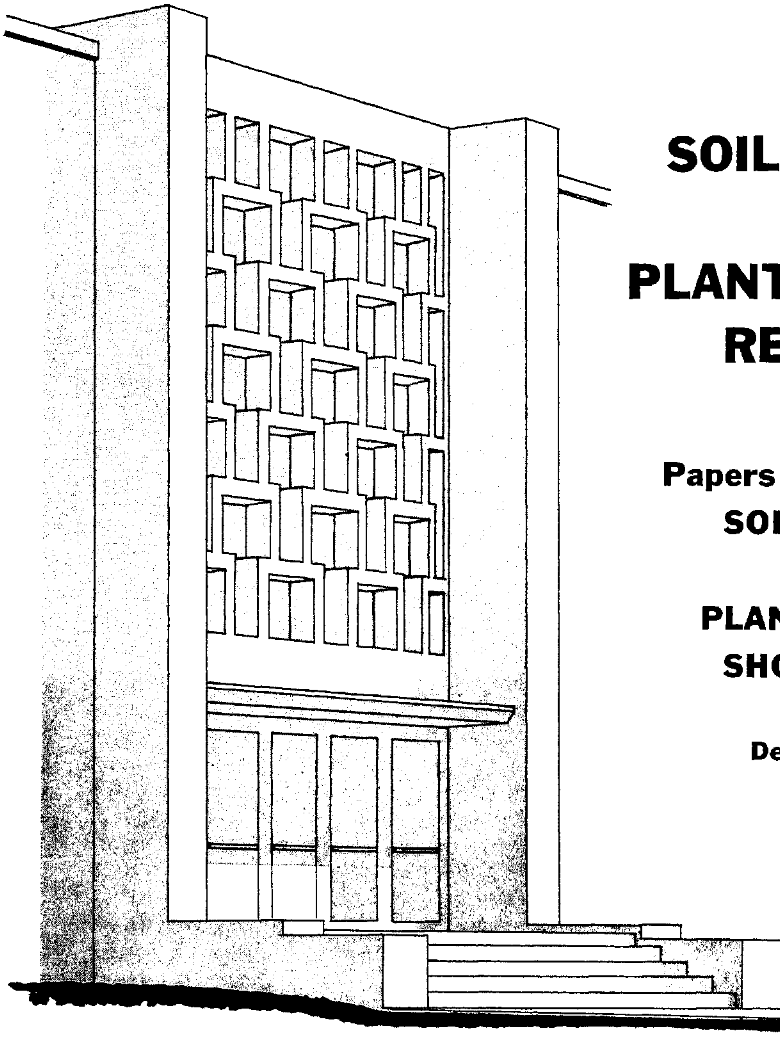

SOIL FERTILITY and PLANT NUTRITION RESEARCH

Papers presented at the
SOIL FERTILITY
and
PLANT NUTRITION
SHORT COURSE

December, 1960

University of Missouri

AGRICULTURAL EXPERIMENT STATION

Special Report 7 *July, 1961*

TABLE OF CONTENTS

SOIL FERTILITY AND PLANT NUTRITION RESEARCH

This bulletin contains a summary of the presentations made at the annual Soil Fertility and Plant Nutrition Short Course at Columbia, Mo., December 1, 1960. This is the eighth year that this series of meetings has been held under the cooperative sponsorship of the University of Missouri, College of Agriculture, and the Missouri Soil Fertility and Plant Food Council of Missouri--an organization dedicated to the promotion of sound soil fertility practices.

Agriculture is the biggest business in Missouri. A large percentage of the urban population of the state is dependent upon the transportation, processing, and distribution of these farm products for its income. The capacity of a soil to deliver nutrients required for plant growth largely determines the crops that can be grown, the yield, the quality, and, to a great extent, the profit that is possible from a farm enterprise. Most Missouri soils are lower in natural fertility than those in some surrounding states. Exploitive cropping has greatly reduced these limited supplies of mineral elements. We are rapidly approaching the time when most Missouri farm land will require fertilizer materials to profitably operate and compete with other states in the national market.

The fertilizer industry is the largest chemical industry in the country. Efficiently produced and distributed plant foods are an essential in our farm economy. The products of this industry now account for one-fifth of our food production--30 to 35 per cent in Missouri. Without these products we would have a more simple, high carbohydrate diet--and probably food shortages. Fertilizer use is one of the major farm production expenses in the state. Most efficient farm operation requires that industry supply those materials that are needed. Soil fertility and plant nutrition research must furnish the information concerning the elements needed--and the ratios to be added, to permit optimum plant growth on the highly diverse soil and plant growth conditions encountered in the state.

Research in soil fertility and plant nutrition is bound to have an increasingly important role in the future development of agriculture, industry, and agri-business in the state.

HIGHLIGHTS OF 1960 FERTILIZER RESEARCH

Earl M. Kroth, Assistant Professor of Soils

Soils differ widely in their properties and response to added nutrients. It is not possible to use experimental results obtained at one location and make generalizations that are applicable over a wide area. The Missouri Experiment Station has research centers in the different sections of the state. Portable equipment is used to obtain data on additional soil types through work with cooperating land owners. The results obtained from plant nutrient research show that many soils cannot provide a profit for the operator without the proper use of fertilizers. Soil moisture is rapidly becoming the limiting factor in growth of summer crops where nutrient deficiencies are corrected.

Northwest Missouri Research Center

Heavy snow in this section of the state recharged subsoil moisture and delayed spring operations. Heavy spring rains prevented plantings on the alluvial soils. Wheat yields were low and oat yields were only average. Corn gave the best response to soil treatments since the field has been in operation.

The Edina silt loam at this station was plowed from an old pasture in 1955. The organic matter was high and 1960 was the first season that substantial response was obtained from most fertilizer applications.

