Soil Fertility and Corn Production

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The production of a good corn crop may well continue to be the ambition and pride of those farmers who manage their soil accordingly. Photograph—Missouri Farmers Association.

FOREWORD

In the age-old struggle for food, modern man like his primitive ancester still is a nomad at heart. He looks to new horizons for an easier way, for more extensive areas to despoil. Less appealing to his natural instinct is the alternative of more intensive application of effort to the care and conservation of the resources within reach of his hand.

As an example, there is the situation of the farmer who has grown corn at one time or another on all the arable land he owns until the unstable body has been weakened through depletion of minerals and organic matter. Productive capacity of these fields—so far as corn is concerned—has declined until corn growing by traditional methods is no longer profitable.

As a consequence of the farmer having grown corn on most tillable fields and having suffered heavy losses through soil erosion, shrinkage in areas of productive soil, and declining nutritional values of grain protein, many have been ready to accept the erroneous charge that corn—as an erosive crop—was to blame for these disasters.

Yet the fact is that the crop itself is not erosive, and in no sense a criminal agent of soil depletion. It was rather our persistence in using the crop extensively, and our failure to condition our soils to produce this noble crop at its best. Corn production is becoming more and more an effort to provide a fertile soil as nourishment for a crop as nutritious and as profitable for the human family as it was in the days of the pioneer clearings and the newly opened prairies.

We can no longer keep going west to mine virgin fertility out of new soils to grow more corn. We are being confined to those of limited potential in production, and to those which must be wisely managed through costly fertility restorations and improvements. Our fields are no longer the equivalent of open pasture for our crops to which the seeds are turned out in the spring, like cows on the range, to rustle for themselves. Instead, they are feedlots to which we must carry fertilizers for the crops if the plants are to be properly nourished. Bigger and better corn crops are not a matter of more and newer acres. They are one of wiser soil management that guarantees better balance of plant nutrition.

All too long have we taken our soils for granted, and have disregarded, as an item in the cost of corn production, the gradual exhaustion of the soil fertility. Unfortunately, the extra costs of restoring and maintaining our soils in productivity are crowding into our agricultural economy just when both our lands and our farming business are already burdened with mounting taxes and other costs. But if nutritious food is to be provided, there is no escape from its rising costs, increased still more by those demanded for managing our soils so as to maintain their fertility, to guarantee quality food production, and to conserve our lands for the increasing numbers of our people. In the final analysis there is no food-creating substitute for a fertile soil.

Wm. A. Albrecht

ACKNOWLEDGEMENT

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INTRODUCTION

Corn long has been the crop of highest value produced in Missouri. No other crop could so effectively convert the plant nutrients of the organic matter in virgin soils into animals feeds. When virgin soils were high in nitrogen, no other crop than corn could produce as many animal feed units per acre. Extensive corn production and poor management, however, have left the bare land exposed during a large portion of the season. Erosion has removed excessive amounts of the fertile topsoil. This has resulted in a loss of not only the soil body but also of its most fertile portion containing the nutrients essential for plant growth.

The yields of corn declined gradually and now fail in too many instances to pay the cost of production. Efforts have been made to restore this lost production through the use of green manure crops and small additions of fertilizer. In some instances on the less erosive soils the decline in fertility has been halted or the fertility has even increased under better management.

Soil rebuilding is a long, slow and difficult process. Substitute cropping systems omitting corn with fall seeded small grains and grasses have been promoted extensively. But with the nutrients depleted and with insufficient of them added in fertilizers, the soil fertility continues to decline. Crop failures from winter killing, droughts, or insect injury are frequent. Yields and profits too often are low. Stands and growth of grasses have been so poor that the soils are not adequately covered, and erosion continues. Those species of grasses surviving on less fertile soils are also those which have protein and mineral contents too low to be adequate for efficient livestock feeding. Land formerly adapted to corn production has come to be considered as submarginal and is being classified as suited only for rough pasture or forestry. Thus after only a half century of cropping, much land, formerly fertile, is now considered unsuited for agriculture.

Experiments conducted in recent years show that the plant nutrients to produce maximum corn yields, rather than only small "starter" applications that promote early growth and a starved plant before maturity, not only can produce profitable yields, but also pay for soil rejuvenation that will increase the growth of forages and pastures, provide good ground cover and reduce erosion to a minimum. The adoption of soil management practices providing adequate nutrient levels will permit the production of corn on soils formerly considered low in fertility.

Yields of more than 100 bushels are being produced regularly through proper management of soils that once had been depleted of their nutrients or had lost most of their topsoil through erosion, and where nutrient levels were so low in the virgin condition that they were considered unfit for corn. Not only can high yields of corn be produced by adequate soil treatment on soils of low nutrient levels, but the fertility can be rapidly increased and at the same time return yields and profits larger than those obtained when the land was first brought into cultivation.

This publication describes experimental work conducted on various soils in Missouri under additions of both low and high levels of fertility. Soil management practices are outlined that can be used (a) to rebuild the soil fertility, (b) to keep corn production profitable and (c) to help maintain the soil fertility on most soils in the state.

CORN PRODUCTION IN MISSOURI, AN AGRICULTURAL REQUISITE

Corn was produced on an annual average number of 4,230,000 acres in Missouri from 1941 to 1950. The yield per acre during that decade varied for the state from 24.5 bushels in 1947 to 45.5 bushels in 1948. The average for this ten-year period was 34.7 bushels. These figures stand out in contrast to the decade from 1931 to 1940 when, with a mean acreage of 4,990,000 acres, the average yield per acre was 22.2 bushels. This average yield of even the last decade leaves a low labor income after fixed costs of production are paid.

During the past five years, Missouri imported from other states and fed about 55,000,000 bushels more corn than was produced, which in 1951 cost nearly 100 million dollars. Efficient soil management that would produce these grains on individual farms could greatly increase the production of meats and reduce feed costs. Meat shortages are associated with low productivity of the soil. Declining yields in our major crop, namely corn, erroneously condemned as if it, rather than the soil conditions, determined the erosion. Corn is the foundation for animals or protein foods and consequently a requisite in the agriculture that must feed us.

NUTRIENTS IN SOIL MUST MATCH CROP NEEDS

Crop production has become more and more a matter of supplying the plants with their required fertility elements through the addition of fertilizer. We now are learning more about (a) the plant nutrients required by a crop, (b) how those are demanded from the soil in differing amounts at different periods of the crop's growing season, and (c) what nutrient removals from the soil, besides those in erosion, may be losses not so commonly considered. If the crop yields are to be improved by soil management, we must first take inventory of what the soil can supply and what the crop needs, if we are to know what we must add as soil fertility treatments. We cannot be considered wise managers of the soil if we disregard this inventory procedure.

Nutrient Requirements

The corn plant is known to require at least 13 elements that must be obtained from the soil. Even though the percentage composition of these nutrients in a single corn variety may differ when grown on different soils, or though their concentrations in the plant may be increased by liberal application of single elements, the corn fails to make normal vegetative growth or produce grain abundantly when the soil does not deliver these essential elements in proper balance. It is necessary not only that the total quantity of the required nutrients be present to obtain optimum yields, but also that these essential elements be delivered in adequate amounts at the various stages of plant growth. A deficiency in the early stages of growth may cause a stunting of plants and permit the inroad of insects and diseases. A shortage of nutrients later in the growth period may prevent normal pollination, the filling of grain, and the better yield and grain quality.

Table 1 -- Amounts of Nutrients Contributed by the Soil for the Production of 100 Bushels of Corn.*

		Pounds per Acre**		
Element	Symbol	Grain	Stover and Roots	Total
Nitrogen	N	85-115	75-100	160-215
Phosphorus	P_2O_5	35-45	20-35	45-80
Potassium	K_2O	15-25	75-140	90-175
Sulfur	S	10-20	15-30	25-50
Magnesium	Mg	10-25	15-25	25-50
Calcium	Ca	5-10	20-40	25-50
Iron	Fe	.2-.5	1.0-1.5	1.2-2.0
Manganese	Mn	.1-.4	.5-1.0	.6-1.4
Copper	Cu	Trace	Trace	.3-.6
Boron	B	Trace	Trace	.2-.4
Zinc	Zn	Trace	Trace	.4-.6
Molybdenum	Mo	Trace	Trace	Trace
Chlorine	Cl	Trace	Trace	Trace

*The composition of corn producing 100 bushels per acre will vary widely depending on soil nutrient level, environmental conditions, crop variety, and many other factors.

**One hundred bushels of corn, Grade No. 2, with 15 1/2% moisture weighs 5600 pounds. The plants that support this yield produce from 800 to 1200 pounds of cobs, and from 3500 to 5000 pounds of stalks. Reports of root weights vary from one-fourth of the top weight to weights greater than the tops.

Seasonal Schedule of Nutrient Absorption

The nutrient requirements of corn plants are greatest during the period from tasseling to maturity, although a deficiency at any time will hinder growth. The greatest need is in the latter third of the growing season when the ears are forming. Although the plants will store much larger quantities of some nutrients during the early stages of growth for translocation and utilization later, it is highly desirable to have sufficient nutrients in proper ratio at all times if optimum yields are to be secured.

Measurements made in Missouri on corn requiring 130 to 140 days for maturity, indicate that from 10 to 30 per cent of the nutrients are absorbed during the first 60 days of growth. At tasseling, or from 75 to 85 days after planting, no deficiencies were observed on plants that contained only 30 to 60 per cent of the nutrients found in the total crop at the time of harvest. From 40 to 70 per cent of the nutrients (particularly nitrogen) were utilized in plant processes in the last 45-50 days of growth. The situation shown by these analyses has been verified by many experiments where small applications (100-200 lbs. of mixed fertilizers applied in row at planting) to poor soils produced satisfactory early growth but developed extreme nitrogen and potassium deficiencies as soon as ear formation was well under way, and gave little better yields than where no fertilizer was applied.

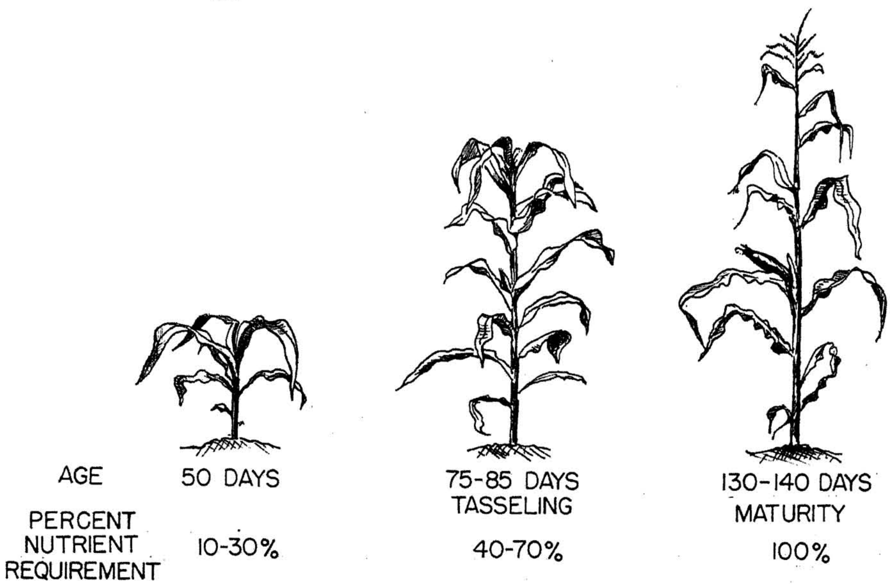

Fig. 1. The nutrient requirement of corn is greatest during the period of tasseling and after pollination. During the first 50 days of growth the plants will absorb only 10 to 30 per cent of the total requirements, but after tasseling as much as 60 per cent of the nutrients may be absorbed.

Nitrogen—Corn requires much nitrogen. A bushel of grain contains approximately one pound of this element and slightly less is usually required as carry-over in the vegetative portion to produce this amount of grain. Nitrogen is found in every plant cell. It is an essential part of all proteins, through which growth takes place. With inadequate nitrogen, new tissue cannot be formed and plant growth is reduced. The highest concentrations are found in rapidly growing and reproductive tissues. A nitrogen deficiency in corn is indicated by pale color, retarded growth, yellow bottom leaves, and a dead center of the midrib with extreme deficiency. Nitrogen deficiency is frequently called drought injury when the bottom leaves "fire," but this condition develops even when the plants are well supplied with water.

The relationship between corn yields and available nitrogen is well illustrated by the production obtained on experimental plots on various soil types where corn has been grown without benefit of legumes or commercial fertilizers.

Table 2 -- Yields of Corn Grown on Different Soils Without Benefit of Legumes or Fertilizers.

Soil Type	Nitrogen in soil in surface 7 inches Pounds	Corn Yield Bu./Acre
Cherokee silt loam	1950	22.5
Crawford silt loam	2840	25.4
Eldon silt loam	3160	31.2
Gerald silt loam	1890	19.0
Grundy silt loam	3370	32.0
Marshall silt loam	3630	38.6
Putnam silt loam	3400	31.0
Union silt loam	2634	26.4
Wabash silt loam	5600	60.5
Average	3164	31.8

Without soil treatment, approximately one bushel of corn will be produced under Missouri conditions for each 100 pounds of nitrogen in the organic matter in the soil, according to the data given in Table 2. Further studies have shown that in seasons when production is greater, weather conditions promote a rate of organic matter breakdown above the average. In those years when yields are reduced, the rates of nitrogen delivery from the soil humus are lower. This relationship between nitrogen supplied by the soil and corn yields is further demonstrated by organic matter tests and corn yields when expressed on a county basis in the state. Those counties in the northwest part of the state with high organic matter content and those with a high percentage of alluvial land have the highest yield per acre.

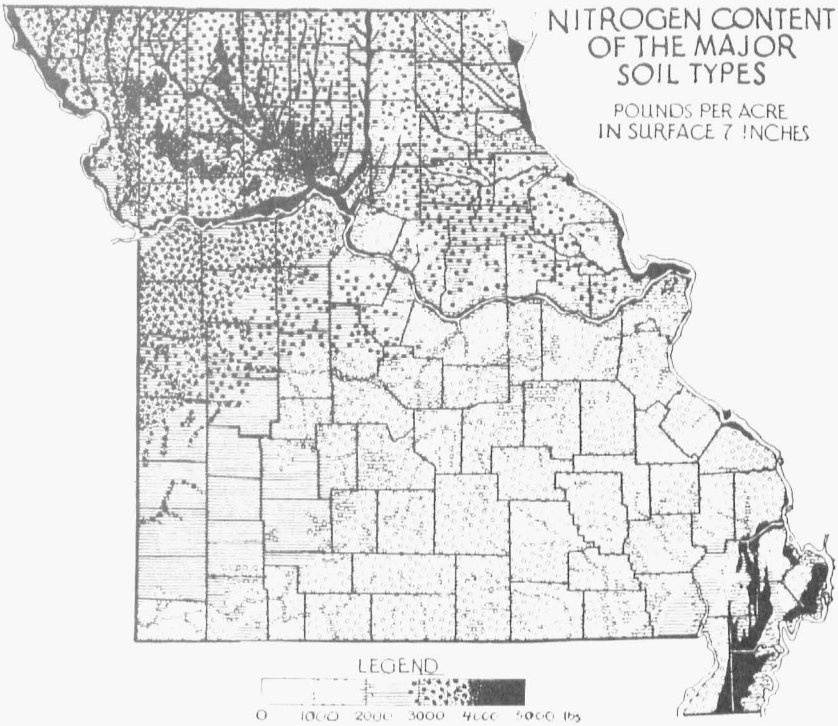

Fig. 2. Higher nitrogen content of soils in the northern part of Missouri gives reason for higher yields of corn per acre there.

Fig. 3. Highest average yields of corn in Missouri are produced in the northwest part of the state and in the counties with a high percentage of bottom land.

Corn yields have been closely associated with July and August rainfall, but where no chemical nitrogen is applied and most of the nitrogen absorbed by the corn plant is from soil humus,* or that added in plant residues or manure, the fluctuations from weather conditions are much greater. When there is insufficient moisture in the soil, the activity of microorganisms is reduced and the breakdown of organic materials is slow. When plant symptoms of nitrogen deficiency develop under these conditions it is frequently referred to as drought injury. However, a shortage of available nitrogen, not water, is the immediate cause. In seasons of excessive moisture there is insufficient oxygen in the soil, biological processes are hindered, and organic materials are only slowly decomposed with a rate of nitrogen release too low for normal plant growth.

Phosphorus—Required by all plant cells, it is found in greater concentration in the reproductive parts (seeds and growing tips). It is particularly essential in cell division (plant growth) and reproduction. When plants are deficient in this element, growth is retarded, pollination is poor, and the grains fail to fill properly. On young plants a deficiency of phosphorus may cause development of red pigments, but this symptom is not specific since other conditions will bring on similar symptoms. It has been shown that young plants will fail to absorb sufficient phosphorus from wet heavy soils when the weather is cool, although the total amount in the soils as shown by soil tests appears adequate. This condition appears to be due to the phosphorus being temporarily unavailable, or that plants are unable to absorb the element under these conditions. Most Missouri soils have a high capacity for the so-called "fixation" of soluble phosphates.

