will average about 1 pound of nitrogen for each bushel of grain produced.

In an experiment (Table 28), different varieties of oats received 250 pounds of 0-20-20 when planted

TABLE 28 -- EFFECT OF NITROGEN APPLIED TO OATS
(Putnam Silt Loam 2-yr. av. 1952-53)
Starter Fertilizer-250 lb. of 0-20-20

Variety	Pounds Nitrogen Added 0	33	66
Mo.-205	25.6	49.2	53.1
Columbia	25.0	47.7	58.7
Clinton	17.9	35.7	45.3
Andrew	24.2	46.1	50.7
Mindo	20.3	44.9	56.9
Average	22.6	44.7	52.9

and were fertilized with different amounts of nitrogen immediately after planting. Results from two years of the experiment (1952-53), when the yields were reduced by hot weather, show that the addition of 33 pounds of nitrogen per acre to this Putnam silt loam nearly doubled the yield.



Three oats crops planted at the same time on phosphorus deficient soil. *Lime* alone (top) has produced a yield of 26 bushels per acre over a 9-year period. Where *lime* and *phosphorus* have been added (middle), the yield has been 35 bushels per acre. The oats crop (bottom), grown on *limed* soil well supplied with *phosphorus* and *potassium,* produced 42 bushels per acre. Note how phosphorus speeded maturity.

Combines, which have largely replaced binders and threshers, brought changes in straw handling. A heavy covering of straw may smother young grass seedings.

Straw contains most of the potash. If it is removed, potash must be added. If the straw is plowed under, add at least 20 pounds of nitrogen per acre for each ton of straw.

All of the varieties gave similar response to the added nitrogen. The highest yields were produced by the early maturing varieties when growth of the later varieties was arrested by hot weather. There is little suggestion of much difference in response from the various varieties. Hence, it can be assumed that under field conditions any variety will give a response to nitrogen application when the soils are deficient in the available forms. Under these conditions, a bushel of oats was produced from the addition of approximately 1 ½ pounds of nitrogen.

Problems of High Fertility Additions

Nitrogen has been the "crop pusher" that has stimulated crop growth and promoted the use of other fertilizer nutrients. There is a tendency to use more nitrogen than some other elements. Increased yields mean increased amounts of crop growth, greater need for secondary and trace elements and more residues to be returned. If the elements added as soil treatments are not properly balanced, new problems of production may develop. The use of liberal soil treatments has changed many problems of crop production.

Lodging of Small Grains Related to Soil Fertility

When the available mineral contents of most Missouri soils are raised to adequate levels, then nitrogen fertilizer will promote growth and increase the crop yields. If available nitrogen is present in the soil in excessive amounts, relative to other nutrients, the plant growth will be rapid and the stems may be weak. Consequently, if heavy rain and wind occur when the plants are heading, lodging may result. This may be most evident where nitrogen has been added in fertilizer and where spring conditions are ideal for the release of more than average quantities of nitrogen from the organic matter of the soil.

Under average seasonal conditions, from 30 to 40 pounds of nitrogen, top-dressed, have given satisfactory increases in yields of small grains and little serious lodging by the short strawed varieties now being grown. Experiments have been conducted (Table 29) where applications of nitrogen in excess of 160 pounds per acre to wheat (adequate minerals provided) did not cause serious lodging. A certain amount of lodging is not objectionable since a field condition that could be called "swirling" denotes heavy heads and higher yields. Where all nutrients are present in adequate amounts, lodging is seldom so severe that the grain cannot be harvested with combines. Adequate minerals and a balanced supply of nutrients can reduce lodging with the stiff-strawed varieties now available. Without sufficient nitrogen, it is impossible to obtain highest yields. As the amount of available nitrogen is increased, it is necessary that all other elements be present in relatively optimum amounts.

Managing Straw After the Combine

Adequate fertilization of small grains, particularly wheat, will produce large weights of straw. Where land is high in natural fertility there may be a rapid decomposition of the straw. However, where the crop removes a large part of the available nitrogen the straw may be detrimental to legume or grass seedings.

If the straw is baled, provision should be made to replace about 20 pounds of potash for each ton removed. The straw is very low in nitrogen and if turned under may reduce the yield of the following crop through the competition with it by the soil microbes for the soil's available nitrogen. In some sections straw has been burned. This practice frequently gives an immediate increase in yields but it will result in the loss of soil humus, the eventual destruction of soil structure and increased erosion.