Table 1. Effect of Phosphorus and Potash on Yields of Alfalfa
Northwest Research Center

Treatment	Yield-T/Acre 1957-58	Yield-T/Acre 1959-60	4-yr. avg.
No phosphorus--No potash	4.0	3.4	3.7
Rock phosphate. No annual potash	4.3	3.5	3.9
Superphosphate + 120 lbs. K_2O	4.7	4.5	4.6
Rock phosphate + 120 lbs. K_2O	4.4	4.3	4.3

Table 2. Effect of Phosphorus and Potash on Yields of Corn
Northwest Research Center

Treatment	Yield-T/Acre 1957-58	Yield-T/Acre 1959-60	4-yr. avg.
200 lbs. P_2O_5 + no K_2O	87	94	91
200 lbs. P_2O_5 + 120 lbs. K_2O	94	102	98
500 lbs. P_2O_5 (Super) + 120 lbs. K_2O	88	109	98
500 lbs. P_2O_5 (Rock) + 120 lbs. K_2O	94	106	100

All plots received 80 lbs. N plowed down

During the first two years (Table 1) the untreated alfalfa produced 4 tons per acre with phosphorus and potassium treatments giving yields of 4.3 to 4.7 tons. In 1959 and 1960, the yield of the unfertilized alfalfa had dropped to 3.4 tons. The need for potash became apparent. Where rock phosphate was applied alone the yield was only 3.5 tons. Where annual applications of potash fertilizer were made the yield was 4.3 tons with rock phosphate and 4.6 tons with super phosphate.

No significant effect of potassium was noted on corn in 1957-58 from additions of potash, but in 1960, with 80 pounds of nitrogen per acre, additions of potash increased yields 7 to 9 bushels per acre. The results of this study thus far indicate that under pasture conditions this soil would release potash from the primary soil minerals and the potash could be stored by the exchange complex for later use by corn or alfalfa. However, the reservoir would soon be depleted if potash was not supplied from commercial sources.

Soil organic matter accumulated while land is in pasture is a source of nitrogen for grain crops. This reserve is soon depleted, however, and yield increases result from applications of nitrogen fertilizers. Table 3 shows that after three years the soil at the Northwest Research Center gave a response to additional nitrogen. Because of the large amount of summer rainfall this nitrogen produced the greatest effect when sidedressed rather than being plowed down in the spring.

Grain sorghum gave a yield response to nitrogen plowed down in the spring as compared with plots receiving no treatment as shown by Table 4. An adequate stand of corn (Population 12,000 - 16,000) is necessary to obtain a satisfactory response to added fertility. In some past experiments on this field the soil could deliver sufficient nutrients for a population of 9,000 to 11,000 plants, and no yeild response was obtained from added fertilizer.

Table 3. Effect of Rate and Time of Nitrogen Applications on Yield of Corn Northwest Research Center

Pounds N per acre	Time of Application	Yield-Bu/Acre 1959	Yield-Bu/Acre 1960
None	-------	84	67
40	Spring	86	102
80	Spring	85	129
120	Spring	84	146
40	Sidedressed	--	120
80	Sidedressed	--	136

Table 4. Effect of Nitrogen Applications on Yield of Grain Sorghum Northwest Research Center-1960

	None	Starter	Starter + 50 lbs. N	Starter + 100 lbs. N
Yields-Bu/A	80	78	111	131

Central Missouri

Corn planted about May 1 on soil with a high fertility level yielded well, some plots as high as 110 bushels per acre, though only 3. 2 inches of rain fell at Columbia during July, August, and September. These yields indicate that where fertility is adequate, early planted corn can make use of the available nutrients and water to produce acceptable crops in spite of inadequate rainfall the later part of the season. Wheat also yielded well at Columbia. Table 5 (Putnam silt loam) shows the effect of residual nitrogen applied to corn on yields of wheat following the corn. A somewhat dry season in 1959 did not permit the use of all the nitrogen applied to the corn and therefore gave the promised residual effect in 1960.

Table 5. Residual Effect of Nitrogen Applied to Corn on Yield of Wheat
Columbia-1960

Treatment	Yield-Bu/A
No N	31
33 lbs. N	48
66 lbs. N	45
132 lbs. N	51
200 lbs. N	54

300 lbs. 3-12-12 starter on all plots

An experiment was begun at McCredie in 1958 to study the lime needs of soil (Mexico silt loam) receiving heavy applications of commercial fertilizers including nitrogen. Data (Table 6) obtained in 1960 indicate the need of adequate lime levels to make the most use of fertilizer nutrients.

Table 6. Effect of Limestone on Yield of Corn
McCredie - 1960

Treatment	Yield-bu/Acre
No lime. No phosphorus	109
No lime. 700 lbs. Rock phosphate	104
4T ($CaCO_3$) + 1500 lbs. Rock phosphate	116
24T ($CaCO_3$) + 1500 lbs. Rock phosphate	120

All plots: 300 lbs. 12-12-12 starter and 150 lbs. N plowed down.

Weldon Spring

Inadequate summer rainfall prevented optimum yields of corn at this location. Little increase was obtained with 120 pounds of N per acre over a 60 pound application. All forms of nitrogen gave good response. Wheat yields were high.

Nitrogen applied at planting gave a greater increase in yield than did mid-winter or March applications. There was little difference in yield between 30 and 60 pound nitrogen applications made at planting, but the larger amount gave significant increases when applied in winter or spring. Solution 32 and anhydrous ammonia appeared to be the better nitrogen carriers in 1960, though the 6-year average does not indicate a marked benefit from either carrier. Urea, ammonium sulfate, ammonium nitrate, anhydrous ammonia, and several solutions are included in the study.

Southeast Missouri*

Rainfall in Southeast Missouri in general was adequate and well enough distributed to permit good yields of corn on loam to clay loam (mixed) soils. More frequent rains would have been needed for high yields on sandy soils. The data given in Table 7 were obtained from irrigated plots. The corn on the sand did not get the irrigation water soon enough which explains the low yields on these plots. Nitrogen applications gave good increases in yield on both kinds of soil. The 80 pound rate increased yields over the 40 pound rate. Sidedressing the nitrogen gave 20 bushels more than a spring plow down for this rate on the loam soil. A 30 bushel increase was obtained with sidedressing over the spring plow down of 40 pounds of nitrogen on this soil. No advantage was obtained from side dressing on the sandy soil. About 8 bushels of corn were obtained, when 80 pounds of nitrogen were used instead of 40 pounds on this sandy soil.

Table 7. Effect of Nitrogen Applications on Yields of Irrigated Corn
Southeast Missouri-1960

Treatment	Yield-Bu/A Sand	Yield-Bu/A Loam
No Nitrogen	26	45
40 lbs. N-Spring	50	72
80 lbs. N-Spring	59	111
40 lbs. N-Sidedressed	50	102
80 lbs. N-Sidedressed	58	131

All plots received 350 lbs. 0-25-25 banded at planting.