Potassium—Most of the potassium in plants is in water-soluble form. The greater portion of it is in the vegetative part of the plant. Potassium functions in the movement of water within a plant and in the formation and translocation of sugars and starches from points of production in the leaves to the grains where these compounds are stored. Plants deficient in potassium have weak stalks and root systems, the edges of leaves die and the ears are small, tapered and poorly filled. There is a definite association between a plant's requirements for nitrogen and potassium. As more nitrogen is made available to corn, more potassium is required.

Only a small portion of the potassium is removed when only the grain is harvested since most of it is in the stems and leaves. Legumes remove several times the amount of potassium contained in corn grain. Potash needs will be greater in cropping systems that include legumes and other crops removed for hay or feed.

*On unfertilized productive soils over 90 per cent of the nitrogen absorbed by corn is released from the breakdown of organic matter.

Sulfur—Some proteins contain more sulfur than nitrogen. Sulfur is a constituent of at least two of the essential amino acids required by animals. With a deficiency of sulfur these proteins are not produced and feed quality is lowered. Plants rich in protein have the greatest content of this element. Sulfur is required by soil organisms and if a soil is deficient, the rate of breakdown of organic matter may be slow and a nitrogen deficiency will result.

In past years, comparatively little attention has been given to the sulfur needs of plants. Since the more common superphosphate (20% P_2O_5) carries liberal quantities of this element, the addition of phosphorus by means of this material has regularly added also sulfur. It is probable that in many instances benefits from superphosphate have resulted partially from the sulfur as well as from the phosphorus. In areas where soft coal is burned, additions of sulfur from the air are probably sufficient to meet the needs of corn. In recent years, however, high analysis phosphates containing little or no sulfur have replaced considerable of the former superphosphate. Other materials of high analysis, particularly synthetic nitrogen materials, containing little sulfur have come into general use, and less soft coal is being burned. Where crop yields are increased by heavy fertilization with these purified materials, sulfur may become a limiting factor in corn production.

Magnesium—Magnesium is an essential part of chlorophyll, the green coloring matter in plants. This compound is essential for the formation of starches and sugars. Without magnesium, this compound is not formed. Plants deficient in magnesium are striped or pale in color. High crop yields and overliming with the pure calcium stone are reducing the availability of this element. Soils in some areas contain too little magnesium for optimum crop yields. Many Missouri soils contain more available magnesium in the subsoil than in the plow layer.

Calcium—Calcium is required by plants for the proper functioning of cell membranes. Without calcium, no growth is possible. The amount within corn plants is not great; nevertheless, it is essential for the absorption of all other elements by plant roots. The utilization of other plant nutrients is most efficient where calcium occupies from 70 to 85 per cent of a soil's capacity to absorb nutrients. When present in smaller amounts, the availability of phosphorus may be low and other elements such as manganese or aluminum may be present in toxic quantities. When it is present in too large quantities the availability of other elements may be reduced.

Trace Elements—Iron, Manganese, Copper, Boron, Zinc, Molybdenum, and Chlorine have been classified as trace elements since they are essential for plant growth but are required in very small amounts. The exact functions of each of these elements are not definitely known, but they are considered as catalysts. They are essential in aiding various chemical processes in the plant without becoming part of the compounds formed. Thus they can be used many times within a plant during growth, which partially explains why the amount required is so small and why there may be no direct relation between the amount of the trace element present and the amount of products resulting from it.

Little attention has been given to these elements in past years since it was believed that there either are sufficient amounts in the soil, or the required amounts are being added as impurities in limestone and other fertilizers. Correcting deficiencies of major plant nutrients and the change to highly concentrated fertilizers are adding much smaller quantities; higher crop yields are removing more; and excessive liming has reduced the availability of these elements. A combination of these factors can reduce the level of these trace elements to a point where they can limit plant growth.

Nutrient Losses by Erosion

The exploitive effects of corn on soil productivity have been due principally to the loss of nutrients through erosion on sloping soils, and the rapid breakdown of organic matter through summer cultivation, particularly when corn is not grown in sequence with sod crops. Experimental data show that essential minerals removed by corn grain are minor in contrast to the loss through erosion on sloping soil. The data given in Table 3 were obtained on Shelby Loam where (a) corn was grown without fertilizers, (b) the crops were planted with the slope, and (c) the population consisted of about 5000 plants per acre. More recent work, however, indicates that through a fertilization program which supplied available nutrients on contoured and terraced land adequate to support populations of 12,000 to 16,000 plants and yields of 100 bushels per acre, the losses from erosion can be greatly reduced.

Table 3 -- Amounts of Nutrients Removed by Corn Grain and by Soil Erosion on a Slope of 3.7%, Shelby Loam.

	Continuous Corn*		3-year Rotation: corn wheat, clover*	
Nutrients	Grain	Erosion	Grain	Erosion
Nitrogen	20	66	40	10
Phosphorus	8	18	16	3
Potassium	4	605	8	85

*Average of all crops for the 3-year period 1926-1928, in pounds per acre.

Recent experimental work during one year has shown that when corn follows corn, where adequate nutrients were added and the residues left on the surface, the losses of soil and water were less than where a sod crop was plowed under for corn.*

Experiments show that through additions of adequate fertility, the more rapid early growth of corn affords more protective cover early in the season. The use of adequate nitrogen speeds the early plant growth and shortens the period during which unprotected soil is left exposed to beating rains. The large amount of organic material from the dense stand returned to the surface affords good winter protection and will add more organic matter than the residues of any other crop normally grown and a portion harvested. Where sufficient fertility and populations are provided to raise yields in excess of 100 bushels per acre, the stalk weights (moisture-free) amounting from 3 to 4 tons per acre are returned to the soil. The weight of organic matter returned after removing over 100 bushels of corn grain will be from 2 to 4 times that added from the best stands of legumes. If sufficient nitrogen and minerals are present, these stalks break down rapidly and yields of the following crops are improved. These experiments indicate that through adequate fertility additions it may be possible to increase the percentage of the time that land is in corn without increasing erosion losses over those amounts obtained with best rotation practices in the past.

BUILD UP SOIL FERTILITY, RATHER THAN ADJUST CROPS

Since ancient times the sower going forth to sow has expected the crop yield to vary in fold according to differences in the soil on which the seed fell. For a long time, too, it has been a prevailing belief that changing the crops in sequence might have some beneficial effect on the nourishment of the crops that follow. But we are coming slowly to understand that when crops are grown and removed they do not contribute nourishment to the crops following on that soil. Even legumes must be sacrificed on the spot and turned under completely if the new nitrogen they gather from the air is to be added to the soil for its improvement. Careful studies are demonstrating that there is little contribution to the soil fertility—more often greater depletion of it—by no more than varied crop sequences.

Rotations and Manure

Rotations which include the corn crop following legume crops and the plowing under of manures have long been the accepted practices for adding nitrogen (potash in the case of manure) and organic matter to improve corn yields and to maintain good soil tilth. On farms where sufficient manure is available, the results from such have been excellent.

*D. D. Smith, Midwest Claypan Erosion Experiment Field, McCredie, Missouri.

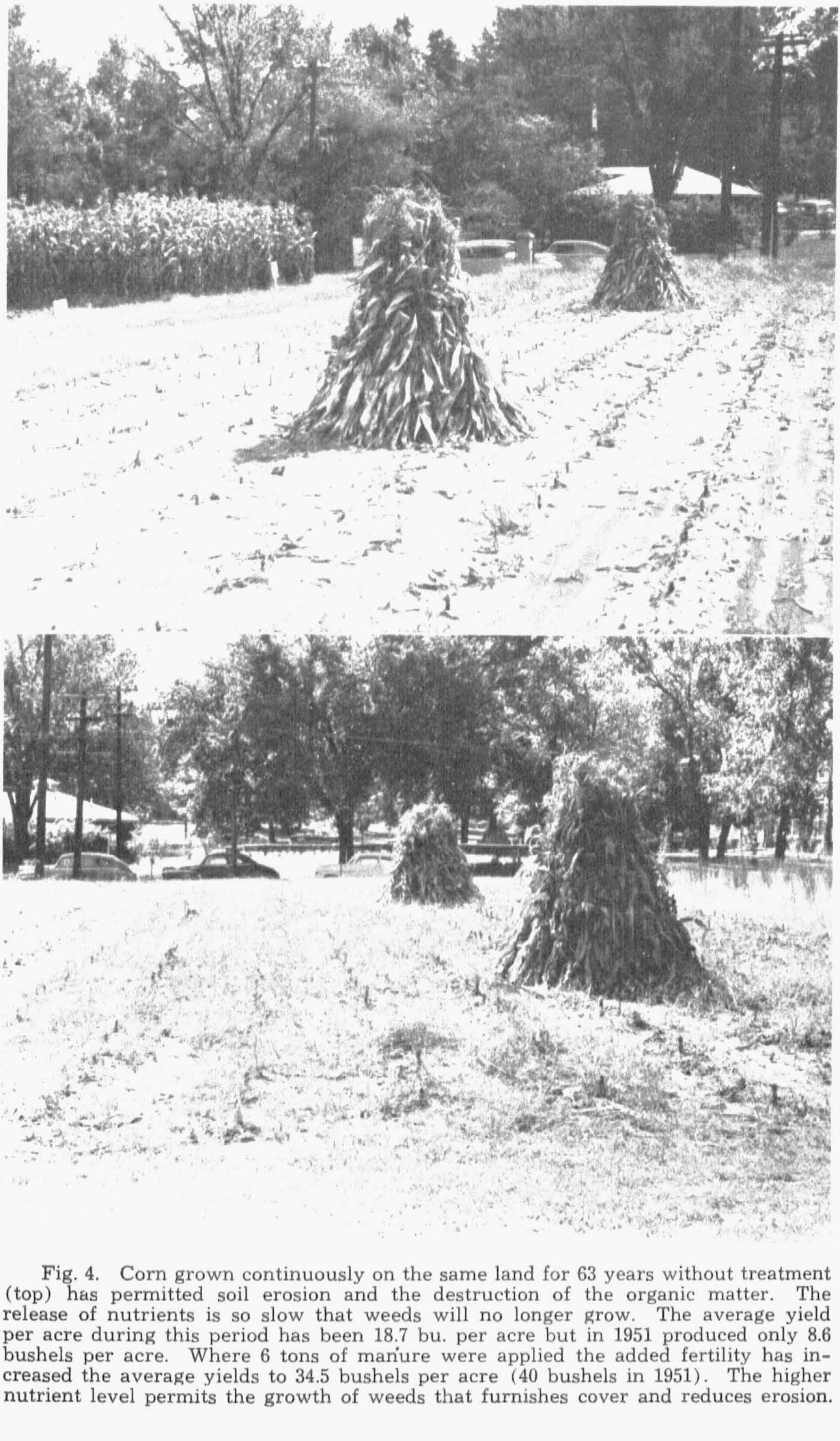

Fig. 4. Corn grown continuously on the same land for 63 years without treatment (top) has permitted soil erosion and the destruction of the organic matter. The release of nutrients is so slow that weeds will no longer grow. The average yield per acre during this period has been 18.7 bu. per acre but in 1951 produced only 8.6 bushels per acre. Where 6 tons of manure were applied the added fertility has increased the average yields to 34.5 bushels per acre (40 bushels in 1951). The higher nutrient level permits the growth of weeds that furnishes cover and reduces erosion.

However, on most farms in Missouri the amount of nutrients returned in manure to be utilized by the corn crop is too small to have significant effect on the average yields of the state. Serious losses of nitrogen and potassium occur even when the handling of manure is careful. Much is dropped on uncultivated pastures and not returned to areas where tilled crops are produced. Under present so-called "Balanced Farming Systems" where emphasis is placed on as much grazing as is possible (from 8 to 10 months of it are frequently obtained) and on the handling of forage crops so as to minimize labor requirements, the amount of manure that can be hauled and applied to corn fields is not significant.

The value of the legumes in rotation for improving the yield of corn has been greatly over-rated. Although legumes can have marked benefits both in adding nitrogen, and improving soil structures, a legume crop removed for hay depletes soil minerals and leaves little nitrogen. When a hay crop is removed, the nitrogen carried away in the forage frequently represents that fixed from the atmosphere by the bacteria while that remaining in the roots represents little beyond the amount absorbed from the soil.

Table 4 -- Average Yields of Corn Grown Continuously and in Rotation of Various Lengths on Sanborn Field During the Last 63 Years. (Bushels/Acre)

	50-year period 1888-1938		13-year period 1939-1951	
Cropping System	No treatment	6 tons manure annually	No treatment	6 tons manure annually
Continuous Corn	18.5	33.1	17.0	41.7
6-year Rotation*	37.9	50.8	25.3	46.3
4-year Rotation**	36.6	45.0	45.7	58.3
3-year Rotation***	31.7	46.9	33.0	60.1

*6-year rotation: corn, oats, wheat, red clover, timothy, timothy.
**4-year rotation: corn, oats, wheat, red clover.
***3-year rotation: corn, wheat, red clover.

Experiments conducted during the past 63 years on Sanborn Field show the influence of rotations on the yields of corn. Its growth continuously and in rotation illustrate the effect of this crop on the reserves of the soil minerals.

On the soil (Putnam silt loam) of average fertility (about 3400 pounds of nitrogen in the topsoil in virgin conditions) corn grown in rotation has produced higher yields than was true for corn grown continuously.

Legumes in the rotations have been of much benefit in helping to maintain soil nitrogen. However, in recent years the nutrient reserves in the untreated rotation plots have dropped to levels where clovers will not grow and non-legumes can obtain both nitrogen and minerals only in quantities producing low yields. Aside from the cover provided by grass and legume crops in rotations, which has reduced average erosion to less than that with continuous corn, the rotations have been more exploitive of mineral reserves than has the corn grown continuously.

Table 5 -- Plant Nutrient Levels in Soil After 63 Years of Cropping to Continuous Corn and Corn in Rotation of Various Lengths. (Pounds Available Per Acre in Surface Soil)

Cropping System	Soil treatment	Organic matter %	Total nitrogen#	P_2O_5	K	Mg	Ca	Lime requirement	pH
Continuous	None	1.3	1420	70	228	400	2912	8000	4.3
Corn	Manure@	1.8	1950	205	280+	780	3530	6000	4.7
6-year	None	1.6	1920	26	152	160	2630	7000	4.5
rotation*	Manure@	2.4	2620	93	280+	240	3520	7000	4.6
4-year	None	2.2	2060	34	228	180	2576	8500	4.5
rotation**	Manure@	2.8	2380	147	280+	240	2576	9000	4.5
3-year	None	1.5	1950	36	280+	180	2580	7000	4.8
rotation***	Manure@	2.2	2400	98	280+	240	2040	6000	5.0

*6-year rotation: corn, oats, wheat, red clover, timothy, timothy.
**4-year rotation: corn, oats, wheat, red clover.
***3-year rotation: corn, wheat, red clover.
@ 6 tons annually
# About 3400 pounds nitrogen in virgin state.

The residual fertility supplies in the soil after 63 years of cropping are shown by the soil test data given in Table 5. Rotations have been more exhaustive of soil minerals than has continuous corn. Legumes have removed greater quantities of these minerals and the low nitrogen level on the continuous corn plots has reduced the amount removed by continuous corn. Soil where corn has been grown continuously for 63 years, whether receiving manure or not, contains more phosphorus, magnesium and calcium and as much or more potassium than companion plots where corn has been grown in rotation. The greatest effect of rotations appears to be in a reduction of erosion from cultivated crops and in the addition of nitrogen by legumes. It is probable that the higher mineral contents of the continuous plots is due to the loss of the more highly weathered and leached topsoil with the consequent incorporation of unweathered minerals from the subsoil as successive plowings reach farther down into the profile. These results are contrary to the generally accepted opinion that rotations are of much value in maintaining soil fertility.

Green Manures for Maintaining Yields

In areas of livestock production, legume crops are usually pastured and the remainder turned under. Where corn is grown for sale of the grain, the entire legume crop is often sold as hay or may be plowed under before corn. Sweet clover and red clover have been the legume crops generally used as green manures, although all legumes have been used in other ways in various farming systems. In Missouri, large acreages of Korean lespedeza have been turned under before planting corn. Because of the close correlation between nitrogen available in the soil and corn production, yields of corn have served as a measure of the soil-building value of different legumes. Some of the earlier experiments are of limited value in this measure since it is now known that mineral levels on many soils were too low for optimum nitrogen fixation through legume growth.

It is well known that the total nitrogen and dry weight per acre increase but the percentage of nitrogen in legumes decreases as they become more mature. When the ratio of nitrogen to carbon in organic matter plowed under is wider than about 1:30, the soil organisms decomposing the organic residues will utilize most available nitrogen in the soil, the

Fig. 5. One hundred twenty bushels of corn on land formerly abandoned because the soil was considered too infertile.

rate of breakdown will be slow, and the following crop will not obtain sufficient nitrogen. For this reason it has become the general rule to plow under immature sweet clover or when it is less than "knee-high." It is then high in its concentration of nitrogen or has a narrow nitrogen-carbon ration, and the decomposition will be rapid. Recent work indicates that only a small amount of nitrogen is fixed by sweet clover in the spring of its second year, but that the nitrogen found in the tops consists mostly of that translocated from storage in the roots during the previous season. The present prevailing practice is moving toward plowing sweet clover under earlier in the spring when the top growth may be of a height of only 5 to 8 inches. This practice increases the availability of nitrogen but reduces the total organic matter added.