In experiments where various treatments have been applied along with straw in growing small grain after small grain the yields have been depressed when the straw was returned. In a 10-year period extending from 1939 to 1948, inclusive, the application of nitrogen with the straw improved the crop yields on Putnam silt loam (Table 30). However, the highest yields were obtained when the straw was burned. In fact,

TABLE 29 -- WHEAT YIELDS AS INFLUENCED BY RATE OF NITROGEN APPLICATION IN SPRING
(Average 2 years -- 1953 and 1954, Bu. per Acre)

Soil Treatment	Total N	Fine Sand	Sandy Loam	Silt* Loam	Silt Loam	Silt Loam	Sandy Clay	Clay	Clay
None	0	13.9	23.4	19.1	28.2	23.7	27.4	18.4	21.6
0 - N + Starter*	36	22.0	29.8	28.8	36.2	37.8	36.4	31.5	28.4
33 N + Starter	69	34.0	37.0	40.1	41.4	45.4	38.0	41.4	33.4
66 N + 3-12-12	75	35.8	43.0	39.6	43.0	48.2	41.6	40.9	39.6
66 N + Starter	102	34.6	40.7	43.7	42.2	46.4	40.4	41.1	40.2
100 N + Starter	136	41.3	41.0	43.2	43.4	47.5	38.5	35.2	38.8
132 N + Starter	168	34.6	38.8	43.0	46.6	49.6	40.5	38.0	41.2

* 300 lb. of 12-12-12 was applied on all areas except one silt loam, low in phosphorus, where 8-24-8 was used.

TABLE 30 -- EFFECT OF RETURNING STRAW AND NITROGEN ON YIELD OF WHEAT
(Putnam Silt Loam 10-year average)
Range 1
Combine Experiment 1939-1948

		Wheat Bu./A.
1. Straw Removed	No treatment	18.0
2. Straw Removed	0-38-0 @ 100	23.1
3. Straw Removed	Cyanamid @ 100; 0-38-0 @ 100	23.8
4. Straw Removed	Lespedeza; 0-38-0 @ 100	24.5
5. Straw Removed	Straw removed Lespedeza 0-38-0 @ 100	24.0
6. Straw Returned	Lespedeza 0-38-0 @ 100	23.6
7. Straw Returned	No Treatment	19.0
8. Straw Returned	0-38-0 @ 100	19.9
9. Straw Returned	0-38-0 @ 100; Cyanamid @ 100	22.0
10. Straw Returned	2 T. Straw; 0-38-0 @ 100	22.9
11. Straw Returned	2 T. Straw, Cyanamid @ 50; 0-38-0 @ 100	22.1
12. Straw Returned	2 T. Straw, Cyanamid @ 100; 0-38-0 @ 100	21.9
13. Straw Returned	2 T. Straw, Fine Lime @ 500; 2 T Straw 0-38-0 @ 100	24.2
14. Straw Returned	Ammonium Sulfate @ 100; 0-38-0 @ 100	25.6
15. Straw Returned	Ammonium Sulfate @ 100; Fine Lime @ 500; 0-38-0 @ 100	26.7
16. Straw Returned	Cyanamid @ 100; Fine Lime @ 500; 0-38-0 @ 100	26.1
17. Straw Returned	Cyanamid @ 100; Fine Lime @ 500; 0-38-0 + KCl	26.7
18. Straw Burned	O-38-25 @ 100	27.1
19. Straw Burned	Cyanamid @ 100; 0-38-0 @ 100	30.4
20. Straw Returned	Disced 0-38-0 @ 100	14.3

TABLE 31 -- EFFECT OF TURNING UNDER NITROGEN WITH STRAW ON YIELDS OF WHEAT
(Putnam Silt Loam 5-year average)