*A detailed report of soil fertility studies with cotton in 1960 is reported in Special Report 4.

Southwest Missouri Research Center

Plant nutrient studies were started on the new experimental farm at Mt. Vernon in the spring of 1959. Where 160 pounds of 12-12-12 fertilizer was applied as a starter to Craig silt loam,* the yield of spring oats was increased 20 bushels per acre. Doubling this amount of soil treatment caused a slight decrease in yield. If the starter were of a 1-3-1 ratio at the increased rate, yield increases were obtained. Thirty-three pounds of nitrogen topdressed in addition to the starter fertilizers gave only slight increases, indicating that phosphorus is needed in greater proportion on this soil than nitrogen and potash.

Table 8. Effect of Fertilizer on Yield of Spring Oats
Southwest Research Center-1960

Treatment	Yield-Bu/Acre
No fertilizer	41.8
160 lbs. 12-12-12	62.6
160 lbs. 12-12-12 * 33 lbs. N (Amm. Nit.)	66.2
240 lbs. 12-12-12	60.3
250 lbs. 8-24-8	72.7
250 lbs. 8-24-8 + 33 lbs. N (Urea)	78.1

Good response was obtained from soil treatments on winter oats and wheat (Baxter silt loam). Unfertilized winter oats produced a yield of 60 bushels per acre, but the application of 250 pounds of 8-24-8 or 4-24-12 produced over 100 bushels of grain per acre. There was little effect of topdressing additional nitrogen in early spring. Wheat yields were increased from about 20 bushels per acre, by 250 pounds per acre of an 8-24-8 or 12-12-12. Top dressing with 33 pounds of N gave 5 to 7 bushels increase and 66 pounds of N further increased yields 4 to 6 bushels. All forms of nitrogen were effective.

Fertilizer studies were made on corn on bottom soils (Huntington silt loam). These studies (Table 9) indicate that 80 pounds of 15-15-15 as a starter, with 100 pounds extra nitrogen plowed down was a good combination. Increasing the starter to 160 or 320 pounds increased yields, but additional nitrogen had little effect over 100 pounds at the 80 pound rate of starter. A similar study (Table 10) indicates that 50 pounds of nitrogen would have been as beneficial as 100 pounds of nitrogen on this soil. A more favorable rainfall distribution in July could have made for greater efficiency of use of the additional nitrogen.

Table 9. Effect of rates of Starter Fertilizer on Yield of Corn
Southwest Research Center-1960

Treatment	Yield-Bu/Acre: No extra N	Yield-Bu/Acre: 100 lbs. extra N
No starter	54.1	91.5
80 lbs. 15-15-15	62.5	102.5
160 lbs. 15-15-15	72.7	104.9
320 lbs. 15-15-15	90.9	101.8

Table 10. Effect of Rates of Nitrogen on Yield of Corn
Southwest Research Center-1960

Treatment	Yield-Bu/Acre
No starter	68.0
160 lbs. 15-15-15	76.9
160 lbs. 15-15-15 + 50 lbs. N	108.6
160 lbs. 15-15-15 + 100 lbs. N	112.7
160 lbs. 15-15-15 + 150 lbs. N	112.6

EFFICIENCY OF NITROGEN FERTILIZER USE

Larry S. Murphy, Instructor in Soils

Cultivation of our soils has generally led to a decrease in the natural store of nitrogen and organic matter. It is from organic matter that the inorganic forms of nitrogen, nitrate, and ammonia, became available to plants. To offset this decline in natural soil nitrogen, the use of synthetic fertilizer nitrogen has been widely instituted.

The consumption of fertilizer nitrogen in Missouri in 1960 was well over the 100,000 ton level and represented an investment of over $25 million. Major problems arising from the use of this fertilizer element include low responses to heavy nitrogen applications and losses of fertilizer nitrogen from the soil.

Although certain forms of nitrogen can be lost from the soil via leaching, much attention has been given to the microbial controlled processes of denitrification which result in losses of gaseous nitrogen products. Soil conditions or management practices that tend to modify the microbial environment may markedly affect nitrogen losses.

Some investigators have concluded that 30 per cent of all the nitrogen used in agriculture is lost to the atmosphere. Further work has indicated even higher losses on various soils with certain nitrogen carriers.

General Background

The nitrogenous substances assimilated by plants can be divided into four major classes: organic nitrogen, ammonium nitrogen, nitrate nitrogen, and molecular nitrogen. The majority of plants can only use nitrogen in the form of nitrate, ammonia, and a few organics such as amino acids and urea.

In specific cases, the absorption of nitrate or ammonia may be favored. In general, low pH tends to favor nitrate uptake while high pH tends to favor ammonia uptake. Variations in uptake of these two ions are evident among different species and at varying stages of plant maturity. Seedlings may favor ammonia feeding, but plants that grow well under conditions of poor soil aeration, in soils low in soluble phosphorus, sodium and calcium appear to tolerate part or all of their nitrogen in the ammonical form.

The negatively charged nitrate ion exists in the soil solution and is not attached to the clay particles as is the positively charged ammonium ion. Nitrate ions are thus susceptible to leaching while ammonium ions are not.

Nitrate is the principal form of inorganic soil nitrogen. Other forms of nitrogen such as amino (NH_2) ions and ammonium ions are rapidly converted to nitrate by the process of nitrification which is mediated by certain soil microorganisms.

One of the intermediates in the oxidation (Nitrification) of ammonia to nitrate is the toxic ion, nitrite (NO_2). Under anaerobic conditions, applications of nitrate may lead to a partial reduction of the nitrate to form the toxic nitrite. In the case of rice or some other crop grown under prolonged water-logged conditions, damage to the crop might occur if fertilized with nitrate. In normal instances, however, only traces of nitrite ever occur in soils and then only for short periods.

Although nitrate is the most important source of nitrogen in most soils and is the principal form of nitrogen taken up by most species of higher plants, it is not an essential constituent of plants. Nitrogen can only be combined into amino acids and proteins when in the amino form. Nitrate nitrogen must undergo the enzymatic reduction to the amino form before it can be utilized by the plant.