An experiment comparing sweet clover as a green manure crop with farm manure was started on Sanborn Field (Putnam silt loam) in 1923. A two-year rotation of corn and wheat was used where one-half of the plots were limed and sweet clover seeded in the wheat. The remaining plots received an 8-ton application of manure turned under before the corn. The yields obtained during the first decade are given in Table 6.

Table 6 -- Fertilizing Values of Farm Manure and Sweet Clover in a Corn-Wheat Rotation as Indicated by Yields of These Grains. (Bushels/Acre)

	CORN						
	1924	1926	1928	1930	1932	Average 1924-1932	Average 1924-1948
No treatment	47.3	47.2	64.8	13.8	14.4	43.5	28.0
Manure*	51.3	62.3	63.0	11.2	55.5	48.7	46.4
Sweet Clover	70.8	62.0	43.8	11.7	45.5	46.7	51.6
	WHEAT						
	1923	1925**	1927	1929	1931	Average 1923-1931	Average 1923-1949
No treatment	21.7	38.6	16.6	21.6	16.0	22.7	16.5
Manure	27.6	44.5	20.9	25.0	24.2	28.4	20.0
Sweet Clover	27.3	48.2	17.6	29.1	30.5	30.5	21.7

*Manure was used at the rate of 8 tons per acre. Both the manure and the sweet clover were used ahead of the corn.
**Oats was the crop in this year.

It soon became evident that the sweet clover was supplying more nitrogen to following crops than were the eight tons of farm manure. Although corn yields were higher during the first rotation after turning under sweet clover, production dropped off rapidly, corn lodged and symptoms of deficiencies of potassium were evident and those of phosphorus were suspected. In 1933 the plots were divided and one-half of each received 400 pounds per acre of 0-12-12 with both the corn and the wheat. This addition of phosphorus and potassium in the fertilizers, as shown in Table 7, corrected the earlier depressing effect by sweet clover on corn. This points to the necessity of proper balance between nitrogen and soil minerals for the production of optimum yields and good quality of grains.

Table 7 -- Fertilizing Values of Farm Manure, Sweet Clover, and Each of These Supplemented by Fertilizers, in a Corn-Wheat Rotation as Indicated by Yield of These Grains. (Bushels/Acre)

	Corn yield 6-year average*	Wheat yield 9-year average
No treatment	38.5	15.6
0-12-12 @ 400 lbs.**	40.7	23.6
8 tons manure before corn	44.6	17.7
8 tons manure before corn 0-12-12 @ 400 lbs.	50.8	20.8
Sweet clover	55.6	19.8
Sweet clover 0-12-12 @ 400 lbs.	60.2	20.2

*Yields for 1934 and 1936 are omitted from averages. Corn failed to produce grain because of summer droughts.
**0-12-12 @ 400 lbs. applied to both corn and wheat.

Effect of Legumes on Yields

In the majority of cropping sequences the corn follows the legumes for most efficient utilization of the nitrogen furnished by the legumes. The amount of nitrogen added by legumes will depend mainly on the inorganic fertility of the soil and the species of plant. However, experiments using organic matter for soil improvement show that in average seasons about 30 pounds of nitrogen will be released during the first year from each ton of dry material added and 15 pounds during the second year.

The results given in the Table 8 were obtained from 1936 to 1949 on Putnam silt loam where various legumes were turned under for corn. A three-year rotation of corn, small grain, and legume or grass was the basic cropping sequence. Where sweet clover was turned under as a green manure, or where lespedeza was the legume, there were two years of small grain, or one year of soybeans and one year of small grain. The plots growing red or sweet clover had been limed with 10-mesh agricultural limestone. They showed an amount of exchangeable calcium ranging from 5000 to 6000 pounds in the plowed layer and a pH of 6.3 to 6.6 in 1949. The remaining plots were not limed. They gave test results of about 3500 pounds of exchangeable calcium and a pH of from 4.9 to 5.2. At the start of the experiment, 400 pounds per acre of 0-10-10 were applied with the small grain. In 1945, the application was split. Half was placed in bands with the corn and the other half with the small grains. Soils tests made in 1949 suggested that deficiences of phosphorus and potassium were limiting the yields. The test showed that available phosphorus amounted to only from 25 to 40 pounds per acre and that the exchange-

Table 8 -- Comparison of Legumes in Rotation. (Putnam silt loam) (Bushels/Acre)

Plot No.	Cropping System	Average Yield* 1936-1949 12 year Corn	Average Yield 1945-1949 Corn	Average Yield 1945-1949 Wheat
1	Corn, small grain, red clover, 2nd crop under (Fall plowed)	56.4	67.8	35.8
2	Corn, small grain, red clover 2nd crop under (Spring plowed)	52.2	64.3	35.7
3	Corn, small grain, sweet clover Entire crop under	60.3	67.4	33.6
4	Corn, small grain, sweet clover Hay and seed crop removed	64.5	71.1	35.2
5	Corn, small grain, lespedeza under	56.3	66.7	33.8
6	Corn, small grain, lespedeza Two hay crops removed	53.2	63.5	32.5
7	Corn, small grain, grass, hay	53.5	68.4	30.7
8	Corn, soys (hay), small grain, lespedeza, Two hay crops	50.9	55.7	32.0
9	Corn, soys (hay), small grain, sweet clover (under)	57.6	58.2	35.4
10	Corn, soys (hay), small grain, soys, soys (2nd) under	54.8	53.3	33.6
11	Corn, small grain, soys (hay)	52.2	55.1	28.6
12	Corn, small grain, soys all stalks and straw removed	56.3	57.6	30.3
13	Corn, small grain, grass Am. sulfate @ 100# before corn	51.5	63.3	30.4
14	Corn, small grain, grass Am. sulfate @ 200# corn, 100# grass	52.5	64.8	31.6
15	Corn, small grain, grass Am. sulfate @ 300# corn, 200# grass	54.5	62.9	33.4
16	Corn, small grain, grass	51.9	63.9	29.1
17	Corn, wheat, barley and sweet clover (under)	57.0	64.9	34.7
18	Corn, wheat + lespedeza, barley lespedeza (hay)	49.6	56.0	29.2
19	Corn, wheat, lespedeza, barley + lespedeza (under)	54.6	63.0	32.1

*Lime only on red and sweet clover plots. 200 lbs. 0-10-10 with small grain and in row with corn.

able potassium varied from 80 to 160 pounds per acre. In general, the potassium levels were lowest where the grasses and legumes had been removed for hay. They were highest where sweet clover and lespedeza were turned under.

The small response from ammonium sulfate applied to corn indicated that on thin, unlimed soil, deficient in phosphorus, nitrogen was not the limiting element. More recent work shows that little response will be obtained from nitrogen applied to corn if phosphorus, potash, calcium, or magnesium are not present in adequate amounts.

The results for the 14-year period from 1936 to 1949 (12 crops of corn) and the last five-year period of 1945 to 1949 show that the highest yields of corn and small grains were produced in crop sequences using sweet clover as the legume for soil improvement. Where the sweet clover matured, the seed was combined and the straw removed, namely, plot 4, the yields have been higher than where the sweet clover straw was turned under on plot 3. It is probable that this material was so woody that its decomposition compelled the microbes to compete with the following corn crop for valuable nitrogen. The same situation existed where a full season's growth of lespedeza was turned under, plots 5 and 6. The reverse condition was found where two years of small grains were grown with corn and the lespedeza turned under green, plots 18 and 19. Yields were slightly higher where the lespedeza was turned under, plot 19. Where the dry, mature material was plowed down, it appears that the nitrogen added was not sufficient to decompose the lespedeza straw and to leave as much nitrogen available to the corn as where hay was removed.

Fall-plowing of red clover land gave slightly higher corn yields than spring-plowing. Both the turning under of the soybean straw after combining the seed and the removal of soybeans for hay depressed the corn yields.

Table 9 -- Yields of Corn in Rotations With Different Legumes Preceding on Putnam Silt Loam. (10-year average)

Rotation.	Bu. Per Acre
Corn, oats, wheat, sweet clover (seed) 4 year.	53.4
Corn, wheat, barley, sweet clover (under) 3 year.	60.9
Corn, wheat, red clover (hay)	49.3
Corn, oats + lespedeza, wheat + lespedeza, timothy + lespedeza (lespedeza and timothy for hay)	40.9
Corn, oats + soybean (hay), wheat + soybeans (under)	43.9
Corn, wheat, 4 years alfalfa	51.3
Corn, oats, (sweet clover under) 2 year rotation	44.1

Soil treatments: calcium limestone, 0-20-10 @ 150 lbs. with corn, 125 lbs. with oats, and 200 lbs. with wheat.

A comparison of different rotations (Table 9) all producing corn on Putnam silt loam and all receiving both lime and 0-20-20 for corn and small grains, shows results in agreement with those previously cited. The highest yields were obtained where corn followed sweet clover, red clover or alfalfa. Either mineral treatments have not been adequate, or some other deficiency was present, since it has not been possible to maintain good stands of alfalfa on this shallow soil for the short period of 4 years. Yields of corn following alfalfa have not been as high as where good stands of sweet clover were turned under for the corn. A two-year rotation of corn and oats, with sweet clover in the latter, produced satisfactory yields for the first few rotations, but dropped off in later years. It is believed that greater erosion contributed to these reduced yields. The lowest corn yields were obtained following lespedeza and soybeans. In-

Fig. 6. Different legumes plowed under in the fall for corn made these differences in the soil structure the following spring. Top—soybeans removed; center—lespedeza turned under; bottom—sweet clover turned under. Better seed beds for corn resulted in the above order.

Fig. 7. Non-legume crops, when supplemented with adequate nitrogen and minerals as a part of the crop sequence can build soil organic matter and improve yields of the following corn crops. Corn adequately fertilized following this sudan grass on Putnam silt loam produced more than 100 bushels of grain per acre.

jury by the insect (Grape colapsis) was prevalent where lespedeza was the legume. This injury was partially responsible for this lower yield.

Soil tests made on these areas after 14 years of cropping show that the mineral level of the soil is much lower where legumes have been removed for hay than where they are turned under (Table 10). This is particularly evident for the soil's contents of potassium and magnesium. Where sweet clover has been returned with only the seed removed, the exchangeable potassium and magnesium are 137 and 503 pounds per acre, respectively. Where red clover has been removed for hay, the soil contains only 75 pounds of exchangeable potassium and 397 pounds of magnesium. The phosphorus levels on the untreated soils are all low, but the level is slightly higher where legumes are not removed. However, the addition of superphosphate as a starter fertilizer to the grain crops has, in most cases, doubled the soil level of this nutrient after 14 years. There is evidence that the organic matter of the soil has increased where sweet clover has been grown. But where the corn followed soybeans, the soil organic matter has decreased.

Fig. 8. Legumes plowed under as green manure may not provide sufficient nitrogen nor break down rapidly enough for optimum corn yields. Nitrogen fertilizers turned under with legumes for corn may be wise soil management.

Table 10 -- Nutrient Contents of Soil After 14 years of Rotations With Different Legumes. (Each Figure Represents an Average of the Determinations-on Three or Four Plots-of Pounds Available Per Acre of Surface Soil.)

	Soil treatment	Organic matter	Phos-phorus	Potash	Magnes-ium
Corn, oats, wheat, sweet clover (seed)	Lime	2.5	29	123	510
	Lime + 0-20-0	2.7	48	142	495
	Lime + 0-20-10	2.7	68	146	505
	Average	2.63	48	137	503
Corn, wheat, red clover (hay)	Lime	2.5	20	69	426
	Lime + 0-20-0	2.3	41	75	426
	Lime + 0-20-10	2.6	58	81	340
	Average	2.47	40	75	397
Corn, oats + lespedeza, wheat + lespedeza, timothy + lespedeza, lespedeza + timothy removed for hay	None	2.5	15	75	510
	0-20-0	2.6	31	67	500
	0-20-10	2.6	34	69	495
	Lime + 0-20-0	2.6	46	64	415
	Lime + 0-20-10	2.6	40	65	390
	Average	2.58	33	68	462
Corn, oats + soybeans (hay), wheat + soybeans (under)	None	2.1	25	92	520
	0-20-0	2.1	53	114	540
	0-20-10	2.1	58	101	560
	Lime + 0-20-0	2.3	71	103	447
	Lime + 0-20-10	2.3	77	125	430
	Average	2.18	57	107	500

Green Manures and Growing Legumes

Cropping sequences, where two years of corn are followed by oats, legumes or with various combinations of winter legumes in the corn, were conducted for 10 years on a Lintonia fine sandy loam. The soil is deep and well drained. Soil tests made after termination of the experiment showed a pH of about 5.2, an organic matter content of 1.6 per cent, available phosphorus of 25 lbs. per acre, exchangeable potash 200 lbs. per acre, exchangeable calcium, 3 M.E. per 100 grams and an exchange capacity of 5 M.E. Only the soil growing sweet clover was limed. Superphosphate (20 per cent) at the rate of 150 lbs. per acre, was applied in the row with the first year of corn. A 4-12-4 fertilizer at the rate of 150 lbs. per acre was applied with the second year of corn. Oats received 200 lbs per acre of 20 per cent superphosphate. Although it is now known that this soil was too low not only in nitrogen, but also in phosphorus and calcium to show maximum benefits from the legumes, the differences in yields given in Table 11 show contrasts between the various green manure crops. Additional plant nutrients and thicker plantings would probably have increased the yields greatly.

The average yield of corn the first year after legumes or small grain was larger by six bushels than where corn followed corn. The highest yield of corn was obtained following sweet clover, with its residual effect on the second year of corn clearly evident. Vetch planted in both corn crops produced the next highest yield. This was about 7 bushels larger than corn following oats but it was 7 bushels less than where sweet clover was the legume. The second year of corn in the cropping sequence containing vetch gave a yield only two bushels larger than that following oats, and 4 bushels less than the yield from second year corn after sweet clover. Where 200 pounds of sodium nitrate or ammonium sulfate were applied to the corn, the yields of corn the first year were similar to those from plowing under vetch, but in the second year the chemical nitrogen as extra additions produced from 2 to 4 bushels more. On this acid soil, sodium nitrate was superior to ammonium sulfate. Stands of crimson clover on this untreated soil were inadequate to give any increase over oats or rye. Rye planted in the corn failed to increase the yield. It is probable that if sufficient quantities of nitrogen fertilizer had been applied, this rye would have reduced leaching and increased the yield of the following corn crop. Soybeans and cowpeas produced from 5 to 7 bushels more corn the first year than did oats, but the residual effect the second year was small. Yields following cowpeas were slightly higher than those after soybeans. Soybeans planted with corn failed to show much benefit. The application of 32 to 40 lbs. of chemical nitrogen

Table 11 -- Yields of Corn Reflecting the Effects on Them by Different Crop Sequences on Lintonia Fine Sandy Loam. (bushels per acre, ten-year average)

Plot	Rotation and Soil Treatment*	1st yr. Corn (Bu.)	2nd yr. Corn (Bu.)
1	Corn, corn, soybeans	42.1	36.0
2	Corn, corn, soybeans, sodium nitrate @ 200 lbs. side-dressing	48.9	43.9
3	Corn, corn, soybeans ammonium sulfate @ 200 lbs. at planting	47.7	42.7
4	Corn + crimson clover, corn + crimson clover, soybeans + crimson clover	41.1	38.6
5	Corn + rye, corn + rye, soybeans + rye	41.1	34.6
6	Corn + vetch, corn + vetch soybeans	48.6	40.5
7	Corn + soybeans, corn + soybeans, soybeans	42.5	35.4
8	Corn, corn, cowpeas	47.4	39.7
9	Corn, corn, soybeans	45.0	39.0
10	Corn, corn, oats	40.8	37.9
11	Corn, corn, oats followed by soybeans (off)	43.8	38.2
12	Corn, corn oats followed by soybeans (under)	47.6	40.8
13	Corn, corn, oats + soybeans (soybeans off)	39.8	36.7
14	Corn, corn, oats + soybeans (soybeans under)	43.3	38.7
15	Corn, corn, oats, lespedeza	47.8	39.5
16	Corn, corn, oats, red and alsike clovers	44.2	38.8
17	Corn, corn, oats + sweet clover (limed)	55.8	44.1
18	Corn, corn, oats	42.1	36.4
	Average	44.9	38.9

*Sweet clover plots were limed. First-year corn received 150 lbs. of 0-20-0 in the row; 4-12-4 @ 150 lbs. per acre applied in the row with second-year corn.

in a rotation with soybeans increased the yield of corn from 5 to 7 bushels indicating that nitrogen was the limiting factor. Where the soil was deficient in both calcium and phosphorus, the nitrogen added by legumes was small.