Plot No.	Method of Harvesting	Method of Handling Straw	Soil Treatments	Wheat Bu./A
1	Combine	Off	None	13.5
2	Combine	Under	200 lb. 0-20-10 seeding	17.1
3	Combine	Under	200 lb. 0-20-10 seeding; 100 lb. Ammonium Nitrate under	24.6
4	Combine Lespedeza	Off	100 lb. Ammonium Nitrate under 200 lb. 0-20-10 seeding	25.3
5	Combine Lespedeza	Off	200 lb. 0-20-10 seeding	24.0
6	Combine Lespedeza	Under	200 lb. 0-20-10 seeding	24.5
7	Combine	Under	None	16.9
8	Combine	Under	200 lb. 0-20-10 seeding 100 lb. NH_9NO_3 under 100 lb. NH_9NO_3 spring	28.2
9	Combine	Under	200 lb. 0-20-10 seeding 200 lb. Ammonium Nitrate under	26.8
10	Combine	Double straw under	200 lb. 0-20-10 seeding	21.9
11	Combine	Double straw under	200 lb. 0-20-10 seeding 200 lb. Ammonium Nitrate under	27.9
12	Combine	Double straw under	200 lb. 0-20-10 seeding 200 lb. NH_9NO_3 under 200 lb. NH_9NO_3 spring	25.9
13	Combine	Double straw under	200 lb. 0-20-10 seeding 100 lb. NH_9NO_3 under 100 lb. NH_9NO_3 spring	28.8
14	Combine	Under	200 lb. 0-20-10 seeding 333 lb. Ammonium Sulfate under	26.3
15	Combine	Off	200 lb. 0-20-10 seeding 333 lb. Ammonium Sulfate under	30.2
16	Combine	Under	200 lb. 0-20-10 seeding 300 lb. Cyanamid under	30.2
17	Combine	Under	200 lb. 0-20-10 seeding 150 lb. urea under	29.1
18	Combine	Burn	200 lb. 0-20-10 seeding	21.3
19	Combine	Burn	200 lb. Ammonium Nitrate under 200 lb. 0-20-10 seeding	31.3
20	Combine	Burn	200 lb. 0-20-10 seeding 100 lb. Ammonium Nitrate under 100 lb. Ammonium Nitrate spring	28.7

Wheat and barley have been planted in wide rows in an attempt to increase grain yields through heavy nitrogen additions and still use them as a nurse crop. This practice has not improved legume or grass stands and has decreased yields of the small grains by 10 percent. In some years lodging (right) has been greater than with conventional drilling.

burning the straw increased the yields more than the addition of 20 pounds of nitrogen per acre in Cyanamid or ammonium sulfate. This suggests that the added nitrogen was not sufficient to decompose the straw without the decomposition process interfering with the growth of the succeeding crop.

The importance of incorporating the straw is shown by the low yields obtained on plot 20 where the land was only disced. Although phosphate fertilizers were added, the yields were much less than on the untreated soils where no fertilizer was applied but the land was plowed.

The experiment was revised and additional nitrogen was added. The results, given in Table 31, show that the additional amounts of nitrogen have corrected the depressing effects on wheat yields by the straw. Yields where the straw has been burned are dropping rapidly except where nitrogen is being added. It appears that about 20 pounds of nitrogen are required to balance each ton of straw and that an additional 30 to 40 pounds of nitrogen per acre will increase grain yields where adequate minerals have been applied.

These results would indicate that where heavy straw is produced and there is a satisfactory market, it may be desirable to remove it to favor legume or grass stands. In fact, heavy straw growth can smother new grass and legume seedings unless removed after combining. Provisions must be made, however, to return the nutrients, particularly potassium, if the fertility level is to be maintained.

Double Cropping of Small Grains and Soybeans

Improved machinery that permits rapid harvesting and planting, combined with the use of early varieties of wheat or barley, has made it possible to follow these crops with an early maturing variety of soybeans and so obtain two crops in the same year. Where small grains are removed early as silage or hay crops the success of this system is improved. In seasons when there has been sufficient moisture for rapid germination and growth of the soybeans, this one-year rotation has shown promise. Where land can be irrigated this double-cropping combination has merit in the southern two-thirds of the state. However, an adequate supply of nutrients for rapid germination and growth is essential for satisfactory yields and speedy maturity of both crops.

In the early experiments, the barley was rotated with soybeans. The barley was removed with a binder and the soybeans were harvested for hay. The land was not plowed. Yields of both barley and soybeans as shown in Table 32 were low. It is now realized that the nutrient addition was not adequate for satisfactory growth. In the original plan no potash was added and after about five years of repeated removals of the entire barley and soybean crops, the yields were declining and potassium deficiencies were evident as plant symptoms. The experiment was changed by adding potassium to a portion of the plots.