Nitrate is readily absorbed by plants and once taken up may be reduced in the manner mentioned above or may accumulate. The factors which favor nitrate accumulation are of two groups: (a) factors which favor rapid ion accumulation in general such as vigorous root aeration, low initial salt content of tissue, high external nitrate level, and absence of competing ions which might supress nitrate uptake; and (b) factors which are unfavorable to nitrate reduction in the plant such as trace element deficiencies and conditions which act in the direction of limiting the carbohydrate level of the plant.

Methods of Nitrogen Losses

1. Volatilization of ammonia

This process can possibly occur in the treatment of soils with anhydrous ammonia or materials that are rapidly converted to ammonia in the soil, such as ammonium sulfate and urea. Ammonia that is not adsorbed by the soil colloids may diffuse out of the soil into the atmosphere or be carried to the surface by the evaporation of water where it will be volatilized and lost.

2. Leaching of soluble nitrates

The nitrate ion is present in the soil solution and not adsorbed on the soil colloids due to its negative charge. Excessive amounts of water percolating through the soil may carry the soluble nitrates down out of the immediate reach of the plants or remove them entirely by runoff.

3. Denitrification

This process is microbiologically controlled. The term denitrification designates the complete reduction of nitrate to atmospheric nitrogen and oxides of nitrogen. Under anaerobic conditions, heterotrophic organisms utilize the oxygen of the nitrate and nitrite ions for the oxidation of carbon compounds or inorganic substances such as sulfur. The energy thus derived is used to reduce the nitrate or nitrite to the oxides of nitrogen or to molecular nitrogen, all of which can escape to the atmosphere.

4. Van Slyke Reaction

Nitrite and ammonia in the soil may react to produce nitrogen gas. This reaction may occur when high concentrations of ammonia in the soil partially impair the process of nitrification through the toxic effect of this gas on the micro-organisms responsible for the oxidation of nitrite to nitrate. The nitrites produced may then react with the ammonia in the manner described above.

Efficiency of the Various Nitrogen Carriers

1. Anhydrous ammonia

In speaking of the "efficiency" of this carrier, reference is made to the retention of this form of nitrogen in the soil. This material is injected into the soil in the gaseous ammoniacal form and it is pertinent that studies of losses of ammonia into the atmosphere be made at relatively short intervals after application in order to maintain the "individuality" of the compound.

It has been demonstrated that the loss of ammonia from soils treated with anhydrous ammonia is related to depth of placement, soil moisture, and exchange capacity. On a Putnam silt loam, 100 pound nitrogen applications under optimum moisture conditions at a 6-inch depth resulted in no demonstrable loss of ammonia and only a 0.8 per cent loss when applied at a depth of 3 inches. Losses were greater at both lower moisture levels and higher moisture levels on sandy soil, silt loam, and a clay soil. Even then losses were generally insignificant.

Recent studies of the effect of cultivation on the retention of applied anhydrous ammonia have revealed that ammonia losses from Putnam silt loam treated with 100 pounds of ammonia nitrogen and plowed 1 and 2 weeks after application were insignificant. Under a wide range of moisture and tilth conditions, under both sod and cultivation, and at varying depth, losses from 100 and 200 pounds of applied ammonia nitrogen were nil.

2. Ammonium Nitrate

This material is unique among our dry fertilizers in that it is a source of both ammonium and nitrate nitrogen. In supplying nitrogen for crops, however, it follows much the same pathway as anhydrous ammonia and urea in that as time progresses most of its nitrogen is available in the nitrate form due to microbial nitrification of the ammonium nitrogen.

Some experimental results have indicated losses varying from 0 to 50 per cent of the applied nitrogen of ammonium nitrate in 5 months. Of the eight soils used in this experiment the average loss from ammonium nitrate was 15 per cent as compared to 10.7 per cent for aqua ammonia, 19.4 for urea, 7.4 for ammonium sulfate, and 7.7 per cent for sodium nitrate. These losses were thought to be largely through the process of denitrification. As ammonium nitrate-nitrogen is converted to the soluble nitrate form, the susceptibility of the material to leaching losses increases.

3. Urea

Experimental results show that nitrogen losses of applied nitrogen from Missouri soils fertilized with urea may vary from 0.5 to 85 per cent in 5 months. Studies of these losses showed them to be mainly in the forms of the various oxides of nitrogen with only relatively small amounts escaping as ammonia.

Later work indicated that losses of nitrogen from urea may be even higher than those reported on the same soils under similar conditions. Losses of 36.8 per cent of the applied urea nitrogen from Sharkey clay, 88.5 per cent from Putnam silt loam, and 75.2 per cent from Weldon silt loam were reported after 12 weeks of incubation. The effect of the microbial population and the soil catalytic activity on these losses were investigated and results show that soil treatments which destroyed the catalytic activity and the soil population and prevented their return were most efficient in retarding these losses. The soil treatments enlisted in this work were impractical as far as good agronomic practices are concerned but they do shed light on the problem of nitrogen losses.

In the unaltered soils of this study, accumulations of the ammonium ion shortly after application of urea to the soil indicated that hydrolysis of urea has occurred. Disappearance of the ammonium ion, however, was not followed by the expected concomitant increases in nitrite and nitrate.

Losses of nitrogen as ammonia were checked and found to be significant only in the case of Weldon silt loam where losses of this form of nitrogen amounted to 18 per cent of the applied amount. The loss of ammonium ions could not generally be attributed to this avenue.

The poor nitrification rates experienced do not directly indicate nitrogen losses since the nitrogen could have been immobilized by the soil microbes. However, since the nitrogen did not escape as ammonia and was not present in the protein of the soil microbes the only alternative left for explanation is denitrification.

Control of Nitrogen Losses

In the course of studying the characteristics of these nitrogenous materials, various methods of controlling the loss of nitrogen when experienced have been noted. The loss of ammonia gas from soils treated with anhydrous ammonia has been shown to be at the very lowest point when applications were made at periods of about optimum soil moisture. This is not to say that there is a critical moisture level but rather that losses are substantially larger when applications of this material are made to extremely wet and extremely dry soils. Actually, under the higher moisture condition giving the higher ammonia losses, field work would not be feasible in the first place so we can generally eliminate this trouble source. On the other hand the extremely dry conditions investigated would probably render the soil too hard for effective penetration of the applicators. These investigations also indicate that nitrogen loss of anhydrous ammonia is in direct relationship with depth of placement, so proper placement (at least six inches deep) is another means of eliminating losses. The exchange capacity of the soil must also be considered when applying the readily absorbed ammonia. Whenever exchange capacity of the amended soil is low and concentrations of ammonia in excess of the exchange capacity are applied, volatilization of the ammonia may be expected. Retention of ammonia may be increased by closer knife spacing, (smaller quantity per knife) although this will increase the power requirement for application.