That the cropping system has influenced both chemical and physical properties of the soil is indicated by the chemical data and aggregate determinations given in Table 12. There is an indication that sweet clover has increased the soils' content of nitrogen and organic matter. This is further shown by an increase in the exchange capacity. This effect is

Table 12 -- Soil Differences as the Result of Cropping for Ten Years. (Lintonia fine sandy loam)

Plot	Cropping System	Soil Depth	lbs. N per A.	M.E. per 100 g. pH	Exc. Cap.	Exc. Ca.	Aggregation Over 1/32
6	Corn + vetch, corn + vetch, soybeans	0-7	1620	5.1	4.7	2.5	23.9
		7-14		6.1			
9	Corn-corn, soybeans	0-7	1750	5.5	6.1	5.4	18.5
		7-14		6.3	6.5	4.2	
15	Corn, corn, oats + lespedeza	0-7	1700	5.4	5.1	3.6	19.7
		7-14		6.2	5.7	4.3	
17	Corn, corn, oats, + sweet clover	0-7	1920	7.2	8.0	10.4	33.1
		7-14		6.5	6.7	8.0	
18	Corn, corn, oats	0-7	1700	5.6	5.8	4.0	21.9
		7-14		6.7	6.1	7.1	

manifested further by the higher percentage of stable soil granules where sweet clover has been grown. The soil producing sweet clover was 33 per cent in aggregates of over 1/32-inch in diameter while the percentage ranged from only 18.5 to 23.9 for the other soil treatments measured for their effects on this soil property.

Winter Legumes for Nitrogen and Organic Matter

In areas where cotton is grown, the cropping system frequently used on land of high value is one with corn and cotton grown in alternate years. Since there is little livestock to utilize the grain, this is sold as a cash crop. Consequently, there is little interest in crops for soil improvement when the land can grow and produce those with a ready sale value. Winter legumes are planted in both the corn and cotton to add nitrogen and organic matter The values of these legumes for increasing yields are shown by an experiment conducted on Lintonia fine sandy loam of which the data are given in Table 13.

During the five-year period of this experiment, vetch was superior to crimson or bur clover for increasing the yield of both corn and cotton. Vetch grown in the cotton and turned under in the spring for corn increased the grain yields nearly 12 bushels per acre. Where vetch was grown in both the corn and cotton the average yield of corn was increased an additional five bushels per acre. The application of ground limestone greatly increased the yield of all winter legumes. This effect is reflected in the higher yields of both the corn and cotton on the soil receiving limestone. Crimson and bur clovers did not make as satisfactory growth as vetch. Yields of corn and cotton following these two kinds of clovers were increased, but in lesser amounts than where vetch was turned under. The increased yields were greater following the legumes than where 32

Table 13 -- Yields of Corn (Bushels per Acre) and Cotton Seed Cotton, (Pounds per Acre) Grown in Alternate Years as Influenced by Winter legumes. (Five Year Crop Averages)

Plot	Cropping System and Soil Treatment	Yields Corn bu. per acre	Yields Seed Cotton pounds per acre
1	Corn - cotton	30.2	1232
2	Corn - cotton + vetch	42.0	1394
3	Corn + vetch, cotton + vetch	47.0	1474
4	Corn, cotton + vetch (2 tons lime)	46.5	1740
5	Corn, cotton + vetch (2 tons lime-100 lbs. per acre 0-20-0 drilled with legume)	44.2	1636
6	Corn, cotton + crimson clover	31.0	1501
7	Corn, cotton + crimson clover (2 tons lime)	36.0	1452
8	Corn, cotton + Bur clover	28.5	1302
9	Corn, cotton, Bur clover (2 tons lime)	36.0	1530
10	Corn, cotton - 100 lbs. $NaNo_3$ at planting and 100 lbs. ammonium nitrate side-dressed on cotton only	29.5	1314
11	Corn, cotton	24.8	1240
12	Corn + soybeans (under) cotton	18.0	1276

pounds of nitrogen as sodium nitrate were applied to the cotton. The planting of soybeans in the corn for a green manure crop not only depressed the yield of corn but failed to increase the cotton yield.

While legumes have been much heralded as "soil builders," and while crop rotations of many varied combinations were put together for supposed soil improvement by way of the rotations and the effects of these legumes, the yields of non-legumes have not shown that they were getting much nitrogen uplift as a result of particular crop sequences. The necessity of using the legume crops for feed has too often aborted the good intention of using them to increase the nitrogen in the soil.

Availability of Nitrogen Changes Management Practices

The fact that chemical nitrogen is now extensively on the market as fertilizer has resulted in the initiation of new experiments in producing continuous corn on soils where erosion is not a serious problem. By supplying all the nutrients required by corn, it can be planted more thickly or as heavier populations of stalks. With adequate nitrogen, yields of 100 bushels per acre have been produced for four years on Putnam silt loam. (Table 14.) Formerly corn had not been recommended on this soil except

Table 14 -- Yields of Corn on Putnam Silt Loam Grown Continuously With Adequate Plant Nutrients. (Yield in Bushels per Acre)

Nitrogen treatment and rate of planting	1948	1949	1950	1951	Average
No nitrogen 10,000 plants	79 bu.	49 bu.	62 bu.	56 bu.	61.0 bu.
150 lbs. nitrogen 10,000 plants	98 bu.	79 bu.	95 bu.	84 bu.	89.0 bu.
150 lbs. nitrogen 16,000 plants	107 bu.	102 bu.	109 bu.	102.6 bu.	105.2 bu.

one year after legumes. Yields of 40 bushels per acre were formerly considered good.

All of this soil under experiment has received lime, rock phosphate, and potassium in amounts indicated by soil tests. Twenty per cent superphosphate was applied in bands at planting time at the rate of 150 lbs. per acre. Nitrogen had been applied on the surface and plowed down. It is of interest that where no nitrogen was applied the yield varied 30 bushels, (from 49 to 79 bu. per acre) but where both the nitrogen application and the plant population were high the seasonal variation in production was only 7 bushels per acre.

This heavy application permits thick planting. This stand and heavy growth serve for the addition of more organic matter residues annually, while yet producing a crop for harvest, than is possible with any other system in this Midwest area. The data in Table 15 show the tonnage of air dry material as crop residues added by corn when planted at different rates and where varying amounts of nitrogen were plowed down.

Table 15 -- Corn Stover returned to Soil in 1951 With Varying Nitrogen Treatments and Rates of Planting. Crop-1949, Lespedeza; 1950, Corn. Average of Two Varieties - US 13 and Dixie 33. Moisture Content Corrected to 15 Per Cent.

	Nitrogen Plowed Down (pounds per acre)		
Plants per acre	50 (lbs.)	120 (lbs.)	250 (lbs.)
8,000	3790	3980	4130
10,000	4210	5050	4830
14,000	4920	6720	5623
18,000	5000	5860	7180

The more dense population possible with this heavy fertilization not only has increased the yields and added increased quantities of organic matter, but also has greatly reduced erosion through this addition of organic fertility. The use of adequate nitrogen hastens the early growth of corn and shortens the period during which unprotected soil is left exposed to beating rains. The increased fertility permits thicker planting of corn and furnishes additional soil cover. The same principle applies to soybeans and other row crops.

The shredding of from 3 to 4 tons of corn stalks per acre to be left on the soil surface in the fall provides much protection to the cornland over winter. The cornland is unprotected for only the short period from the time of plowing under the stalks until the new crop affords cover. If sufficient nitrogen is plowed down with the corn stalks no depression in the subsequent crop yield from the addition of this large amount of carbonaceous material is noted.

Experimental work in progress for only a few years indicates that the value of rotations of different lengths and of continuous cropping systems should be re-examined and reconsidered under conditions where crop yields are not hampered by inadequate plant nutrients. There are not many instances where the number of kinds of crops being grown would not make a rotation (particularly from the standpoint of disease and insect control or distribution of labor) most practical. However, it now appears that on soils where erosion is not a serious problem and where adequate fertility is added, the continuous growing of cultivated crops such as corn may be feasible. Contrary to results of former experiments, high yields can be produced and preliminary data indicate that the soil's content of organic matter and nitrogen may be increased.

Nevertheless, the rotation of crops for other values than soil improvement by means of legumes will still be a worthy crop management matter. While the use of chemical nitrogen can add nitrogen readily to the soil, the legume crop in the rotation can by no means be disregarded for its feed value in terms of the compounds of higher nutritional values only better legumes on better soils can provide. Chemical nitrogen is an addition to, but not a replacement of, other parts and practices in the better management of the soil.

ADJUSTING SOIL FERTILITY TO CROP NEEDS IS GOOD SOIL MANAGEMENT

While nitrogen has long been recognized as the dominant nutrient deficiency in the soil to limit the size of the crop, it has only recently been possible to add the extra nitrogen in experiments to demonstrate how seriously deficient our soils are in this element. While legumes can add nitrogen to the soil by sacrificing the values of these crops as feeds, we have not been prone to make that sacrifice for soil improvement in terms of nitrogen. Instead, legume crops have been going off the land as protein-rich feeds for the animals. At the same time they have been carrying away other elements of fertility beside nitrogen at depletion rates higher than those for non-legumes. Even if nitrogenous fertilizers seem costly, they are demonstrating that through the use of them, crop yields can be obtained in amounts per acre scarcely ever anticipated before. War nitrogen for explosives, now diverted to soils for more food production, has changed our concepts of managing the soil for corn production.

Fig. 9. More bushels of grain per acre and more crop residues plowed under to build up the soil organic matter can be had from corn than from any other Corn Belt crop. Proper soil treatments are required. 1. The yield of corn on Putnam silt loam, given adequate soil treatments, was 134 bushels of grain and 3½ tons of stover (dry weight). Runoff and erosion are reduced during the growing season and at other times by the better soil structure resulting from more organic matter put into the soil. 2. The heavy crop of stalks left after harvesting over 100 bushels of grain requires special cutters to chop them before they can be worked into the soil effectively.

Fig. 9. (Continued) 3. A ground cover of chopped residues from a 100-bushel corn crop protects the soil from beating rains and serious erosion. 4. The plow must be well adjusted and the coulter sharp to turn under the heavy growth of corn stalks. With adequate nutrients in the soil the rapidly decaying stalks can add more organic matter than legume crops, and yet maintain optimum yields of all crops grown. The corn crop is not erosive—man's mismanagement of the soil is.

Supplementing Legumes with Nitrogen

Starting in the fall of 1949, chemical nitrogen was added to half of the plots of an old legume experiment before the corn crop. All plots were limed individually according to soil tests. One thousand pounds of rock phosphate per acre were placed in the subsoil with a T.N.T.* plow, and an additional 1000 pounds were worked into the surface soil. Muriate of potash was applied in varying quantities to bring the exchangeable potassium to 280 pounds per acre. Supplemental nitrogen was added to the corn in the rotation on one of each pair of legume plots as outlined in Table 16 and in varying amounts following timothy.

Data for two years of corn and one year of wheat show that, with adequate mineral levels in the soil, the addition of commercial nitrogen with all the legumes produced significant increases in yield of both grains. (Table 16). Where 66 pounds of nitrogen were plowed down ahead of corn with the red clover sod, the yield of corn was increased from 90.3 to 106.9 bushel per acre. Where sweet clover was the legume, the chemical nitrogen raised corn yields from 100.8 bushels to 113.4. Similar increases were obtained when chemical nitrogen was used along with lespedeza and soybeans. It is of interest that, in previous years, lespedeza produced the greatest corn yield when the growth of this legume was removed as hay. When chemical nitrogen was added to the soil the highest yield and the greater increase in corn yield from nitrogen was obtained where the lespedeza was turned under. This would indicate further that the percentage of nitrogen in this dry material is not high enough to release sufficient amounts of this element to the following corn.

The increase in corn yields from applying increasing quantities of nitrogen to timothy sod (Plots 12-16, Table 16) before plowing the plots for corn indicates that a high mineral level is essential for the utilization of nitrogen. An application of 132 pounds of nitrogen per acre increased the yield of corn by 12 bushels over the yield where 66 pounds were applied. The increase by the application to 200 pounds of nitrogen did not give a significant additional increase. In previous years nitrogen was applied to these same areas, but then the low supplies of phosphorus, potassium, and calcium prevented a significant response.

On soils with a high clay content in the subsoil, the residual effect of nitrogen after corn is significant. Wheat on Plots 12 to 17 (Table 16) all received 300 pounds per acre of 3-12-12 and showed the effect of nitrogen applied to corn. Where no nitrogen was applied, the wheat produced 15.7 bushels per acre. Where 66 pounds of nitrogen were applied, the

*This is an ordinary mold-board plow with a small plow following behind to be set at variable greater depts. Produced by the Oliver Corporation.

Table 16 -- Crop Yields Indicating the Beneficial Effects of Nitrogen Fertilizer as Supplement to That From Legume Residues.

Plot	Cropping System	Nitrogen Added	Yields* Corn	Yields* Wheat
1	Corn, wheat, red clover	None	90.3	15.7
2	Corn, wheat, red clover	66 before corn	106.9	25.8
3	Corn, soybeans, wheat, sweet clover	None	100.8	21.1
4	Corn, soybeans, wheat, sweet clover	66 before corn	113.4	24.1
5	Corn, wheat, lespedeza wheat, lespedeza	None	93.8	19.8
6	Corn, wheat, lespedeza wheat, lespedeza	66 before corn	97.6	21.5
7	Corn, wheat, lespedeza (under) wheat, lespedeza (under)	None	98.8	17.8
8	Corn, wheat, lespedeza (under) wheat, lespedeza (under)	66 before corn	105.5	19.5
9	Corn, wheat, soys	None	90.3	16.2
10	Corn, wheat, soys	66 before corn	112.6	19.5
11	Corn-wheat-alfalfa-timothy	66 before corn	103.5	22.8
12	Corn-wheat-timothy	200 before corn 66 before timothy	116.7	28.0
13	Corn-wheat-timothy	132 before corn 66 before timothy	114.5	22.7
14	Corn-wheat-timothy	66 before corn 66 before timothy	102.5	19.0
15	Corn-wheat-timothy	33 before corn 66 before timothy	95.7	18.0
16	Corn-wheat-timothy	None	86.2	15.7
17	Corn-wheat-timothy	66 before corn	120.4	17.8
18	Corn-wheat-timothy	66 before corn 33 before wheat 66 on timothy	119.0	20.8
19	Corn-wheat-timothy	66 before corn 66 on wheat 66 on timothy	131.5	22.1

All soils limed to pH of 6.2, 2000 lbs. rock phosphate in 1949, 3-12-12 @ 150 lbs. on corn and @ 300 lbs. on small grains.
* Corn, 2-year average, wheat 1 year.

yield was 19 bushels, and where 200 pounds of it were plowed down ahead of corn the wheat yield was 28.0 bushels. Considering price levels of wheat and costs of fertilizer nitrogen in 1951, the residual effect of 200 pounds of this element applied to corn increased the yield of the following wheat crop by 12.3 bushels per acre. This increase of the wheat was sufficient to pay for all of the nitrogen applied on the preceding crops.

On soils having a high clay content in the subsoil, it appears that the loss of nitrogen through leaching is small and much of the residual nitrogen applied to corn may be held to be used by the following crops. Similar results were obtained where the corn was preceded by various legumes used as nitrogen-fertilizing crops. In the rotation with red clover preceding the corn, the residual nitrogen increased the yield of wheat following the corn by 10.1 bushels per acre. After sweet clover in place of red clover in a similar crop sequence, the yield of wheat was raised from 21.1 to

Table 17 -- Nitrate Contents Remaining in Various Soil Horizons (Putnam Silt Loam) in Early November After a 90-Bushel Corn Crop Following Soil Treatment With Ammonium Nitrate. (Pounds nitrate nitrogen per acre.)

Nitrogen applied per acre (pounds)	Soil Depth 0-7"	7-14"	14-21"	Total
0	16 lbs.	7 lbs.	4 lbs.	27 lbs.
50	10 lbs.	6 lbs.	7 lbs.	23 lbs.
120	23 lbs.	14 lbs.	6 lbs.	43 lbs.
250	64 lbs.	54 lbs.	8 lbs.	126 lbs.

24.1 bushels. Similar increases in wheat yield following corn were obtained in the rotation where lespedeza and soybeans were the legumes.

The determinations of the nitrate nitrogen at different depths in a Putnam silt loam show that a considerable quantity of this form of nitrogen remains in the soil following heavy applications of nitrogen fertilizers (Table 17).

Considerable nitrogen from the 120- and 250-pound applications remained in the soil in nitrate form in the fall after the corn was harvested, according to these analyses. However, most of it was still in the surface 14 inches, and little was found in the heavy clay at the depth of 14 to 21 inches. The quantity found the following spring was much smaller, but it is believed that most of it was converted into other forms of nitrogen by microbial action and thereby not lost from the soil.

To Increase Yields Fertilize by Tests

In the past few years, soil tests have been developed and calibrated to give a measure of the nutrient reserves in the soil and to correlate them closely with crop yields and with the response by corn and other crops to additions of chemical forms of plant nutrients. A better understanding of the nutrient needs of corn, together with a fuller appreciation and wider use of soil tests, have not only made fertilization of corn profitable but also have made possible the production of high yields of corn on soils formerly classified as unadapted to this crop.

Corn producing 100 bushels per acre requires approximately 175 pounds of nitrogen, 30 pounds of phosphorus, and 80 pounds of potassium. Experiments conducted during the past six years show that if the levels of available nutrients in the surface soil, according to the soil tests, are raised to supply 200 pounds of soluble nitrogen, 125 pounds of available phosphate, and 280 pounds of exchangable potassium during the growing season, then with a sufficient stand of a good variety of corn, it is possible to produce profitable yields approaching 100 bushels per acre on most Missouri crop land in average seasons. Not only can this high yield be obtained, but the protein content and quality of the grain can also be improved.