This addition of potassium increased the yields greatly, particularly where the soil had been limed. All yields continued low because the nutrient level was inadequate for high yields.

This experiment was then discontinued and a new one initiated. Soil mineral deficiencies were corrected and adequate nitrogen added when the soybeans were planted to decompose the wheat straw and furnish adequate nitrogen for the germinating wheat after the soybeans. In the three years during which this new plan has been in operation, the yield of wheat has

TABLE 32 -- YIELDS OF BARLEY AND SOYBEANS IN A ONE YEAR ROTATION SYSTEM
FERTILIZER APPLIED ONLY TO BARLEY

Soil Treatment (lb. per acre)	14-year av. Barley	1936-49 Soybeans (hay)	10-year av. Barley	1940-49 Soybeans (hay)
None	7.5 bu.	2280 lb.	7.7 bu.	2698 lb.
0-20-0 @ 150	13.2	2500	13.4	3153
0-20-20 @ 150	----	----	16.4	3371
0-20-0 @ 150 + lime	15.8	2830	14.8	3407
0-20-20 @ 150 + lime	----	----	23.6	3802

On soils low in organic matter, nitrogen may benefit young legume plants until nitrogen-fixing organisms develop. Here nitrogen benefitted both the oats "nurse" crop and the clover. An excess of nitrogen may improve the small grains but smother the legume. Soil mineral levels should be high and nitrogen treatment moderate.

averaged more than 30 bushels per acre, giving a substantial increase from the adequate nitrogen applied in the starter fertilizer, with the wheat straw, and in spring top-dressings.

Yields of beans have ranged from 10 to 15 bushels or about one half the yields for full season soybeans. However, summers have been dry and the growth of the beans has been retarded. It appears that yields of small grain can be as high in this system as in many other cropping systems, if adequate nutrients are provided. Yields of beans will be determined much by the summer moisture as well as the fertility of the soil. If the seeds germinate promptly and there is sufficient moisture for growth, this cropping system appears practical. Preliminary results indicate that at least 30 pounds of nitrogen must be added for each ton of straw returned from either small grains or soybeans to help prevent the retarding of growth from nitrogen deficiency.

In the southern part of the state where facilities for supplemental irrigation have been available, a rotation of barley and soybeans has been operated with good results. When the soil was dry after planting the beans as the crop following barley, the supplemental water speeded their early germination and growth. Where adequate nitrogen and minerals were provided, the yields of both crops were well above the average. There has been little benefit from added water on the small grains, although in dry seasons it is possible an application of water immediately after planting would hasten germination and be of benefit.

Obtaining Stands of Legumes in Small Grains

Small grains are used regularly as "nurse" crops for grasses and legumes in changing from row to sod crops. Soil treatments that produce high yields of grains frequently produce a heavy growth of straw and give a competition too severe for ample nourishment of the forage seedlings. This heavy straw growth causes shading and a " tender" growth of the legume or grass plants. If high temperatures follow the harvest of the small grain, the intense heat and sunlight may cause a loss of the stand. Also, the higher production

Small grains serve as nurse crops for legumes. It is difficult to obtain both maximum grain yields and a stand of the forage crop. Potash (left side, left picture) increased the stand of red clover. Nitrogen applied to wheat (right side, right picture) suppressed the growth of lespedeza. On most soils where minerals are adequate, the addition of 25 to 40 pounds of nitrogen will increase small grain yields without serious detriment to the legume.

of the small grain crops may, in some seasons, use much of the available moisture and leave a small amount for the young seedlings, especially in the surface soil where the shallow-rooted young plants need it.

Losses of legume or grass stands are more frequent when an excess of nitrogen is applied to soils with inadequate mineral reserves. Residual nitrogen from the small grain may stimulate wild grasses that compete with the legume seedings. Adequate and well balanced supplies of soil minerals will aid these young seedings to withstand this competition. However, with information now at hand it does not appear possible to apply sufficient nitrogen for maximum yields of small grains and still use them for "nurse" crops. If the small grain were removed as a silage or hay crop at an earlier date than for grain, the chances of survival of the forage seedings would be increased.