In the case of urea, surface applications have frequently been inferior to those applications mixed with the soil. The rapid hydrolysis of urea to ammonia and carbon dioxide by the catalytic activity of the soil has long been known. When this reaction occurs, as it can on the surface of the soil or in contact with decomposing organic materials on the surface of the soil, the resultant ammonia can escape into the atmosphere. Urea might be expected to react much like anhydrous ammonia since it is readily hydrolyzed to the same form and would thus be expected to react in much the same manner in regard to retention characteristics. A considerable amount of work remains to be carried out in regard to all the characteristics of this material.

Losses of leachable material can be reduced by applying the material close to time of plant need. Applications of leachable materials to small grains when the soil is frozen may result in loss of surface runoff since the material may be washed away before it has an opportunity to be washed into the soil.

Local conditions are the governing forces in nitrogen losses. In fact, greater variation in nitrogen loss may be noted between different soil types than between different materials.

The nitrogen material best suited for use by the agricultural producer cannot be prescribed in general terms. The material to be used should be chosen on the basis of crop needs, expected time of applications, soil type and soil conditions that are expected to be prevalent.

NITRATE IN ANIMAL FEEDS

G. B. Garner, Department of Agricultural Chemistry

The nitrate toxicity problem has come into sharp focus in recent years as we push toward higher yields in both row and pasture-meadow crops. There are at least two approaches to this problem. I hope we have chosen the correct one.

The first approach would be that of the Alarmist. It is certainly the easiest approach and justifiable as one views the staggering loss of cattle we saw in the 1954 drouth. It is also justifiable when one sees the human health hazard as a death attributed to silage fumes carrying large amounts of nitrogen dioxide.

The approach we have tried to follow is that of learning to live with nitrate. We must learn and teach the fundamentals of the soil, of plant physiology, of preservation methods and the physiological response of animals with respect to nitrate.

In no way do I imply we have all the answers to each facet of the problem but that we must consider each item as contributing to this problem of nitrate toxicity.

Let us consider the various environmental factors known to influence nitrate accumulation in plants. Starting with the soil, we know that the nitrate content of the soil, whether applied in the preparation of the seed bed or produced by nitrification in the soil, will influence the uptake of nitrate by the plant. The potential level of nitrate in the plant would be greatest under high nitrogen fertilization.

The use of ammonium ion in fertilizers undoubtedly plays a role in intensifying the problem. Practically all plant species will preferentially utilize ammonium ion over nitrate. This is a defensive action of the plant in that ammonium ion is more toxic to the plant and less energy is required to utilize ammonium ions in the synthesis of protein. Thus, application of ammonium nitrate or anhydrous ammonia to a growing crop will tend to increase the nitrate content of the plant simply because the nitrate can be stored while the ammonium ion is being used.

The organic matter of the soil appears to play a role in this problem because of increased holding capacity of nitrogen and its role in nitrification. Our dairy farmers have been hard hit with the nitrate problem because of their utilization of manure and their failure to assign any significant contribution of the manure to nitrogen fertility.

Another problem is that of proper soil nutrient balance. Many experiments have been performed to show that a very slight phosphorus deficiency will cause an accumulation of nitrate in plants. One experiment with grasses at the Missouri Station (1958) indicates the magnitutide of nitrate accumulation. In this experiment treatments were 100 lbs. N/acre plus phosphate to soil test plus potassium to test with lime. The data is presented in the following tabular form.

Plant Species	% NO_3-N of Dry Matter by Soil Treatment		
	100N/A	PO_4 only	Complete
Timothy	0.430	0.007	0.078
Blue grass	0.175	0.007	0.023
Fescue	0.243	0.004	0.055
Orchard grass	0.354	0.102	0.030
Brome	0.107	0.011	0.062
Ladino	0.046	0.003	0.006

Crude protein was highest with 100 N/A, however, precipitable protein varied by species with a trend toward equal to higher values with the complete treatment. This fact is to be mentioned again. Further studies with sudan grass in the green house revealed that the amount of NO_3-N found in the field was less than the plant could tolerate using dry matter yield as the criteria. (High field value 0.71 versus 1.36) Added phosphorus increased the dry matter yield but did not influence the nitrate level. In this same study the effect of trace elements was tested and no detectable effect on nitrate accumulation could be measured. Analysis of Missouri crops in 1954-56 failed to show any molybdenum deficiencies. Therefore one would not expect a lack of nitrate reducing enzymes to be a factor.

Three additional factors can be discussed together. They are: temperature, soil moisture and humidity. Classical nitrate toxicity is usually a product of low soil moisture and low humidity. Under these conditions, the soil solution is highly concentrated and the plants transpire rapidly, thus taking in more nitrate than can be used. We add high temperature to this and transpiration increases. Not only does transpiration cause the accumulation, but also the very high temperature (100^{o} ≠) appears to damage the crop to the extent that it never recovers, even with the return of ideal conditions. Drouth will certainly intensify the nitrate toxicity problem; however, it is not necessary to produce the problem.

Day length and light intensity play a role in nitrate toxicity. Burston found increased light intensity resulted in nitrate assimilation in wheat leaves and shading or crowding of plants contributes to nitrate storage. This is evident in the high incidence of nitrate accumulation in crops grown in a narrow valley as reported by Gilbert.

The evidence of herbicides contributing to nitrate accumulation in plants is not conclusive. The recent paper of Frank and Grisby ("Weeds" Vol. #5, 1957) shows that a given herbicide may cause weed plant species to show accumulation while the same level of the herbicide does not influence the second specie. It seems one must take each plant specie and each herbicide as individuals and not make any generalizations. More work is needed in this area.

Plant species vary markedly in their capacity to accumulate nitrate. The following classification for common crops is based on observations and analyses of the Missouri Station. The weeds are based on a report of Frank and Grigsby and Missouri data. Corn, Sudan, the small grains, rape and fescue are potentially high nitrate accumulators. Alfalfa, ladino, sorghum, milo and sargo are moderate accumulators while brome and red clover show lowest levels of nitrate. The weeds which are commonly accumulators are lamb's quarter, pig weed, bull-nettle, jemson weed, canada thistle, wild mustard, golden rod and boneset.