A summary of 208 fertilizer tests conducted on a wide variety of soils in various sections of the state from 1945 to 1951 is reported in Table 18. In most cases where nitrogen was added, the phosphorus and the potassium were also supplied in needed amounts by soil tests. The yields reported for untreated soils, or those untested include the plots where no fertilizer was added or where only a small application was made in the row at the time of planting. The rate of planting was generally the same

Table 18 -- Yield Responses by Corn to Adequate Soil Treatments From 1945 to 1951. Fertilizers Applied According to Soil Tests. Phosphorus and Potassium Added in Quantities to Eliminate These Limiting Factors.

		Soil Treatments according to soil tests.			No treatment or soil treatment without soil tests.	
Years	No. of Experiments	Av. N. lbs. p/A	Plants p/A	Yld bu. p/A	Plants per acre	Yield bu. per acre
		Northeast Missouri				
1945-49	20	94	10,000*	92.8	10,000*	63.4
1950	10	133	11,240	101.6	10,438	67.4
1951	21	70	13,420	98.4	10,743	60.4
		Northwest Missouri				
1945-49	10	28	8,252	70.1	7,186	52.1
1950	27	74	11,220	103.5	10,990	77.2
1951	31	41	12,300	87.6	11,362	51.4
		Southwest Missouri				
1950	17	125	13,000	89.4	8,240	45.6
1951	26	118	12,760	90.4	8,100	39.2
		Missouri Ozark Region				
1945-50	9	78	9,890	82.1	6,620	56.3
1951	20	85	10,532	93.1	8,800	57.3
		Southeast Missouri Lowlands				
1950-51	17	85	13,600	93.2	11,050	57.6
Average (total) all experiments	208	79.6	11,770	92.3	9,000	56.9

*Number of seed planted per acre. Remainder of population figures based on stand count at time of harvest.

for all soil treatments. In a few cases, the grain was planted thicker as heavier additions of nutrient was made. Although the seed was planted at the same rate with the same planter, it was generally observed that the well-fertilized corn had stands from 5 to 15 per cent thicker at harvest than the corn not fertilized. Apparently, the increased fertility improved germination, emergence, and survival. The more rapid growth of the fertilized corn probably resulted in less destruction of it by early cultivation.

When all of the experiments are considered, fertilization according to soil needs, which included an average nitrogen addition of 79.6 pounds per acre, produced an average yield of 92.3 bushels per acre. This was an increase of 35.4 bushels above the 56.9 bushels obtained with inadequate fertilization. This is approximately one bushel increase in yield for each 2.2 pounds of nitrogen added. The average yield for the state during this same period was 36.3 bushels per acre. This state yield is twenty bushels below the yield of 56.9 bushels obtained on the low treatment plots. However, the soil treatment and crop management were probably better on the experimental areas with low treatment than under average farm conditions of the state. It appears reasonable to believe that if all corn land were fertilized and managed as well as the treated areas in these experiments were, there would be little difficulty in doubling the state's corn production without increasing the acreage.

It is also evident that with adequate fertilization, the natural levels of soil fertility in different soil types become of less importance. In the Ozark Region, Southwest, and Northeast Missouri where soils are considered lower in plant nutrients, the yields were not significantly lower than those in the sections of the state where the soils have higher natural contents of nitrogen and organic matter and have formerly been considered the superior corn producing regions.

Increased Fertility Supports Increased Planting and Larger Yields

Increasing the fertility supplies of the soil will result in larger ears of corn. However, this increase in size soon reaches its limit. In order to obtain the maximum benefits from these higher fertility levels, it is necessary to increase also the rates of planting or to grow more ears. That yields are increased as the population is increased is shown by the data given in Table 19, even if individual ear weight may have been decreased. The results of numerous experiments indicate that under practical farm conditions a population that will give ears weighing about .6 pound will produce maximum yields. If populations are increased to re-

Table 19 -- Yields of Corn and Weights of Ears With Adequate Fertilization of the Soil but at Different Rates of Planting.

Soil Type	Nitrogen Added (lbs/A)	Population - Plants per Acre 5-6,000 Yield bu/A	5-6,000 Wt. lb/ear	8-9,000 Yield bu/A	8-9,000 Wt. lb/ear	10-12,000 Yield bu/A	10-12,000 Wt. lb/ear	16-18,000 Yield bu/A	16-18,000 Wt. lb/ear
Putnam silt loam	150	--	--	--	--	89.0	.81	105.2	.67
Putnam silt loam	100	--	--	87.5	.78	101.6	.69	111.5	.62
Putnam silt loam	120	79.5	.68	87.8	.66	94.8	.60	112.3	.57
Sarpy sandy loam	132	--	--	121.0	.90	151.0	.80	149.0	.70
Wabash silt loam	100	--	--	93.9	.78	108.0	.69	113.5	.64
Marshall silt loam	150	--	--	94.6	.83	102.5	.70	121.3	.62

duce the ear weight below this point, the yields frequently decline because smaller ears are produced.

If ears weigh .6 pound, then a total of 11,666 ears with a shelling percentage of 80 per cent will be required to produce a yield of 100 bushels. Planting rates of 12,000 to 13,000 plants per acre appear most desirable for producing 100 bushel yields with adequate fertility.

A population of 13,000 plants per acre will require a spacing of about 12 inches within the row and in 40-inch rows or 13 inches within the row and in 38-inch rows. Experiments have indicated that closer spacing of the rows than 38 inches will reduce the amount of sunlight reaching the lower leaves, and will make cultivation difficult with present tractor equipment. There is evidence that planting two or three plants per hill with the same number of plants per acre will permit better utilization of plant nutrients with higher yields resulting.

SCIENTIFIC SOIL TREATMENTS INCREASE QUANTITY AND QUALITY

Not only has the tractor changed our methods of corn production, but various other machines are now increasing the efficiency of producing this crop. Machinery for applying fertilizers in bands along with the planted corn, for putting it down deeper into the soil, and for supplementing the corn with extra nutrients during its later growth periods are now available. The chemical engineer, too, has done much in giving us forms and compoundings of fertilizers, not to mention single materials now going into the soil to build it up for crop yields and animal feeding qualities. Most of these advances were scarcely anticipated only a few decades ago.

Methods of Applying Fertilizer

A high percentage of the corn-producing soils in the state have "claypan" or heavy subsoils, so that the leaching of nutrients in percolating water is not a serious problem. Most of these subsoils are acid, are low in plant nutrient contents, and have a high capacity to "fix" nutrients. In wet seasons, corn roots do not penetrate into this less fertile subsoil in sufficiently large numbers for ample nutrition. In dry seasons many plant symptoms of nutrient deficiencies are observed when roots must depend on these lower less fertile horizons for moisture. On many of these soils it is not possible to add sufficient nutrients in row application to obtain maximum yields. Because of summer droughts, side dressing applications may not penetrate to the root zone in time to prevent deficiencies. Plowing down the major portion of the soil treatment, with a "starter" application near the row at the time of planting, has given superior results on the heavier soils in dry seasons. On those soils that are sandy, side dressing of nitrogen at the early stages of growth is desirable since plowing nitrogen down may result in a leaching loss on these soils.

Some trials of different methods of applying fertilizer were carried out on a Putnam silt loam that was limed according to soil tests. The soil was low in phosphate but contained adequate amounts of potassium. A two-year rotation of corn and oats with sweet clover was followed. These results during a three-year period indicate that row applications of fertilizer were not adequate, and that the different methods of applying the phosphate made little difference in the yield. The data obtained are given in Table 20.

Table 20 -- Different Yields Representing Responses by Corn to Different Methods of Applying Fertilizers on a Putnam Silt Loam With Sweet Clover Turned Under. (3-year average)

Fertilizer Used (Kind, Lbs. / A)		
Ahead of Planting	With Planting (in row)	Yield
----	----	77.7 Bu.
----	3-12-12, 150	81.9 Bu.
0-20-0, 900 under	3-12-12, 150	99.1 Bu.
0-20-0, 900 surface	3-12-12, 150	98.4 Bu.
Rock phosphate, 1000 under	3-12-12, 150	100.5 Bu.
Rock phosphate, 1000 surface	3-12-12, 150	100.6 Bu.

Fourteen experiments were conducted during 1942 to 1944 where from 200 to 300 pounds of mixed fertilizers applied in the row were compared with the same quantities plowed under. In these trials on various soil types, the corn without treatment produced an average yield of 37.1 bushels. Where all the fertilizer was applied in the row, the yield was 40.6 bushels, but where the fertilizer was plowed under, the yield was increased to 46.3 bushels per acre. In only one instance was the yield of corn fertilized in the row higher than where the same soil treatment was plowed under.

Nitrogen as ammonium nitrate was applied to corn on Putnam silt loam at different times of the year for the 1950 season. Mineral deficiencies had been corrected according to soil tests. The data, shown in Table 21, indicate that all of the applications of nitrogen in this one trial increased the yield but there was no significant difference under these conditions because of the time of the application.

All the experimental data at hand, and the results obtained by cooperating farmers, indicate that the major part of the fertilizer applied should be plowed under on all but the sand soils in Missouri. In years of adequate rainfall the method of application makes little difference; but in dry years, the fertilizer will be inefficiently absorbed by corn plants if it is applied on only the surface of the land.

On the heavier soils there appears to be no serious loss of nitrogen applied in the fall for the next year's crop. This is particularly true of those materials containing nitrogen in the ammonia form. Where leach-

Fig. 10. This corn produced from 125 to 150 bushels per acre. Where the nitrogen addition was high (upper picture) lodging amounted to nearly 100 per cent. When only a small amount of nitrogen was added (lower picture) in starter fertilizer the plants remained standing much better. Both areas received adequate phosphorus and potash. It is suggested that some other elements than those normally considered deficient may be lacking.

ing or erosion losses will not be a serious problem, the application of fertilizer for turning under may be done in advance of plowing in connection with a more efficient utilization of farm labor.

Table 21 -- Corn Yields as Related to Time of Application of Ammonium Nitrate on Putnam Silt Loam, 1950.

Treatment	Time of Application	Yield of Corn per acre
Starter fertilizer only*		79.6
100 Pounds N	Fall	105.4
200 Pounds N	Fall	106.8
100 Pounds N	Spring	109.8
200 Pounds N	Spring	112.6
100 Pounds N plus	Spring	
100 Pounds N	Side Dressed	110.4
100 Pounds N	Side Dressed	106.4

*This was a 3-12-12 at the rate of 150 pounds per acre applied in the row on all plots, with the nitrogen as supplements to it.

Applying Fertilizers in the Row

Before adequate soil testing procedures were developed and before the practice of fertilization that supplied nutrients according to crop removal, extensive experiments were conducted with various fertilizer ratios on numerous soil types in various parts of the state. Comparisons of various fertilizer ratios for corn were a regular phase in the plans for all outlying experiment fields. A modern-type corn planter was used on all fields. Replicated experiments were conducted on individual private farms. For some years the following fertilizer formulae were applied at 150 pounds per acre in bands near the seed at the time of corn planting:

0-12-4	4- 8-4	4-12- 0	8- 8-8
4-12-4	4-12-4	4-12- 4	0-20-0
8-12-4	4-16-4	4-12- 8	No fertilizer
12-12-4	4-24-4	4-12-12	
		4-12-24	

Results from these experiments were erratic. Yields were frequently lower than when no fertilizer was applied. In many cases, these experiments had a negative demonstration value. They were convincing farmers that the increases from fertilizing corn were not dependable and not profitable. Yields were inferior in contrast to those obtained from turning under manure or sweet clover and the use of chemical fertilizers was too often considered an unprofitable practice. During this period the price of nitrogen was high in relation to the value of the corn and, except in a few areas, little nitrogen was used. It was even believed that corn could no longer be proftably grown on many soils. As a consequence, the small grains and grasses were substituted in the cropping sequence.

The fertilizer ratios in these experiments were changed and the following formulae were applied at the rate of 150 pounds per acre at time of planting:

0-20- 0	10-20- 0	No fertilizer
0-20-10	10-20-10	
0-20-20	10-20-20	

The resulting increases in yields were only slightly more than those obtained with previous fertilizer ratios. Frequently those increases were not sufficient to pay consistently for the cost of the treatments. In many cases increases or decreases in yield could be correlated with the past soil management, but results were disappointing. When the soil tests were developed, then it was usually possible to explain the positive response, or lack of increase, from the particular nutrient level in the soil.

A survey of 473 replicated fertilizer treaments made over a period of seven years from 1937 to 1943 shows that, in 366 instances, the average increase in yield of corn from these treatments was 7.8 bushels per acre. However, in the same experiments there were 97 trials which resulted in a decreased yield of 5.9 bushels per acre. The increases in yield resulting from 150 pounds of fertilizer varied from a low of 1 bushel to a high of 28 bushels. With 125 cases, or 34 per cent, the increases in yield were 4 bushels per acre or less. The decreases in yield were as much as 31 bushels per acre, and there were 35 instances, or 36 per cent, where the decreases were 5 bushels per acre or more.

It is now believed that the amount of nitrogen then being applied was insufficient and the quantity of phosphorus applied in bands was inefficiently absorbed during the dry seasons so frequent at this Midwest location. In many cases where decreases in yield were recorded, early stimulation of the plant growth was striking. It is believed that this increased early growth raised the total plant nutrient requirement so much that when the limited amount of plant nutrients supplied in fertilizers was exhausted these plants suffered as much or more deficiency later in growth than those for which there was no early stimulation.

Improper Fertilization Reduces Yields

Adding an excess of one nutrient element, particularly when another element is deficient, may result in an improper balance and may reduce crop yields. An excess of nitrogen may not only amplify deficiencies of other elements but may result in other irregularities as increased lodging of the corn, for example, so that a significant percentage of the stalks is missed by mechanical pickers. This has been demonstrated in individual experiments. The results given in Table 22 were obtained when nitrogen was applied to Putnam silt loam in combination with different levels of available phosphorus and exchangeable potassium.

These data indicate that an excess of nitrogen, or a deficiency of po-

Table 22 -- Yields and Lodging of Corn According to Nutrient Balance of Putnam Silt Loam. (Average of Two Years)

Soil Treatment	Available Phosphate	Exchangeable Potassium	Yield corn bu. per acre	% lodging
Lime-Nitrogen	26	122	53.1	9.0%
Lime-Nitrogen Phosphate	140	116	50.5	46.0%
Lime-Nitrogen Phosphate-Potash	132	240	110.5	3.0%

Soil Limed to pH 6.5.
Ammonium Nitrate @ 500 pounds per acre plowed down.
Rock phosphate applied to phosphate treated plots.
Muriate of potash plowed down on potash plot to furnish 280 lbs. per acre of exchangable potassium.
0-20-0 and 0-20-20 applied to respective plots in bands when corn was planted.

tassium, (the amount of nitrogen applied to all plots was the same) reduced the yields and increased the lodging. The use of phosphate in previous years reduced the level of exchangeable potassium below that in the area receiving only lime. These results were obtained where the same soil treatments, except nitrogen, have been used for ten years.

In an experiment on Baxter silt loam, the use of nitrogen in a starter fertilizer failed to increase the yield of corn when potassium was inadequate.

Table 23 -- Yields of Corn According to Various Starter Fertilizers on Baxter Silt Loam Deficient in Potassium. (Two year average - Three replications)

Soil Treatment	Yields of Corn
None	39.3
0-20-0	54.5
0-20-10	56.8
0-20-20	56.0
10-20-0	40.8
10-20-10	55.6
10-20-20	60.0

Other elements in excess can also result in improper balance to influence both the yield and the composition of the grain. Even though yield and quality may not be affected by the addition of unneeded nutrients, the cost of treatments will be unnecessarily increased and results may be disappointing. The use of soil tests offers the best guide for proper soil fertility additions. One can scarcely proceed on the general belief "If a little is good, more will be better."