Missouri is in an intermediate position between the lower rainfall west, where winter wheat is the principal crop and no legumes are grown with it, and the humid east where legumes are regularly seeded with most small grains. When summer rainfall is adequate, a moderate application of nitrogen will permit the production of good yields of small grains with a stand-over crop of legumes or grasses. However, when summers are hot and dry the conditions are more similar to conditions in the states farther west and the forage stands in the small grains may be disappointing.

In the states farther east, it is a common practice to plow small grain stubble and make legume seedings in August. This practice has been satisfactory in some seasons in Missouri. But if there is insufficient moisture to start the young seedings and permit a vigorous fall growth, winter killing may destroy a large part of the stand. To secure a stand of legumes in high yielding small grains, it appears that the following practices should be used:

(a) Provide a high level of phosphorus, potassium, calcium, magnesium and sulfur in proper balance.

(b) Apply not more than 40 pounds of nitrogen per acre, preferably in the fall or early winter.

On many soils, larger amounts of nitrogen may increase the small grain yields, but regularity of success from the forage seedings will be reduced. Where most of the interest is in maximum small grain yields and where legumes are desired, it may be necessary to change from the "nurse" crop to a cropping sequence and make forage seedings separate. The vigor of alfalfa in dry seasons has demonstrated its value. It is possible that with proper fertility additions, alfalfa can substitute for clover and some grasses in farm management systems. Small grain could be fertilized for maximum yield, the land plowed immediately after harvest, and alfalfa seeded in August with a full hay crop the following year.

Evidence is accumulating to tell us that legumes may not be as essential in soil fertility maintenance as previously considered. Soil organic matter content can be increased through non-legumenous crop residues and chemical nitrogen. Experiments comparing the long time effects of this type of soil management with use of legumes for maintenance of nitrogen and soil fertility are now in progress. Where livestock feed is needed, every effort should be made to increase legume production for feeds. The legumes stand far higher for their feed value than for maintenance of soil organic matter.

Soil Tests as Guides in Soil Management

Soil tests are being used extensively to determine the inorganic fertility reserves in soils. They have been most helpful in indicating elements which are in short supply and those which must be added for higher crop yields. Soil tests (or any other method that has been developed) cannot consistently show a difference in need for mixed starter fertilizers carrying different amounts of plant nutrients. When soils are low in a particular element, it is logical that the amount of that element in an applied fertilizer should be increased. It is frequently difficult, because of seasonal variations, to show consistent results from small differences in amounts added in starter fertilizers. Table 33 gives suggestions for some starter fertilizers under average soil conditions.

TABLE 33 -- SUGGESTED STARTER FERTILIZERS FOR FALL SEEDED SMALL GRAIN*

	Summer plowed			Late seedbed preparation or spring oats**		
Soil Test	Low Potash	Med. Potash	High Potash	Low Potash	Med. Potash	High Potash
Low Phosphorus	4-24-12	8-24-8	8-24-8	12-24-12	12-24-12	13-39-0
Medium Phosphorus	4-24-12	6-12-12	8-24-8	12-12-12	12-12-12	10-20-0
Phosphorus Reserve High	6-12-12	6-12-12	None*	12-12-12	12-12-12	Nitrogen only

*On most soils 30 pounds of nitrogen or a top dressing is suggested where land is summer plowed.

**After lespedeza for pasture, soybeans or corn.

With late seedbed preparation 40 to 50 pounds of nitrogen will give additional increases in yield, but may make more difficult the establishment of legumes and grasses.

Organic Matter

Soil testing laboratories in Missouri make determinations for organic matter, since it is the principal source of nitrogen in unfertilized Missouri soils.

Experiments indicate that for each 1 percent of organic matter in the plow layer (top 7 inches, 2,000,000 pounds per acre) a silt loam will release an average of 15 pounds of nitrogen during the cool season of the year (when fall seeded small grains are growing). When conditions are ideal for organic matter breakdown, the amount released will be greater, and where conditions are not so favorable the amount made available will be much less.

For clay and clay loam soils, the percentage released will be less or about 10 pounds of nitrogen for each 1 percent of organic matter.

The open texture of sandy soils favors humus decomposition. Correlation of field experiments and laboratory measurements indicate a release of about 40 pounds of nitrogen for each 1 percent of organic matter.