What can be done to control the nitrate content of forage as it will be fed? Harvest at various stages of maturity and by using various techniques in preserving the forage. The state of maturity is important, particularly with reference to crops such as corn, oats, milo and others where the seeds contribute a significant dry matter of high nutritional value. One can see the nitrate to dry matter ratio decreasing with maturity in the following table. There is an increase in NFE with increasing maturity which becomes important. Although the protein may drop; it is true that the nitrate declines and the NPN or crude protein nitrogen also declines. From the nitrate toxicity point of view, harvest at maximum dry matter yield would be better than at maximum protein level. The exception to this would be crops which have a great tendency to lignify with the latter stages of maturity thus lowering its digestibility.

State of Maturity as Reflected by Chemical Analysis
Data from South Dakota Expt. Sta. Tech. Bull. No. 7.

		% Dry Weight - Based on Entire Plant			
Date	Part of Plant Identifiable	Total N	Soluble N	NO_3N	True Protein N
July 2	------------	4.2	1.7	.7	2.5
July 13	------------	3.3	1.1	.5	2.2
July 23	tassel	2.9	0.9	.5	2.0
August 10	tassel	2.1	0.7	.3	1.4
August 29	Ears, sheath, tassel	1.3	0.4	.09	0.9

Another way nitrate concentration can be controlled at harvest time is by the method used. With field curing, the plants, as they wilt, use up some of their carbohydrates and at the same time the nitrate is being converted to ammonia and protein. In comparison, we can force dry, preserving both the nitrate and the carbohydrate, at near the level of the intact plant. This is an area where we need to do more research in light of possible field pelleters, dryers, etc. This operation is quite similar in a sense to the soiling operation or to pasturing in terms of nutrients and nitrate intakes. However, a difference in ruminal response is noted when one compares green crop, pasture or soilage with its dried counter part.

The use of silage as a way of preserving forages has an interesting consequence with regard to nitrate levels. First, consider the ensiling of a crop, say corn, at low nitrate levels. There is a marked decrease in the nitrate level at the end of fermentation. Barnett, in his book, "Silage Fermentation" has suggested that this loss of nitrate would average 30%. Missouri data indicates even higher losses, which are encouraging. However, a crop which is high in nitrate, (above 1% KNO_3 equivalent on a dry matter basis) may still contain 0.6% KNO_3 after the fermentation loss. Thus, by ensiling one can make a safer feed. Once the silage has come to equilibrium, no further reduction of nitrate or nitrite occurs. Silage preservatives such as sodium bisulfite tend to preserve the crop as ensiled. Missouri data indicates molasses and ground corn helps the fermentation and aid in reducing the nitrate content. They also add to the energy value of the silage.

What is the fate of nitrate in ruminant animals and their fate in the presence of nitrate? As sheep are less sensitive to nitrate intoxication, the discussion will deal mainly with beef and dairy cattle.

We can represent the pathway of nitrate to protein as follows. Nitrate $\longrightarrow$ Nitrite $\longrightarrow$ hydroxylamine $\longrightarrow$ ammonia $\longrightarrow$ protein. Notice, we go from the highly oxidized form of nitrogen to a highly reduced form. Thus for nitrogen assimilation in the animal reduction must take place. The bacteria of the rumen can reduce the nitrate to nitrite which is the ion that is most toxic. Not only will it combine with hemoglobin of the blood to form the chocolate brown colored methemoglobin but it will inhibit further bacterial action in the paunch. The action seems to be bacteriostatic in that the stasis will finally disappear and the bacterial action return.

The ration has a great effect on whether this stasis occurs. For instance, dairy cattle fed grain could consume corn stalks that killed beef animals. In vitro work has shown additions of glucose increased the rate of reduction, however, when sheep were on rations high in carbohydrate less reduction occurred. This data plus other data we have obtained indicate a shift of flora has occurred with the ration high in carbohydrate. At low level nitrate with ample energy, the bacteria can utilize the nitrate for protein synthesis without any consequences. However, at high level nitrate intake, the bacteria are rushed, thus both nitrate and nitrite are passed on to the abomasum or true stomach and contribute to the physiological phenomenon seen in the cattle. High energy rations may support a flora incapable of reducing nitrate, if so high level nitrate intake would result in less drastic physiological responses.

What effect high protein and Non-Protein-Nitrogen has on nitrate toxicity needs further work. In theory, one might expect these to aggravate the situation because both protein and NPN would be available for bacterial synthesis in preference to nitrate.

Field cases of suspected nitrate toxicity are often related to generally poor nutrition. The role of accessory factors needs to be considered. When one has a bacteriostasis of the paunch, a source of vitamins would improve the situation. Our practical recommendations have included blackstrap molasses and a source of vitamin A and D. Adequate mineral must be supplied.

As indicated earlier, nitrite is more toxic than nitrate and more likely to occur in the rumen of animals consuming dry forage than those eating green chopped forage or pasture. Just what physiological properties can be ascribed for these ions? Listed in the 24th edition of the U. S. Dispensatory the properties for potassium nitrate are: (1) Does not alkalize system as organic K compounds. (2) Increases urine flow. (3) Not very potent as a poison. (vomiting, purgative). (4) Long exposure to small amounts. (Anemia, low blood pressure, mild nephrites). (5) Cyanosis in milk fed infants. The properties listed for sodium nitrite are: (1) pulse rate increase. (2) Marked lowering of blood pressure. (3) Motor weakness and diminution of reflex activity. (4) Relaxation of all smooth muscle. (5) Hemoglobin converted to methemoglobin.

The response seen in the field and experimentally at the Missouri Station for cattle are:

1. For High Nitrate Intake (above 1% KNO_3 or 0.14% K NO_2-N).
   a. Death
   b. Abortion
   c. Milk Production Loss (immediate problem)
   d. Vasodilation

2. Moderate Nitrate Intake (0.5-0.8% KNO_3 or 0.07-0.11% NO_3-N.)
   a. Milk Production Loss (delayed)
   b. Non-thrifty Appearance
   c. Reproductive Difficulty

The Wisconsin Station has reported concurring results with respect to abortion. The Cornell Station reported recently that the level of the Missouri Station were too low and they failed under their experimental conditions to find abortion, loss of milk production or death in their cattle. Field data in the Midwest continues to support the level suggested by the Missouri Station.