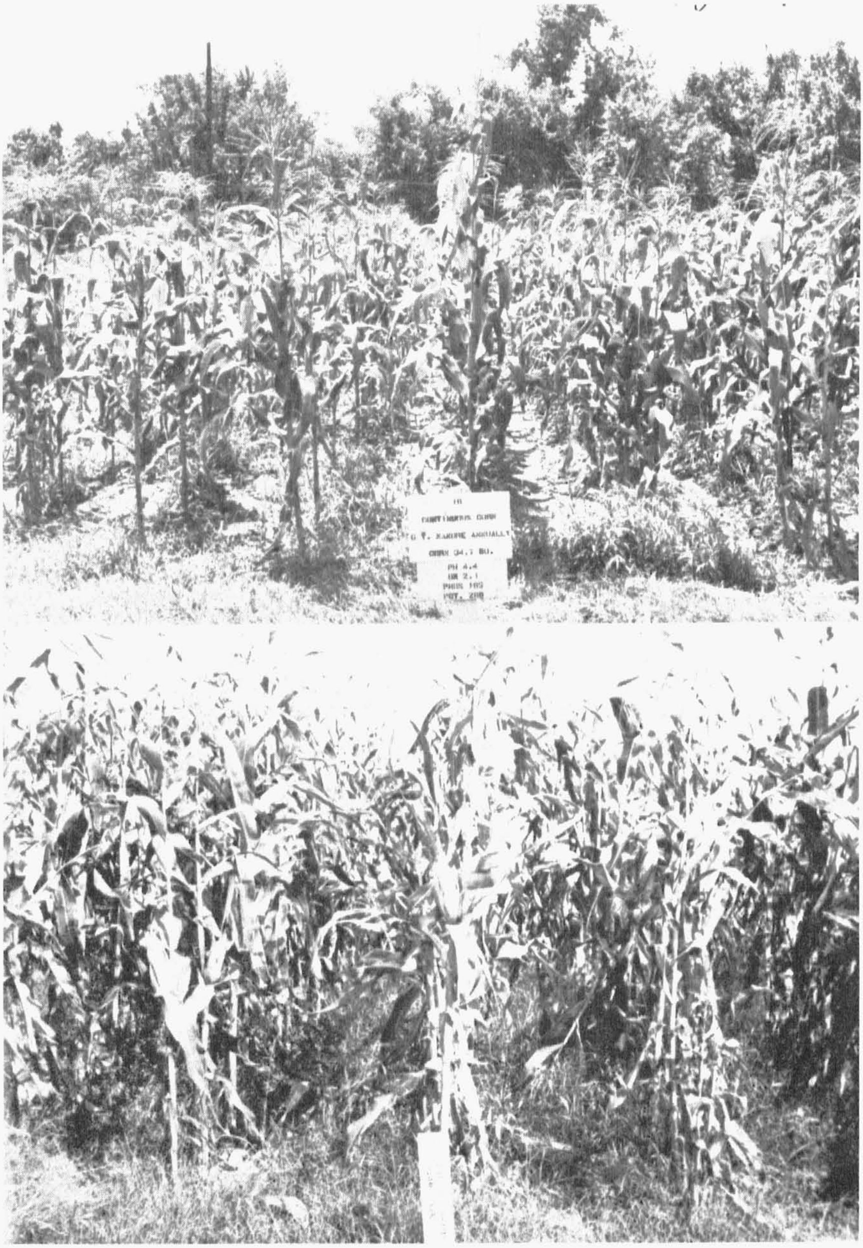

Figure 11. Soil treatments made the difference on these two plots of similar original fertility. Manure only (above), yield 34.7 bushels of corn per acre. Manure plus fertilizers according to soil tests (below), yield 120 bushels of corn per acre.

Kinds of Chemical Nitrogen for Corn

The present demand for chemical nitrogen fertilizers far exceeds the supply. A number of different nitrogen-providing materials are on the market and all will be satisfactory if properly used according to the results given in Table 24. Where more than one kind of the materials described below is available, the price per pound of nitrogen should be the deciding factor. This can be determined by dividing the number of pounds of nitrogen per ton into the cost per ton. It is frequently possible to buy nitrogen in the late fall or early winter for the next season. It can be kept in satisfactory condition if stored in a dry place on boards (not on concrete). The bags should not be piled more than 5 high.

Table 24 -- Yields of Corn According to Different Forms of Nitrogen Used as Fertilizer. (two-year average, Putnam silt loam, 200 pounds nitrogen per acre plowed down)

	Yields corn per acre
No nitrogen	91.3 bu.
Ammonium nitrate	106.7 bu.
Anhydrous ammonia	108.8 bu.
Ammonium sulfate	101.0 bu.
Cyanamid	112.0 bu.
Calcium nitrate	111.6 bu.
Sodium nitrate	101.7 bu.
Urea	113.4 bu.

This soil had been adequately treated with lime, phosphorus and potassium.
A starter fertilizer of 3-12-12 @ 200 pounds per acre was applied at time of planting.

Ammonium Nitrate.—This is probably the most widely used source of nitrogen in Missouri at the present time. It usually contains 33.5 per cent nitrogen, half of which is in the nitrate and half in the ammonia form. The nitrate moves rapidly through moist soil and is immediately available to the corn plants. The ammonia portion of this nitrate does not move through the soil so readily. This form can be used by corn, but most of the ammonia is changed to the nitrate in the soil before being utilized.

Ammonium nitrate takes up moisture readily from the air and is difficult to handle when exposed during humid weather. It will corrode metals, and distributing machinery should be washed with water immediately after use, dried and then thoroughly oiled with a mixture of lubricating oil and kerosene.

Anhydrous ammonia.—This is a gas at ordinary temperatures and pressure, but a liquid containing 82 per cent nitrogen when highly compressed. In the liquid as commonly delivered, it exerts a pressure of about 200 pounds per square inch at 100°F and expensive equipment is required for storage and application. It must be applied by means of

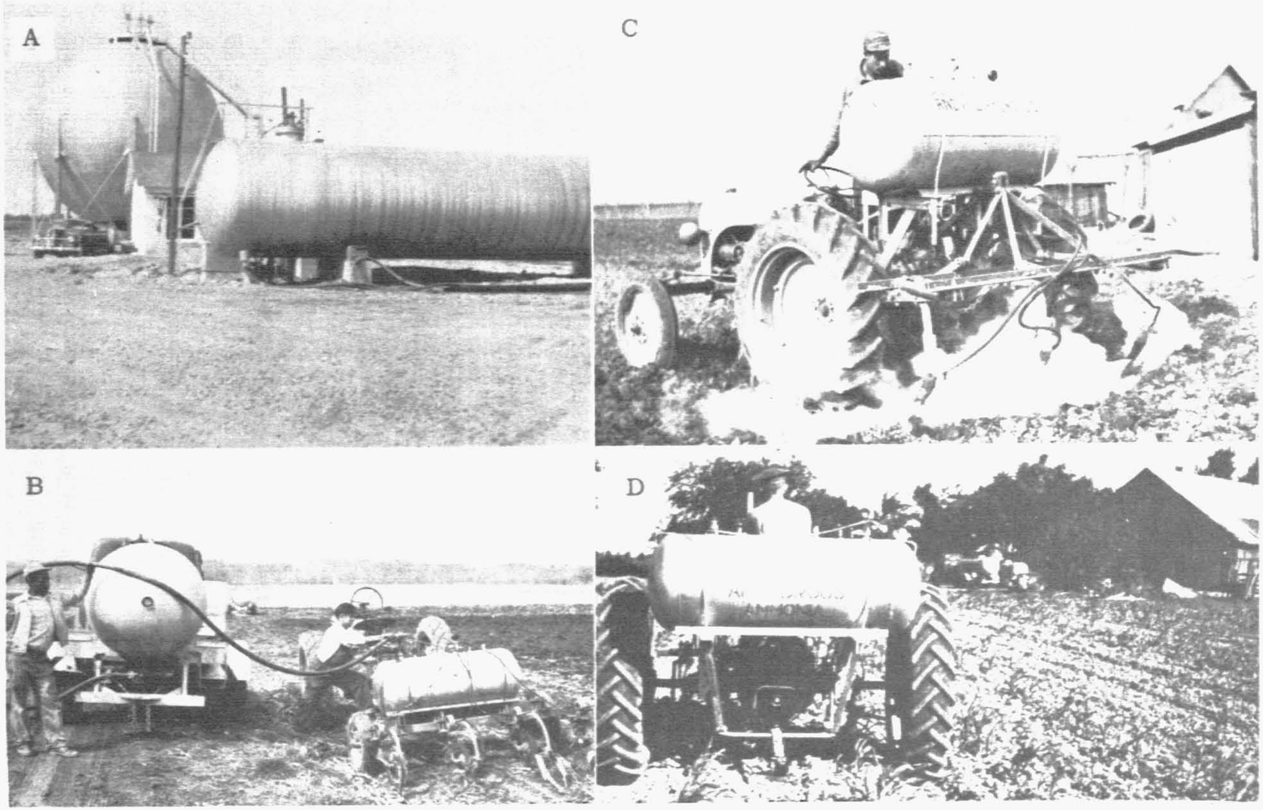

Fig. 12. Anhydrous ammonia is an important source of nitrogen—particularly for the corn crop. (A) High pressure tanks are required to store ammonia, which is a liquid when compressed. (B) Anhydrous ammonia is being transferred from tanks on truck to tractor tank. The truck can haul about 4000 pounds or sufficient nitrogen to apply 100 pounds per acre to 40 acres. The tank on the applicator holds about 350 pounds of nitrogen. (C) Ammonia gas is being released to test equipment before starting application. When placed deep in moist soils the ammonia is absorbed and held in the soil. (D) Anhydrous ammonia can be applied as late as corn can be cultivated. On soils with a high clay content application before planting is desired. On sandy soils later applications are more efficiently utilized.

special applicators at a depth of at least six inches within the soil. The ammonia gas is rapidly absorbed on the clay of the moist soil. After a few days the soil can be safely worked without any danger of loss of the ammonia. Since all of the nitrogen is in the ammonia form it can be applied earlier in the season than most other forms. When the soil is moist, however, it will give good results on corn if applied as late as the last cultivation. Even when applied late in dry seasons, it may give better results than some of the solid forms applied then since the points on the applicator can place the material 6 inches below the surface and in a moist region where roots are actively growing.

Anhydrous ammonia is probably the cheapest source of nitrogen available. Present indications are for greatly increased supplies within a few years. Because of the expense of storage and application of nitrogen on small farms it is usually more economical to have the material applied by custom operators. However, if as much as 80 pounds of nitrogen are applied per acre, it can usually be purchased applied to the soil for about the same cost as that of solid materials at the dealer's warehouse. This saves transportation and application costs. Expense records indicate that it is more economical to own application equipment and small storage tanks and to make one's own applications on larger farms.

Table 25 -- Corn Yields (Bushels per Acre) Under Comparison Test of Ammonium Nitrate and Anhydrous Ammonia. (Phosphorus, Potassium and Lime Levels Were Either High or Were Made Adequate by Addition of These as Soil Treatments).

Soil type	No Nitrogen	Ammonium Nitrate 80 lbs. N.	Anhydrous Ammonia 80 lbs. N.
Marshall silt loam	82.1 bu.	103.1 bu.	98.2 bu.
Marshall silt loam	64.9 bu.	90.9 bu.	85.2 bu.
Cass silt loam	99.7 bu.	119.9 bu.	118.9 bu.
Grundy silt loam	94.4 bu.	121.5 bu.	117.7 bu.
Wabash silt loam	69.2 bu.	76.2 bu.	85.5 bu.
Wabash silt loam	74.0 bu.	81.9 bu.	81.2 bu.
Cass silt loam	84.1 bu.	104.7 bu.	106.5 bu.
Marshall silt loam	82.1 bu.	88.6 bu.*	91.7 bu.*
Marshall silt loam	64.9 bu.	85.5 bu.*	88.0 bu.*
Average	79.5 bu.	97.0 bu.	96.9 bu.

*32 pounds of Nitrogen

That the response to applied nitrogen by corn is not widely different whether it be applied in the ammonium nitrate or in the anhydrous ammonia forms is shown in Table 25 where the same quantities of nitrogen from the two materials were compared on different soil types. In these nine trials the yields of corn were increased by slightly more than 17 bushels per acre from 80 pounds of nitrogen on a soil producing nearly 80 bushels per acre without nitrogen. There were no significant differences between the responses from ammonium nitrate and those from anhydrous ammonia.

In other experiments anhydrous ammonia has given consistent increases in yields as shown in the summary of the yields from the numerous experiments listed in Table 26. In those 40 separate experiments where the nitrogen applied as ammonia varied from 40 to 120 pounds per

Table 26 -- Yields of Corn According to Applications of Anhydrous Ammonia. (Bushels per Acre)

Number of Experiments	Anhydrous Ammonia applied lbs. N per acre.	Yields: No nitrogen	Yields: Anhydrous Ammonia
13	73	81.7	112.3
9	71	64.7	88.5
6	40	97.7	116.2
6	80	97.7	120.5
6	120	97.7	115.6
Average 40 experiments	75.7	85.0	109.2

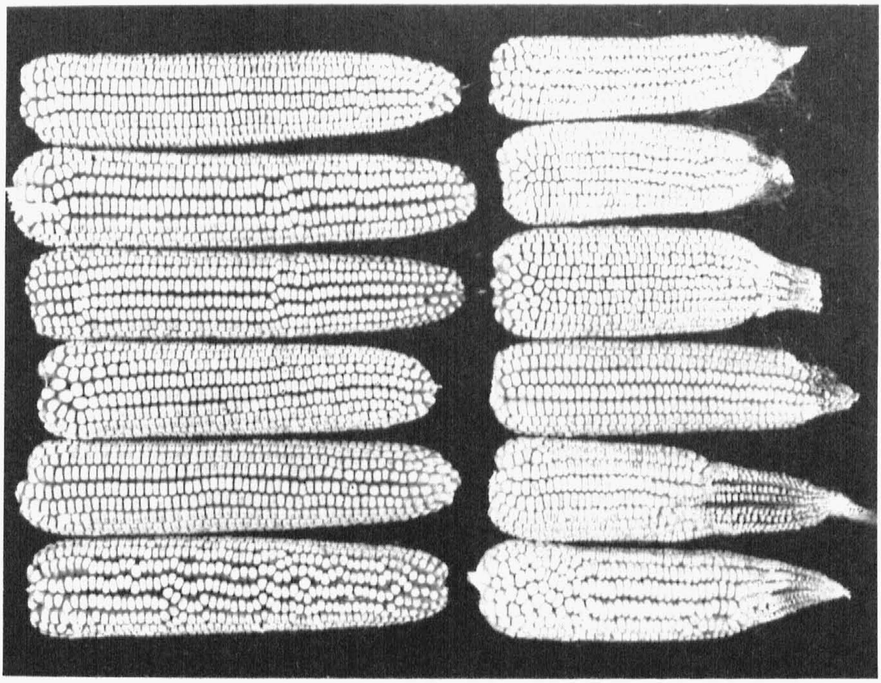

Fig. 13. Effect of potash on corn. The ears at left were grown on soil well supplied with potassium. Those on the right were produced on soil where the removal of legume crops for hay without adequate fertilization had made the soil deficient in potassium. Note the tapered ears and poorly filled grains.

acre (average 75.7 lbs.) the yield of corn was increased from 85.0 to 109.2 bushels per acre, as a mean. This is an increase of about 1 bushel of corn for each 3 pounds of nitrogen applied.

Ammonium Sulfate.—Most ammonium sulfate is a by-product of the coke industry. It contains from 20 to 21 per cent nitrogen, and is used extensively in making high analysis mixed fertilizers. It leaves an acid residue requiring about 110 pounds of limestone to neutralize the acid resulting from each 100 pounds of ammonium sulfate. This is not objectionable on Missouri soils that have been limed. In addition to supplying significant amounts of sulfur, this acid residue will increase the rate of solubility of rock phosphate, ground limestone and reserve minerals of fertility value in the soils.

Cyanamid.—This is a nitrogen-carrying material containing 21 per cent of nitrogen with a calcium residue. It is slower in becoming available for plant use than most nitrogenous fertilizer materials. It is toxic to growing plants from the time of application until it has undergone certain chemical changes in the soil. It should never be applied in the row at the time of planting. It has given excellent crop response when plowed down for corn. Three days should elapse between plowing and planting for each 100 pounds applied in order to permit the necessary chemical changes to take place.

Urea.—This is a synthetic nitrogen compound containing about 42 per cent nitrogen. It is slightly slower in becoming available than are the ammonia compounds but has given excellent results on corn.

A.N.L.—(Ammonium Nitrate with dolomitic limestone). This is ammonium nitrate that has been processed with magnesium limestone. It contains 20.5 per cent nitrogen and about 7 per cent magnesium oxide. It has better physical properties than ammonium nitrate, and is easier to handle. It is made only in the eastern part of the United States and little is shipped to Missouri.

CalNitro.—(Calcium ammonium nitrate). This compound is similar to A.N.L. It contains 20.5 per cent nitrogen. Most of this material available in Missouri is now imported from Europe.

Ammonium Nitrate-Sulfate.—This is a material imported from Europe. It contains about 26 per cent nitrogen. It is a mixture of ammonium nitrate and ammonium sulfate.

Sodium Nitrate.—This is a saltpeter containing 16 per cent nitrogen. It is either imported from Chile or made synthetically. It is very soluble and excellent for side dressing.

Nitrogen solutions.—Some nitrogen solutions are being offered for direct application to the soil. One of these contains 32 per cent nitrogen, half of which is derived from urea and half from ammonium nitrate. This solution weighs about 10 pounds per gallon and will furnish 32 pounds of nitrogen for each 10 gallons. It can be applied with weed sprayers. Preliminary work indicates it is a good source of nitrogen.

CHEMICAL COMPOSITION MAY BE MODIFIED THROUGH SOIL TREATMENTS

While the chemical composition of this grain has had research attention by the efforts of the plant breeder in careful selection and propagation of certain lines for higher or lower concentration of crude protein in this feed, it is now evident that this quality is markedly responsive to the fertility treatment as a phrase of management of the soil. We are, therefore, moving toward putting the nutritional quality of this crop as animal feed under improvement and control much as we are lifting its yields of bushels per acre. That this can be a by-product effect from the soil treatment serving to give more returns in bushels per acre is a significant fact in bringing more soil treatments into practice.