Where soils have deep surface layers, the total amount of nitrogen made available will be increased. However, the rate of release from the lower layers will be some what slower than from the plow layer.

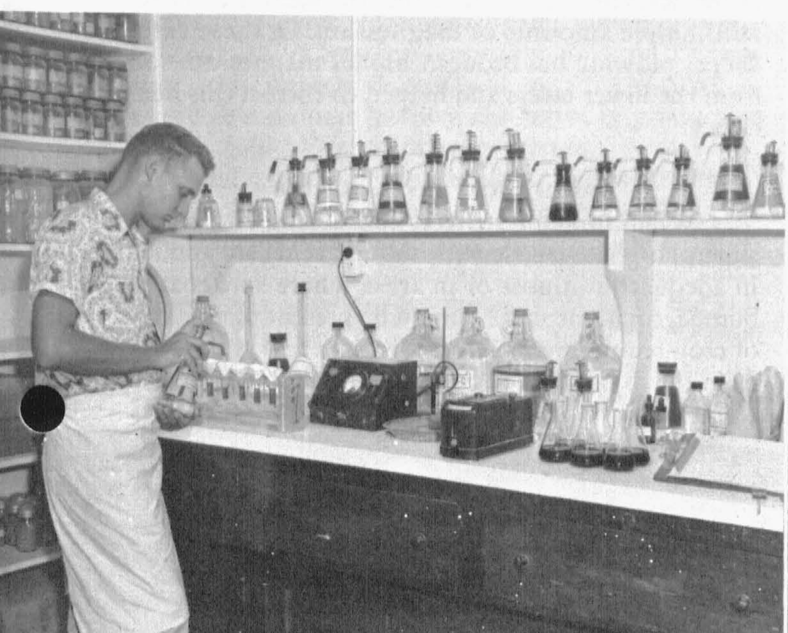
Wheat contains about 1.7 pounds of nitrogen in 1 bushel of grain, plus the straw producing this grain (1.2 pounds of nitrogen per bushel of barley; 1.0 pounds of nitrogen per bushel of oats). In favorable seasons on soils well supplied with minerals, but receiving no fertilizer nitrogen, the average yield of wheat under good management conditions has been about 10 bushels per acre for each 1 percent organic matter content of the soil (25 bushels per acre on soils with 2.5 percent organic matter).

All essential elements must be in proper balance for optimum plant growth. This experimental plot received the same fertilizer treatment throughout at time of planting but the left half had not been limed. Fertilization by guess may be disappointing. Soil tests can show the elements that are in short supply.

Assuming a release of 15 pounds of nitrogen for each 1 percent of organic matter, this would indicate a yield of one bushel of grain for 1.5 pounds of nitrogen. Under these same soil conditions (2.5 percent organic matter), the addition of 30 pounds of available nitrogen in fertilizers has constantly produced increases in yield ranging from 10 to 15 bushels. This would mean a yield of 40 bushels from 67.5 pounds of available nitrogen (2.5 percent organic matter releasing 37.5 pounds N plus the 30 pounds N fertilizer), or 1 bushel of wheat for each 1.7 pounds of nitrogen.

Although the amount of nitrogen released will vary with the season, an organic matter determination of the soil can serve as a good indication of the amount of nitrogen that may be released and the quantity that may be added in average seasons to give high yields.

Soil tests are the best rapid means of determining soil nutrient reserves. Good soil samples are essential for accurate laboratory results. Field experiments test the response to soil treatments and give comparison with soil test results. On this field, proper use of plant nutrients increased the yield of wheat 25 bushels per acre. The soil test showed that nitrogen, phosphorus and potassium were needed.



Phosphorus

Soil tests measure phosphate reserves in a soil. Where phosphorus is in low supply, the root growth is retarded, the plants do not survive severe winters, and the grain does not fill. Numerous experiments have shown that in normal seasons a soil showing a phosphorus test of less than 100 pounds of available phosphate per acre will give reduced yields. In unfavorable seasons a test of nearly 200 pounds per acre is necessary for maximum yields.