In conclusion, some knowledge has been gained concerning high nitrate levels, both in plants and animals. Re-evaluation and retesting with more and more variables under our control are needed. It will be a team approach, starting with the seed, the soil, the fertilizer, the climatic conditions, the plant maturity at harvest, the method of harvest, the ration formulation when fed, and finally in the evaluation of the animal's response. By this approach we will "learn to live with nitrate" as a part of our modern agricultural technology.

TRACE ELEMENT STATUS OF MISSOURI SOILS

E. E. Pickett
Department of Agricultural Chemistry
University of Missouri

The Spectrographic Laboratory has made a brief survey of the trace element composition of Missouri soils, (1) and has also made two more extensive surveys of the trace element composition of two forage crops, lespedeza (3) and alfalfa (4). The results of the forage crop analyses probably tell us more about the trace element status of the soils than the results of the soil analyses themselves.

The difficulty with analyzing for trace elements in soils is that we do not know what fraction of the analytically determined quantity is usable by plants. The same problem arises in studying major element composition of soils but a great deal of progress has been made in finding methods which give meaningful results for soil major element analyses, at least for restricted ranges of soil types or regions.

The data on trace element composition of soils was summarized by Swaine in 1955 (2). About 750 papers were examined and some 65,000 results were included for all trace elements. However, from all this no clear picture emerges as to how one should analyze Missouri soils for trace elements.

In 1951 we chose to use four different extracting solutions, 2.5% acetic acid, 0.1 normal hydrochloric acid, 1 normal ammonium acetate and sodium chloride solutions, and we analyzed for the major elements, calcium, magnesium, potassium, and sodium and for the trace elements iron, manganese, copper, cobalt, and zinc in extracts prepared by shaking the soils with these solutions. We also used hot water to extract boron and ammonium oxalate-oxalic acid solution at pH 3.3 to extract molybdenum. Total amounts of these elements in the soils were also determined. Only ten Missouri soils were studied. These were selected, with the help of the Soils Department, as being "representative" Missouri soils, from good to poor.

We compared the total and extracted trace element content of the soils with the average economic value of the soil type estimated by Miller and Krusekopf in 1929. This comparison may seem rather far fetched but it showed several interesting things. First, the extracted calcium and potassium contents, especially the latter, correlated well with land value, regardless of the extractant used. This is about as one would expect. The acetic acid-extracted iron correlated negatively with land value. 1 N hydrochloric acid extracted copper and zinc correlated slightly with land value. Total zinc and hot-water extracted boron correlated well. No correlations were found for molybdenum, cobalt, or manganese. This indicated that at least three different extracting solutions would have to be used in assaying the trace element status of Missouri soils and that one still probably would not learn anything useful in regard to three of the seven important trace elements Cu, Co, Zn, Mo, Fe, Mn, and B. On the whole, however, on comparing the trace element composition found in our soil samples with the data compiled by Swaine, we can say that Missouri soils are reasonably well supplied with the important trace minerals but that few if any are very well supplied with any trace element.

Our discussion could end here with this conclusion, which we reached six years ago, for we believe the conclusion still is valid. However, we should present the results of our trace element surveys of the forages, which extend and modify these conclusions.

During each of the years 1950, 1951, and 1952, samples of lespedeza and associated soils were collected, again with the help of the Soils Department, from five important soil types in the state (3). The plants were analyzed for copper, cobalt, zinc, iron, manganese, boron, nitrogen, phosphorus, potassium, calcium, magnesium, sodium, sulfur, chlorine, ash, moisture, fat, and fiber. The soils were analyzed for extractable copper, cobalt, zinc, boron, calcium, magnesium, potassium, and ignition loss. The soil types sampled were Marshall, Putnam, Lintonia, Clarksville, and Cherokee.

Some of the conclusions of this work are: The central Ozark soil at Clarksville gave the highest extractable cobalt content but the plants contained average cobalt contents. The plants from the Marshall soils gave the lowest cobalt on the average but the soils themselves were high in extractable cobalt. The alluvial Lintonia soils contained the lowest levels of extractable copper, cobalt, zinc, boron, and potassium, and the plants from this soil gave the lowest average amounts of copper, cobalt, and zinc. For purposes of animal nutrition, the copper, zinc, iron, and manganese contents of the lespedeza were adequate with almost no exception. On the other hand, many samples of the forage were found to be deficient in cobalt for animal feeding, especially those from the Marshall soil.

The alfalfa (4) was collected in 1954, 1956, and 1957, from 59 locations in 12 counties within the chief alfalfa-producing areas of the state. They were analyzed for moisture, ash, nitrogen, phosphorus, potassium, calcium, magnesium, iron, manganese, cobalt, copper, molybdenum, and zinc. Soils were not analyzed. The amounts of the trace elements iron, manganese, copper, molybdenum, and zinc were generally quite adequate for animal feeding purposes and also indicate reasonably good supplies of the trace elements for plant growth. Many samples were low in boron, reflecting the scanty use of borated fertilizers. The cobalt deficiency found in the lespedeza was found to be much more extensive in the alfalfa. Cobalt content was lower in alfalfa collected from Marshall, Wabash, Shelby, Grundy, Sharkey, Sarpy, and Menfro. On these loess or alluvial soils, 26% of the samples were deficient for cattle feeding (less than .04 p.p.m. cobalt) and 49% were deficient for sheep feeding (less than .07% p.p.m.).

In view of the widespread deficiency of cobalt in the alfalfa, it is surprising that we do not find symptoms of cobalt deficiency in ruminants in practice. Yet there seems to be no well-documented case of it in the state. If there is any cobalt deficiency in the state in practice, presumably the condition gives rise only to borderline disorders, perhaps chiefly in late winter, and is confused with other diseases. According to one authority this is often the case with cobalt deficiency. But it is certain that the condition is not severe.

It is possible that the lack of sufficient cobalt in the forages is made up at least in part by cobalt from other sources. We are attempting to collect and analyze samples of all the feed stuffs from a number of farms in the cobalt-deficient areas in order to test this possibility. Preliminary results indicate that most of the other ration ingredients are also very low in cobalt.