Fertility Level Influences Chemical Composition

The textbook on "Feeds and Feeding" by Morrison* has been the standard of feed and grain analyses in this country for many years. In the 11th edition published in 1911 the crude protein content of corn grain is listed as 10.3 per cent. In the 20th edition of 1936 the percentage protein in No. 2 corn was 9.4 per cent, but in the 21st edition of 1950 it had dropped to 8.6 per cent. It has been suggested that this decline in protein of corn from 10.3 to 8.6 per cent in 39 years, or a relative decline of 16.5 per cent, is associated with the loss of nitrogen from the soil which has taken place under more intensive cropping.

For the past 10 years, corn hybrid U. S. 13 has been used in most experiments in soil fertility at the Missouri Agricultural Experiment Station. Determinations of the crude protein (total nitrogen times 6.25), the amino acids, the mineral contents and the hardness, have been made on a large number of the samples. The results of the determinations of nitrogen in corn grain grown on Sanborn Field in 1950 are presented in Table 27. In these seven samples, the crude protein contents of corn grain varied from a low of 7.09 per cent, produced on soil without treatment, to a high of 11.4 where full soil treatment was applied. This is a relative increase of over 61 per cent resulting from differences in soil fertility levels with the same variety of corn on the same soil type. It is evident that on nitrogen-deficient soils the crude protein content of corn will be low. Adding nitrogen in amounts to produce optimum yields

*F. B. Morrison, *Feeds and Feeding*, The Morrison Publishing Company, Ithaca, New York.

Table 27 -- Protein Contents (N X 6.25) of Corn Grain Produced on Sanborn Field in 1950*

Cropping System and Soil Treatment	Protein Percent	Yield Grain Bu. per acre	Pounds Protein per acre in grain
Continuous corn no treatment	7.09	22.5	89.3
Continuous corn 6 tons manure annually	9.50	51.2	272.4
Continuous corn Full soil treatment	11.00	126.8	781.0
3 year-rotation Full soil treatment	11.41	105.8	664.0
2 year-rotation - Full soil treatment Calcium lime	10.75	109.5	656.1
2 year-rotation - Full soil treatment Magnesium lime	9.75	107.7	585
2 year-rotation Full soil treatment Magnesium lime, trace elements	11.03	107.9	663

*Analyses made by Department of Agricultural Chemistry.

Table 28 -- Protein Contents of Corn in Relation to Legume and Chemical Fertilizers. (per cent)

Rotation	Lime	Lime + 0-20-0	Lime + 0-20-20
4 Year red clover Full Nitrogen*	9.25	10.03	10.7
3 year - red clover under before corn	7.56	7.91	7.56
4 year - sweet clover before corn	8.66	9.12	9.03
4 year - lespedeza before corn	7.72	7.16	7.56
3 year soybeans before corn	7.81	7.44	6.91

*100 lbs. of nitrogen per acre. Remainder of plots received no nitrogen in fertilizers.

may increase the nitrogen content of the grain. It is also evident that other elements can also influence both the percentage of protein and the total production of protein per acre.

Some protein analyses of corn grain produced on Putnam silt loam are given in Table 28. Corn following sweet clover was higher in protein than that following other legumes when no chemical nitrogen was applied. Phosphorus and potassium had no significant effect on the con-concentration of protein although there was indication of a higher value where balanced soil treatments were applied. The addition of 100 pounds of nitrogen per acre to a rotation in another experiment on Putnam silt loam increased the protein concentration in corn following red clover by raising it from 3 up to 4 per cent of the dry weight.

Numerous other chemical analyses show that the addition of nitrogen to soils which are very low in this element may result in a substantial increase in the protein concentration in the crop. However, experimental data do not show that the addition of nitrogen will always increase the concentration of the nitrogen in the grain.

In fact there is evidence that grain from plants receiving a well-balanced supply of nutrients may contain a lower percentage of nitrogen than where nitrogen is supplied but other nutrients may be deficient and the plant nutrient level is out of balance. It is suggested that only when the nitrogen supply is increased in a large proportion to other elements that substantial increases in nitrogen concentration will be obtained.

Soil Treatments and Hardness of Corn

Corn receiving adequate amounts of soil treatments may be less starchy and harder than that grown on soils of low fertility. Soil treatments have greatly influenced the hardness of the grain* as shown by the data in Table 29. Hybrid U. S. 13 showed a relative hardness of only 16.4 when grown on untreated soil, while on a high but unbalanced nitrogen level, which resulted when lime and sweet clover were the only soil treatment, it gave a hardness factor of 20. However, when phosphorus and potassium were added with the sweet clover, the corn was softer than

Table 29 -- Soil Treatments and the Hardness of Corn Grain Grown on Putnam Silt Loam.

Soil Treatment	Yields Bushels per A.	Relative* hardness
None	28.0	16.4
400 lbs. 0-10-10	31.4	15.8
8 Ton Manure	29.5	18.0
8 Ton Manure 400 lbs. 0-10-10	41.0	17.0
Lime-Sweet Clover	51.0	20.0
Lime-Sweet Clover 400 lbs. 0-10-10	56.5	15.5

*Determination by force required to push a 15° point, 2 mm. in diameter into the endosperm. (Average of 100 grains.)

where no soil treatment was applied. The 0-10-10 fertilizer also made the corn softer when manure or no other treatments were added.

It is possible that other changes in the corn grain as well as those which can be measured by tests of hardness may be variables in plant composition that influence the value of these crops as feeds.

*Relative force required to push a 15-degree point into the endosperm.

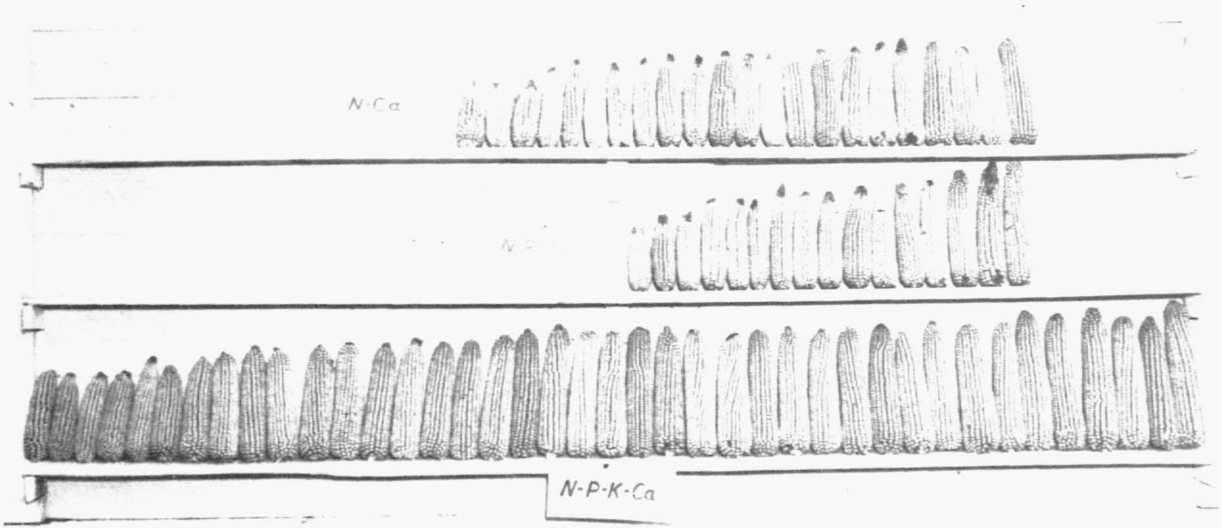

Fig. 14. Proper nutrient balance is necessary for highest yields of quality corn. All of this corn received adequate nitrogen and lime. The bottom row of ears was grown on soil receiving adequate phosphorus and potassium. The yield was 118 bushels per acre. The corn in the middle was produced where potassium had been exhausted by previous cropping. The yield represented by this row of ears was 48 bushels per acre. The top row represents the yield of 67 bushels per acre produced on soil never receiving phosphorus or potassium. The previous phosphorus deficiency left a lower potassium level than where crop yields have been increased in the past by adequate phosphorus. Soil tests offer a reliable means of determining soil nutrient reserves and amounts that must be added for optimum crop production.

Soil Treatments and Shelling Percentage

Heavy soil treatments and thick stands of corn that will produce high yields in bushels do not necessarily give large individual ears. However, these soil treatments and changes in plant population have little effect on the ratio of grain to cobs. Determinations of the shelling percentages were made of corn receiving a wide variety of soil treatments on four soil types. The data are reported in Table 30. Where nutrient levels were very low (Sanborn Field), the percentage of grain was slightly reduced. When either nutrient levels or populations were increased the ratio of grain to cobs was not changed significantly.

Table 30 -- Soil Treatment and the Shelling Percentage of Corn Grain 1950, Season.

Experiment Field or Soil Type	Cropping System and Soil Treatment	Yield Bu/A	Weight/Ear lbs.	Shelling Percentage
Sanborn Field	Continuous corn no treatment	22.5	.23	78.6
Sanborn Field	Continuous corn 6 tons manure annually	51.2	.59	79.4
Sanborn Field	Continuous corn Full soil treatment	126.8	.61	82.2
Sanborn Field	3 year rotation Full soil treatment	122.7	.56	80.9
Putnam silt loam	Starter fertilizer (150 lbs., 3-12-12 per acre	84.2	.50	81.8
Putnam silt loam	Starter fertilizer +50 lbs N.	81.7	.47	82.9
Putnam silt loam	Starter fertilizer +120 lbs N.	112.0	.55	82.1
Putnam silt loam	Starter fertilizer +250 lbs. N.	114.9	.49	82.1
Marshall silt loam	No fertilizer	89.2	.60	80.6
Marshall silt loam	Starter + 100 lbs. N	97.2	.67	80.6
Marshall silt loam	Starter + 200 lbs. N	102.5	.70	81.4
Wabash silt loam	Full treatment 11,000 plants	100.8	.76	83.3
Wabash silt loam	Full treatment 14,000 plants	110.4	.62	84.7
Wabash silt loam	Full treatment 16,000 plants	115.6	.58	81.2

SOIL TESTS GUIDE PLANT NUTRITION

Soil treatments with fertilizer are now a matter of adding to the soil's supply the extra amounts of the nutrients more nearly required to bring the yields of grain and forages up to calculated amounts. Soil tests are being more widely used while being improved. Our knowledge of the dynamics of the different elements in the soil is increasing so that one can more clearly view the soil management as a matter of guaranteeing complete plant nutrition for the crop in question.

Determining Amount of Fertilizer To Apply

The use of soil tests has come into prominence in recent years as a means of determining the reserves of nutrients in the soil. These tests may differ in their procedures and their results in various sections of the country, but when the adapted tests are properly correlated with field experiments they will give a reliable index of nutrient levels. Consequently they can show the amounts of the various elements that must be added to soils to eliminate these nutrients as factors limiting the crop production. For indicating the kind of starter fertilizer to use, these tests are of only limited value. As a case, for example, they cannot show whether a starter fertilizer should be a 3-12-12, 4-12-8 or an 8-8-8. But when used in connection with all other information about the soil, they are of decided help in planning the soil treatments using the different materials.

Nitrogen.—Adequate nitrogen is necessary to obtain high yields of corn. The grain contains approximately one pound of this element per bushel and an equal quantity will be required, in an average season, to grow the stalks to produce one bushel of grain. In ideal seasons a smaller quantity will be needed from the soil and in "poor corn seasons" a larger amount is necessary.

The amount of nitrogen that a soil will deliver to a corn crop will depend on (a) the percentage of organic matter in the soil, (b) the soil texture, (c) the nature of the organic matter turned under, and (d) the moisture and temperature conditions during the growing season. For silt loams from 1½ to 3 per cent of the total nitrogen in a soil will be released annually. The higher figure will hold in ideal seasons and the lower amount when weather conditions are adverse. Clay and clay loam soils will release from 1¼ to 2½ per cent of the total soil nitrogen, while sands and sandy loams will have available from 4 to 6 per cent. Data for release of nitrogen from organic matter are given in Table 31.

Table 31 -- Nitrogen Released From Organic Matter.

In Surface 7 inches of Soil (2,000,000 lbs.):			Pounds Nitrogen Released Through Average Growing Season.		
Per Cent Organic Matter	Stable Organic Matter lbs./A	Total Nitrogen lbs./A	Silt Loams (1)	Clay and Clay Loam (2)	Sands and Sandy Loam (3)
0.5	10,000	500	7.5 to 15	6.25 to 12.50	20 to 30
1.0	20,000	1,000	15.0 to 30	12.50 to 25.00	40 to 60
1.5	30,000	1,500	22.5 to 45	18.50 to 37.00	60 to 90
2.0	40,000	2,000	30.0 to 60	25.00 to 50.00	80 to 120
2.5	50,000	2,500	37.5 to 75	31.25 to 62.50	Sandy Soils
3.0	60,000	3,000	45.0 to 90	37.50 to 75.00	seldom have
3.5	70,000	3,500	52.5 to 105	43.75 to 87.50	over 1 1/2%
4.0	80,000	4,000	60.0 to 120	50.00 to 100.00	Organic
4.5	90,000	4,500	67.5 to 135	56.25 to 112.50	matter
5.0	100,000	5,000	75.0 to 150	62.50 to 125.00	

(1)Estimated that on silt loams that 1 1/2 to 3 per cent of the total nitrogen may be released annually, (2) on clays and clay loam 1 1/4 to 2 1/2 per cent, and on (3) sands and sandy loams 4 to 6 per cent.

Fig. 15. Fertilizers were plowed down before this corn and a small quantity of starter fertilizer was applied in the row. In the top picture, the corn received 150 pounds of phosphate (P_2O_5) and 150 pounds of potash (K_2O). The plants showed nitrogen deficiency and produced 80.7 bushels per acre. The corn in the middle picture received only 150 pounds each of nitrogen and phosphate, no potash, and produced 70 bushels per acre. Lodging was severe. In the bottom picture 150 pounds each of nitrogen, phosphate, and potash were plowed down (equivalent to 1500 pounds per acre of a 10-10-10 fertilizer). The plants were vigorous and produced 93.3 bushels per acre.

Organic matter of a more stable nature contains approximately 5 per cent of nitrogen. A soil showing 2 per cent of organic matter, on analyses or test, would contain 40,000 pounds of organic matter, or 2000 pounds of nitrogen per acre (5 per cent of 40,000) in the plowed layer, which weighs approximately 2 million pounds. According to Table 31, a silt loam soil with 2 per cent of organic matter would release from 30 to 60 pounds of nitrogen per season, while a sandy soil with the same organic matter content would supply from 80 to 120 pounds.

Soil texture influences the rate of breakdown of the organic matter. In sandy soils, which are usually lower in humus materials than are clay or silt soils, there are larger pores, greater air movement, and more rapid biological activity. Clay soils have small pores and air movement is retarded. Although these soils have a higher organic matter content, the lack of oxygen and reduced chemical and biological activity result in a slower rate of nitrogen release. Silt loam soils are intermediate in texture and the percentage of nitrogen released is intermediate also, that is, it is greater than in clay soils, but less than where soils are high in sand.

Crop residues vary widely in nitrogen contents. When materials, low in nitrogen, such as straw or corn stalks are turned under, nitrogen from the soil is required if they are to be decomposed by soil organisms. Under such conditions the crop following the addition of such organic material to the soil may suffer from nitrogen deficiencies. If a green legume, high in nitrogen, is the material added, it rots rapidly and considerable nitrogen is released to the following crop.

Moisture and temperature, particularly during the growing season, will influence the amount of nitrogen made available. In dry seasons the shortage of moisture reduces the biological activity in the soil and the nitrogen in soil humus, farm manure or crop residues will not be released significantly. In excessively wet seasons, insufficient oxygen enters the soil and again the rate of nitrogen release is low. Under both conditions nitrogen deficiencies will develop. In these adverse seasons, applications of quickly-available nitrogen are particularly effective since the growth of the plants is not retarded because of a temporary shortage of this element. In fact, excellent responses to nitrogen fertilizers are being obtained on the drier soils in the Plains States, where annual rainfall may approximate only 20 inches. A balanced supply of these different carriers of this nutrient, particularly if located deeper in the soil, can give a substantial increase in crop yield in dry seasons. Nitrogen can also increase the effectiveness of available moisture when formerly it was believed that fertilizer additions would cause injury and reduce the yield in drier seasons.

In attempting to estimate the amount of a nitrogen carrier to apply, assuming average weather and other conditions affecting growth, the following reasoning procedure should be considered.

Fig. 16. A deficiency of potassium produces weak stalks and poor yields. The corn at left received adequate nitrogen and minerals and produced over 100 bushels per acre. The corn to the right received all essential nutrients except potassium, and produced less than half the yield and lodged badly. Note the broken tassels and weak stalks.

1. Estimate the pounds of nitrogen required for the crop of the desired yield, assuming 2 pounds of nitrogen required for each bushel of corn as suggested in Table 1.
2. Estimate the nitrogen required to satisfy the need of bacteria responsible for the decay of non-legumes turned under (straw, cornstalks, weeds), assuming 30 pounds of nitrogen required for each ton (dry basis).
3. Estimate the nitrogen released from the decay of legumes turned under after estimating what the crop would yield if cured for hay, and then figuring 30 pounds of nitrogen to be released during the first season and 15 pounds the second season from each ton (air dry basis) turned under.
4. Estimate the nitrogen released from the barnyard manure applied, by figuring 4 pounds of nitrogen for each ton of barnyard manure during the first growing season and 2 pounds per ton for the second season. Poultry, sheep and hog manure will deliver about twice the above amounts.
5. Estimate the nitrogen released from the organic matter indicated by soil test, according to the values in Table 31.
6. Calculate the amount of nitrogen to apply by taking the difference between the "requirements" and the "releases."