A 40 bushel crop of wheat contains about 27 pounds of phosphate. However, the efficiency of absorption from soil phosphorus is low. Experimental work using radioactive phosphorus shows that seldom over 20 percent (and usually less on most soils) of the phosphate applied as superphosphate with the seeding will be absorbed by the first crop. Assuming only 20 percent efficiency, it would be necessary to apply nearly 700 pounds of 20 percent superphosphate (none obtained from the soil) if wheat plants were to absorb a sufficient supply for a 40-bushel crop. This points to the necessity for using soil tests to determine phosphorus reserves and to make additions in excess of immediate crop requirements if maximum yields are to be obtained.

On soils low in phosphorus and where the available phosphorus added in fertilizers is not high, the crop yields vary widely with the season. Since organic matter contains about one-tenth as much phosphorus as nitrogen, it is possible that the phosphorus resulting from the breakdown of organic matter would furnish a considerable portion required by small grains on phosphorus deficient soils.

For example, on silt loams that were about 2.5 percent organic matter and low in phosphorus, the yields of wheat averaged about 10 bushels per acre over a long period. About 7 pounds of phosphorus would be absorbed by a 10-bushel wheat crop and if this soil would release 37 pounds of nitrogen (phosphorus one-tenth of nitrogen in organic matter) then over one-half of the phosphorus absorbed could be from the organic matter breakdown. This could serve as a partial explanation of the wide fluctuation in yield on unfertilized soils that are low in phosphorus.

Potassium

Soil tests have been a reliable guide to available potassium in Missouri soils. Although soil depth, type of clay, and moisture conditions influence the quantity delivered to the plants, about 200 pounds (medium test) of available potassium per acre are required for maximum yields. On some soils, and in some seasons, a significant response has been obtained from potassium fertilizers when initial levels have been above 200 pounds per acre. On most soil, however, little response will be obtained from potassium in starter fertilizers when the test report is more than 200 pounds per acre, unless large applications of chemical nitrogen are made. It is seldom advisable to apply more than 40 pounds of potash with small grain seed at the time of planting (the salt can be injurious in dry seasons). If more potassium is required to give a 200-pound level, the additional quantity should be plowed down.

Calcium and Magnesium

Available calcium should make up from 65 to 85 percent of a soil's capacity to hold nutrients. The proper amount as total per acre will depend on the total adsorptive capacity of a soil. This is influenced by the clay and organic matter contents. If calcium is not present in the proper ratio, the small grains may not be able to absorb other nutrients that have been added in ample amounts. If an excess of limestone is added, the rate of decomposition of soil minerals is reduced and deficiencies of potassium, magnesium or other nutrients may develop.

For high yields of small grains, soils should contain magnesium to the extent of about 10 percent of a particular soil's capacity to absorb nutrients. This will vary from a minimum of about 50 pounds per acre of magnesium in the plow layer of sandy soils, 150 pounds in silt loams and over 200 pounds in clay loams. Significant response by small grains has been obtained from magnesium limestone (dolomite) or soluble magnesium salts in fertilizers when soil tests have indicated magnesium supplies below these levels. The surface soil may become deficient in magnesium frequently on Missouri soils when excess calcium limestone is applied. In numerous instances it has been observed that young plants develop deficiencies that disappear as the plants become older. Soil tests in the fields frequently show that the subsoil still contains ample amounts of magnesium. In these cases deeper plowing has brought higher magnesium soil from the lower layers and helped to correct this deficiency.

Sulfur and Trace Elements

When mixed fertilizers containing 20 percent superphosphate (made with sulfuric acid) are applied in adequate amounts or in areas where soft coal is burned, sufficient sulfur should be present to take care of crop requirements. However, in a few areas away from towns on some of the more highly leached soils, responses have been obtained from additions of fertilizers containing sulfur. Much of the high analysis fertilizer now being applied contains little of this element and with continued high crop production it could limit small grain yields. The application of large amounts of nitrogen will increase the need for sulfur. With increased yields, sulfur additions may be needed on some soils.

Trace elements such as copper, boron, zinc, manganese and molybdenum are required in very small amounts and except where their deficiency is so severe as to inhibit plant growth, a shortage may not be detected in vigor of growth or yield. As the use of more nitrogen and high analysis fertilizers increases crop removals, a need for these elements in fertilizer applications may develop. Since these compounds are costly, it is advisable to apply the materials only to test areas until more experimental work shows a definite need.

Summary

The decomposition of organic matter and the breakdown of reserve soil minerals have been the major sources of nutrients for our growing crops. The soil organic matter has been the buffering agent that has compensated for mistakes in soil management.

This soil humus has declined and its delivery of nutrients has been so reduced as to offset improvements made through crop varieties, machinery, and other production factors. Liberal use of legumes and farm manures can only partially restore these losses. The availability of low cost chemical nitrogen, when properly used and supplemented with minerals, can serve in both an immediate improvement in yields and the restoration of the soil's organic content.

The addition of chemical fertilizers alone cannot produce highest yields on run-down soils, or those low in both organic matter and nutrients. For highest yields, small grains should be grown in cropping systems that provide maximum organic matter incorportion (returning crop residues to the soil). At the same time it is imperative that soil nutrient reserves be raised to eliminate fertility as a factor in production for all crops in the cropping sequence.

Small grains are "weak feeders" or "poor rustlers." They do not have the capacity to use some of the less available nutrients that may be absorbed by other crops, particularly grasses and legumes. Since small grain crops grow during the cool season of the year in Missouri, they cannot obtain as much benefit from the effects of soil organisms on nutrient availability, or of higher rates of chemical activity through higher temperatures, as crops that make most of their growth during the warm months.

If we are to obtain optimum yields of small grains, the plants must be supplied with adequate quantities of available nutrients when required. Continued removal of nutrients in excess of those added in manure and fertilizer, and continued losses through erosion have resulted in a decline in productivity. Supplies of farm manure are inadequate and only through the addition of balanced quantities of proper nutrients in fertilizer can this lost productivity be regained.

In recent years, the planting of fall-seeded small grain after lespedeza pasture or after soybeans grown for seed, has largely replaced summer plowing and fallow. These changes in cropping practices have not only reduced the amounts of quickly available nitrogen (and other elements) which accumulate when land is fallowed, but frequently delay seeding dates. It is, therefore, necessary to add more nitrogen in starter fertilizers to enable the plants to make sufficient fall growth. Good fall growth reduces winter injury, develops adequate root systems, and minimizes spring heaving.

Starter fertilizers should be added at the time of seedings on all but a few soils where tests show high fertility levels, where yields are normally high, and where field trials with fertilizers have failed to increase the crop yields. A large number of fertilizer formulae are available. It is usually difficult to show much superiority of a particular ratio under given cropping soil conditions. Suggested starter fertilizers for small grains are listed in Table 32. Under Missouri conditions a 1-1-1 ratio (10-10-10 or 12-12-12), 1-6-3 (4-24-12), 1-3-1 (8-24-8), 1-2-2 (6-12-12), 1-4-4 (5-20-20), or a 1-2-0 (10-20-0) fertilizer will meet most cropping conditions.

The nitrogen content of starter fertilizers should be higher when the seeding is late; where the small grain is following lespedeza or soybeans; and where large amounts of woody organic material are turned under. The quantity of nitrogen added should be equivalent at least to the amount removed in the crop. However, if the soil is dry at the time of seeding, then the combined amounts of nitrogen and potash or potassium applied with the seed should probably not exceed 60 pounds per acre. In very dry soil, excessive amounts of these materials with the seeds may hinder germination. If the soil is moist, the quantity can be increased appreciably without injury to germination and with added benefit to yields.

In addition to starter fertilizers, the top-dressing of most small grains with nitrogen is essential for maximum yields. Under most conditions, about 40 pounds of nitrogen per acre will give most profitable returns. On the more fertile soils, 30 pounds of nitrogen may be sufficient. On poor soils, 60 pounds of nitrogen per acre will give increases in grain yield but will make the establishment of legumes more difficult. Under most conditions, the top-dressings should be made before April 15. On sandy soils, applications in March or April are best to reduce the leaching losses. On heavier soils, where there is little chance for leaching and where erosion is low, the nitrogen may be applied at any time from seeding to April. On oats, nitrogen should be applied immediately after seeding.

Adequate soil fertility is essential for improved varieties to give maximum performance. Costs of production vary little (except for fertilizer) regardless of yield. Where a shortage of nutrients is limiting the yields, proper soil treatments can improve farm efficiency, reduce costs per bushel, and produce grain of higher quality.