7. The amount of nitrogen carrier to apply will depend on the carrier which is used when 100 lbs. of nitrogen are contained in:
300 pounds ammonium nitrate, or
500 pounds ammonium sulfate, or
125 pounds anhydrous ammonia, or
the equivalent in other nitrogen carriers and mixed fertilizers.

Experimental and field results on numerous farms have shown that the above method of calculation is dependable for yields up to 100 bushels per acre during average seasons. For satisfactory correlations, soils must have a reasonable depth of topsoil. They must also possess physical properties permitting root and water penetration. It is necessary that all other nutrient elements required by corn be present in adequate amounts if the soil nitrogen is to be efficiently utilized. The plant population must be high enough to produce sufficient ears to utilize the nitrogen supplied.

Phosphorus.—Experiments show that a soil must contain from 100 to 125 pounds of phosphorus per acre* in the surface soil if maximum use is to be made of the nitrogen offered to produce optimum yields of corn. A 100-bushel corn crop (entire plants) may contain only 50-60 pounds of phosphorus, but the roots can contact only a portion of the soil particles. As a consequence, the larger amount must be available to prevent deficiencies.

Legumes will require a phosphorus level of 200-300 or more pounds per acre. When corn is grown in a rotation with legumes, it is desirable to maintain the available phosphorus above this level. Through the use of radioactive phosphorus (produced by atomic radiation) it is now possible to determine the percentage of any phosphatic fertilizer material that is absorbed by plants. Work done by experiment stations in many sections of the country indicates that when starter fertilizers are placed near the seed, only 15 to 25 per cent of the phosphorus in the plant is absorbed from the fertilizer. The remainder is taken from the soil. On soils low in phosphorus this would indicate that it would be extremely difficult to add sufficient phosphorus at the time of planting to produce maximum yields of corn. Consequently it appears that the phosphorus must be built up in the entire root zone to obtain adequate absorption of this element by the plant.

Most of the phosphates used in mixed fertilizer are made from phosphatic rock that has been processed to make the phosphorus more soluble. These forms are rapidly adsorbed by plants, but in most midwestern soils this form of phosphorus reacts with clay or changes to less available forms that are only a little more soluble than in the original rock. For this rea-

*Based on soil tests where extractions are made with 1/10 Normal (.1N) hydrochloric acid containing 3/100 Normal Ammonium fluoride.

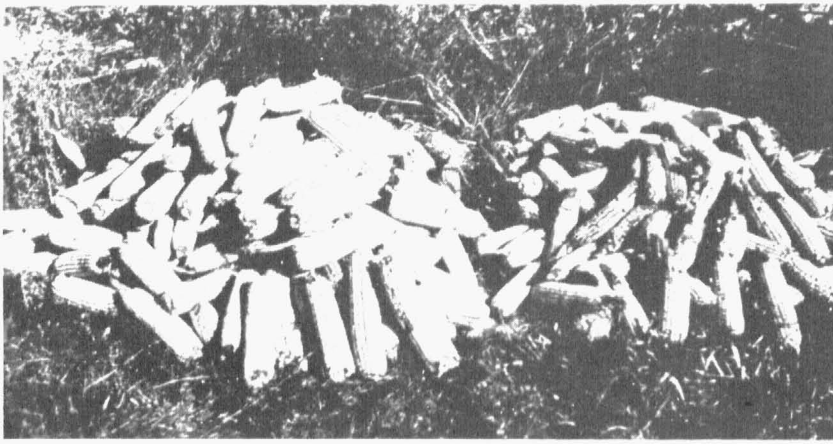

Fig. 17. Adequate soil treatment improves both yield and quality of grain. The corn at left produced 111 bushels per acre. The protein content was 10.1 per cent or a total yield of 627 pounds of protein per acre. The yield of unfertilized corn at right was only 50 bushels per acre and had a protein content of 8.6 per cent. Only 240 pounds of protein were harvested per acre.

son, finely ground phosphate rock (70 per cent through a 200-mesh sieve) is frequently applied in amounts to supply from 300 to 400 pounds per acre of phosphate (P_2O_5). It is slowly available, but if fertilizers containing available phosphorus are applied in the row (as starter fertilizer), equivalent results can be obtained at a lower cost than where available phosphates are the only kinds used. Rock phosphate gives best results when used on slightly acid soils having high clay and organic matter contents. Legumes appear to be more able to use this form of phosphorus than other crops. Nevertheless grasses (corn is a grass) and other summer-growing crops, give better response than that by those crops of which most of the growth is made in the cool seasons of the fall and the spring. The best results from rock phosphate are obtained when grain crops are grown in sequence with legumes, or where liberal applications of farm manure are made.

On very sandy or gravely soils, and those alkaline in reaction, the more available phosphates have given better results.

Rock phosphate and superphosphate have been under comparison in a rotation on Sanborn Field now for 38 years, where the soil has not been limed. During the first two rotations, there was little difference between the effects from superphosphate and rock phosphate as measured by the responses of corn. However, the clover has been much superior in later years where rock phosphate has been applied. The additional nitrogen added by the clover has increased the yields of all grain crops in contrast to the yields obtained from superphosphate. The data are assembled in Table 32.

Table 32 -- Response of Corn in Rotation to Rock and Superphosphate*

	Yield Corn Per Acre		
	38 Yr. Av. 1914-1951	First 2 Rotations 1914-1926	Last 2 Rotations 1940-1951
No soil treatment	29.7 bu.	34.5 bu.	22.6 bu.
Manure	52.7 bu.	50.3 bu.	41.3 bu.
Manure + rock phosphate	54.0 bu.	55.5 bu.	51.6 bu.
Manure + superphosphate	52.5 bu.	51.2 bu.	49.5 bu.

*6 year rotation, corn, oats, wheat, red clover, timothy, timothy.
Manure 8 tons on corn, 5 tons on wheat and on second year timothy.
Rock phosphate @ 1000 pounds with manure before corn, 16 per cent superphosphate @ 300 pounds applied to corn and wheat.

More recent experimental work shows that the soil reserves of phosphorus can be rebuilt and best yields can be obtained when rock phosphate is plowed under deep while the lime is applied to the surface soil and disked. This permits the particles of rock phosphate to be in contact with acid clay and to speed the rate of their interaction. Sufficient mixed fertilizer containing available phosphate can be applied at the time of planting to replace the amounts of this nutrient removed to the crop. When erosion is reduced to a minimum, soils of low fertility can be maintained at high levels of productivity and maximum benefit can be obtained from other nutrients applied.

When superphosphate is used to rebuild nutrient reserves in a rotation system, it is possible to add half of the required phosphorus in each of two years and to reduce the capital outlay required at one time. If rock phosphate is used, the entire amount should be added in one application.

Potassium.—Optimum yields of corn require soil levels of exchangeable potassium of nearly 300 pounds per acre, although this value will vary according to the nature of the clay in the soil, the levels of other nutrients and the season. Lesser amounts may prevent corn from utilizing nitrogen and other essential nutrients efficiently. Potassium reserves can usually be raised most economically by the addition of 60 per cent muriate of potash.

Other Elements.—It is essential that all other elements required by plants be present in adequate amounts if nitrogen is to be fully utilized by corn. Soils should be limed, according to soil tests, to provide calcium, and to prevent other elements from becoming unavailable. Some soils require magnesium. This element should be present to the extent of about 10 per cent of a soil's exchange capacity with the ratio of magnesium to calcium approaching 1:10. Smaller quantities of magnesium may result in improper balances and plant deficiencies.

Sulfur, boron, copper, zinc, and other elements are also required by corn, though in small amounts. Detailed information of these elements is not complete, and few known deficiencies on corn have been reported in Missouri. However, the increased use of larger quantities of fertilizers of higher analysis, particularly on soils that have been heavily limed, may soon make necessary the application of these elements for continued production of maximum crop yields.

PROPER SOIL TREATMENTS FOR BETTER PLANT NUTRITION DECREASE OTHER HAZARDS

The higher yields of corn per acre by way of better nourishment of the plants are demonstrating that weeds are less of a problem. Insect troubles are also less, and very probably plant diseases can be reduced, if it is true for plants, as is often said for people, that "to be well fed is to be healthy."

Cultivation and Weed Control

Experiments conducted over 30 years ago indicated that the killing of weeds is the principal value of cultivating corn. Highest yields were obtained when the ground was only scraped and the soil not disturbed. The detrimental effect of weeds was shown to be mainly in their competition with the corn for nutrients and moisture. Stirring of the soil in these experiments was apparently of little benefit. These experiments led to the development of cultivator sweeps that scrape the surface with little penetration. However, in the intervening period the losses of organic matter and topsoil through erosion have made the cultivated layer higher in clay content and of a poorer structure. Unless the soil is stirred, air movement is slow, water does not penetrate as rapidly and the rate of nutrient release from the soil is retarded. Present experiences of farmers indicate that early cultivation should be deep and later cultivations shallow to prevent root injury.

The detrimental effect of weeds in corn is that of competition for the nutrients and the moisture in the soil. In seasons with abundant rainfall and on soils where adequate nutrients are applied, it is possible to grow yields of corn in excess of 100 bushels per acre without special effort for controlling weeds. It is necessary to supply sufficient nutrients for both the corn and the weeds. When moisture is short, the weeds will reduce yields. When adequate fertility is available, corn makes rapid early growth and it is possible for early cultivation to be more effective in weed destruction. With dense stands and heavy fertilization the corn may shade the ground to such an extent that weeds and grasses are unable to make much growth late in the season. In areas where it is a common practice to seed winter legumes or small grains in standing corn during August, frequent failures may result because of shading if the corn has been adequately fertilized and a thick stand planted.

Fig. 18. Thick stands of corn must be obtained to utilize high levels of fertility and produce optimum yields. When adequate nitrogen is applied the plants make rapid early growth and replants seldom produce ears. If a satisfactory stand is not obtained, the field should be disked and replanted. When early weed control is adequate the shading by the desired stand retards weed growth late in the season.

In recent years selective chemical weed killers have been applied either as pre-emergence sprays or at some time when the plants are small. These materials will kill many weeds but they are no substitute for adequate cultivation on soils low in humus or of poor physical conditions. Excessive amounts of these weed killers will have an adverse effect on corn. They are relatively stable compounds in the soil and if used repeatedly will build up to concentrations that may reduce the activity of soil organisms or be detrimental to legumes or other crops that follow corn in the cropping sequence. These materials should be applied only when weeds cannot be controlled by other means and then in amounts no greater than necessary to effect control.

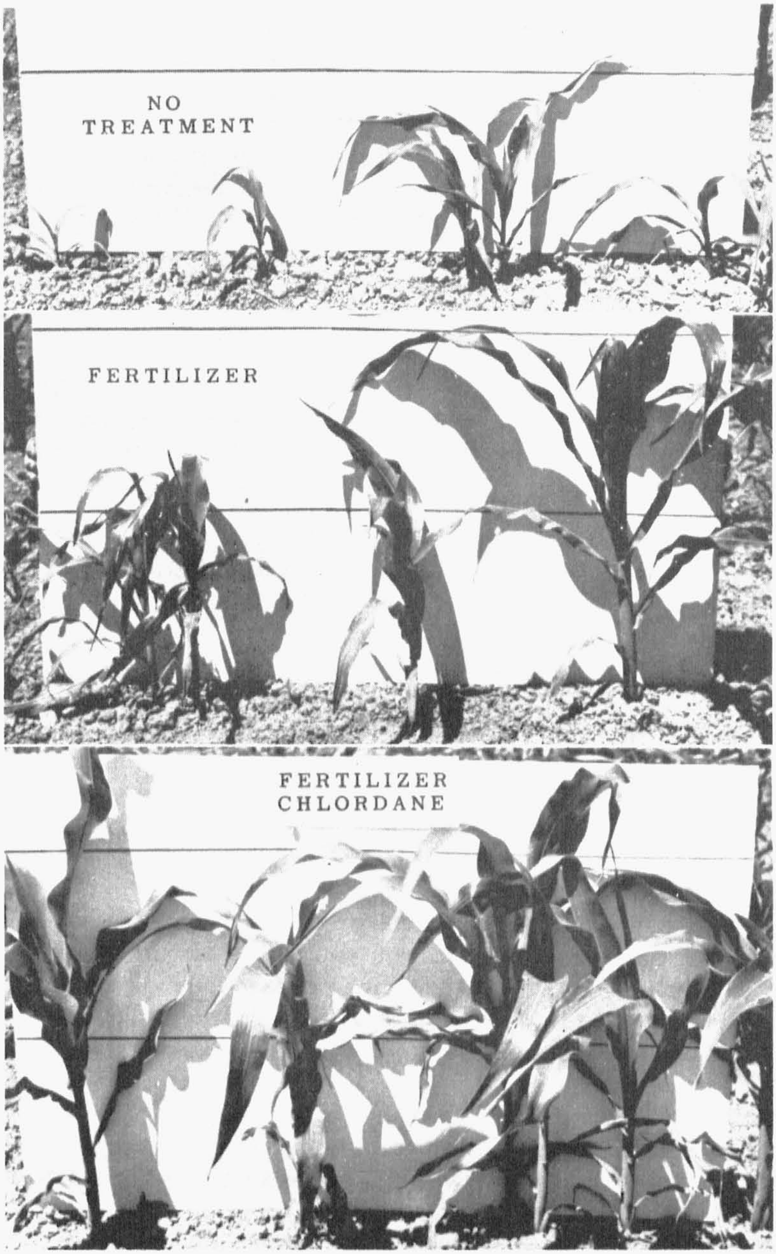

Fig. 19. Insecticides may be mixed with fertilizers to help control root insects. (Top) Unfertilized corn where lespedeza sod was turned under. The small plants have been stunted from root damage by the Grape Colapsis larvae. (Middle) Where starter fertilizer was applied in the row, the plants are much larger but may show the effects of insect injury. (Bottom) The addition of insecticides with the fertilizer has reduced insect damage and stimulated plant growth.

Control of Soil Insects

Insects in the soil frequently do much damage to young corn plants and reduce the stand. The damage is particularly noticable following spring plowing of lespedeza, red clover, or grass sods. Organic insecticides have been mixed with starter fertilizers in attempts to reduce this damage. Results have been inconsistent, although promising in some experiments. Most of these materials break down in the soil only slowly and could build up into toxic concentrations with continued use. Some may be absorbed by the plants, and affect the taste. Some of these materials are toxic to humans and animals and should be used only with extreme care. Much additional research is needed before these soil insecticides can be used judiciously.

Where soils are well supplied with nutrients the young corn plants will make a more vigorous growth and are better able to withstand insect and disease attacks.

SUMMARY

Results of recent experiments by the Missouri Agricultural Experiment Station have demonstrated that, through the adoption of proper soil management and fertilizer practices, yields of corn of 100 bushels or more per acre can be produced on soil once considered unsuited to this crop. It is now known that unprofitable yields of corn on many soils are due mainly to the failure of sufficient nutrients to be released to form the plant tissues required for growth and the formation of grain. Classifications of soils based on their capacity to produce corn is closely associated with the ability to supply the essential nutrients. In many cases, if the necessary elements are made available, the soils formerly considered unsuited to this crop can produce profitable yields.

Corn has a high nitrogen requirement. Each bushel of grain contains approximately one pound of nitrogen, and a like amount is needed to grow the plants to support this amount of grain. A crop producing 100 bushels per acre will require from 160 to 215 pounds of nitrogen, 45 to 80 pounds of phosphate, and from 90 to 175 pounds of potash. Few Missouri soils will deliver this quantity of plant nutrients without supplements. It is possible to add through fertilizers the necessary additional elements that will not be released from the soils. Soil tests are a reliable guide to nutrient reserves and dependable methods are available for calculating the amount of nutrient elements that will be needed for optimum production on a specific soil.

After fertility deficiencies have been corrected, high yields of quality corn can be produced on once depleted soils, while the organic matter and the fertility levels can be increased simultaneously. Returns from corn production can support the soil-building program for other crops. Thick

stands of corn are required for maximum utilization of added nutrients. Because of these denser stands, the amount of crop residue from adequate fertilization can add more organic material than can be added by any other crop normally grown in the Cornbelt while still producing a high value in grain. The use of adequate amounts of nitrogen will promote the breakdown of this organic material in the soil and will aid in increasing the yield of other crops in the cropping sequence.

Erosion of the soil under corn has been excessive. However, experiments show that methods of management are now possible that will not only produce high yields but will protect the soil from beating rains where adequate nutrients are provided for the early rapid growth of the crop. The crop residues from thick stands will afford protection during the winter and spring. Experiments show that if these residues are properly handled and mechanical control measures such as contouring and terraces are used on severe slopes, erosion even from corn following corn becomes insignificant.

The corn crop is not erosive. The mismanagement of the land has been responsible for the soil losses under corn production in the past. Proper attention to soil fertility will permit Missouri farms to produce all the corn that is needed for the feed in the state. It will assist in the rebuilding of depleted soils and will aid in the production of greater quantities of livestock for meat. Like any other, it is soil management that must produce the corn crop and at the same time, conserve the body of the soil and maintain its fertility.