The cobalt content of the soils appears to be adequate, as already noted. The cobalt is not essential for plant growth but is merely picked up by plants incidentally, as are traces of many other nonessential elements in soils. The cobalt is lowest in the alfalfa grown in regions of greatest fertility and moisture supply. Thus the cobalt may be low because the alfalfa grows so rapidly in these regions.

It is still too early to think about cobalt supplementation of feeds in these regions. More work will have to be done to determine the desirability of this step. It should never be necessary or desirable to add cobalt to fertilizers for application to the soil. There seems to be plenty in the soils already.

In summary, the soils of Missouri appear to be generally rather well supplied with trace elements for both plant and animal nutrition with two possible exceptions. The one, for boron for leguminous crops, is generally recognized, and borate amendment of fertilizers is often desirable. The other, of cobalt in feed stuffs for ruminant animals, is not yet well established and no corrective measures can be recommended at this time, and it probably should not be thought of as a soil fertility problem at all.

The amounts of copper and zinc and possibly molybdenum in our soils may occasionally be limiting for plant production, under conditions of excessive liming, continued heavy crop production, or gradual depletion over a long period. However there is no indication that trace element supplementation is desirable in Missouri at the present time with the exception of the boron.

Bibliography

1. E. E. Pickett and R. H. Dinius, "Trace Elements in Missouri Soils," U. of Mo. Agr. Expt. Station Res. Bull. 553, Columbia, Mo., 1954.

2. D. J. Swaine, "The Trace-Element Content of Soils," Commonwealth Bu. Soil Science Tech. Commun. 48, Harpenden, England, 1955.

3. E. E. Pickett, "Mineral Composition of Missouri Feeds and Forages. I. Lespedeza," U. of Mo. Agr. Expt. Sta. Res. Bull. 594, Columbia, Mo., 1955.

4. E. E. Pickett, "Mineral Composition of Missouri Feeds and Forages. II. Alfalfa," U. of Mo. Agr. Expt. Sta. Res. Bull. 724, Columbia, Mo., 1960.

ISOTOPES IN SOIL STUDIES

E. R. Graham, Professor of Soils

There has, until recently, been no way of distinguishing between the element absorbed by plants that is derived from the soil and that obtained from added fertilizer. The use of a radioactive isotope permits the distinction to be made, and provides a means of ascertaining the kind of treatments, and the soil conditions which are best for a given crop. To date, the majority of the investigations have been made with Phosphorus^{32}, Calcium^{45}, Sulphur^{35}, Zinc^{65}, and Cobalt^{60}. These are isotopes readily available and easy to handle. Most of the studies to date have been concerned with availability to plants of the added element. When these processes are better understood, soil management practices can be improved and result in improved production efficiency of crops.

Use of p^{32} in Soil Experiments

Although many radioisotopes have been used in the laboratory for soil investigations, radio-phosphorus has received the most attention. This technique has the advantage of accurately measuring the phosphorus in the soil that is in equilibrium with the phosphorus in the soil solution. If radioactive phosphorus is added to a soil at normal moisture content the ions of phosphate will be distributed into the diffusion layer of the soil as well as into the free solution. When the time interval is long the radioactive ion may move into internal particle boundaries and diffuse through the interior of the clay crystal. If the reaction rates as expressed in per cent exchange per day are sufficiently different it is possible to measure the magnitude of the different systems. This makes it possible to express with quantitative certainty the phosphorus fixing properties of a given soil.

The first use of isotopic exchange was to study the amount of available phosphorus in a soil much in the same manner as had been done by using soil extracts or by growing plants. This is a modified isotopic exchange experiment.

$$\frac{p^{32}\text{ solid (calculated)}}{p^{32}\text{ solution (measured)}} = \frac{p^{31}\text{ solid (calculated)}}{p^{31}\text{ solution (measured)}}$$

At any one time interval the p^{32} in solution can be measured by centrifuging the mixed sample and removing the clear supernatent liquid for counting. If one knew the correct time to remove the portion for counting, this procedure could most likely be used as a "quick test" for available phosphorus. A better way to do the above experiment would be to determine the values for the left hand side of the equation by growing a crop. This would allow the root of the growing crop to integrate the measurement of the liquid held and the loosely adsorbed available phosphorus over the entire growing season. This method has the advantage over the previously described procedure in that the plant is absorbing phosphorus over a period of time from growth to harvest, while in the other method one time interval needs to be selected.

In the early work with radiophosphorus with soils and plants it was pointed out by a number of investigators that the percent phosphorus in the plant derived from the fertilizer varied with the level of available nutrient in the soil. These studies have shown that the use of the radio-phosphorus can give information not possible to obtain by older methods.

1. In a relatively brief period of 48 hours it has been possible to determine the changes in crop response to added treatments of phosphate.

2. Reasonable amounts of P_2O_5 may be added to the soil system without upsetting the experiment. This makes it possible to do a phosphorus experiment without starving the plant for phosphorus as is done in most soil plant experiments.

3. It has been found that surface exchange phosphorus will remain constant over a range of ammonium citrate concentrations from .1 M to .001 M. This lends validity to the quick test extraction procedures.

4. Many important observations have been made on the different plant species. It has been found that eleven weeks after planting corn was absorbing 67% of its phosphorus from the subsoil, cotton 38%, peanuts 68%, and tobacco 83%.

5. Broadcast treatments are the most convenient method of applying fertilizers to pastures. Since it is known that the phosphates penetrate soils only to a limited degree, this method has not been considered as a very good one for the application of phosphorus. The top dressing of established meadows with phosphate containing p^{32} revealed that top-dressing was surprisingly effective.

Observations on Isotopic Exchange Reactions as Shown by Missouri Soils

To study the kinetics of isotopic exchange, samples of soil were equilibrated with a solution of radioactive phosphorus (p^{32}). After time intervals of .1, 1.0, 12, 168, and 336 hours the samples were centrifuged and the amount of radioactive phosphorus determined in the clear supernatent liquid. The results showed that the initial exchange was a rapid process on most soils. However, on some soils the initial rapid process was followed by a slower process (Table 1). These results are in agreement with studies where phosphate was equilibrated with soil in .01 M $CaCl_2$ solutions.

Table 1. Isotopic Exchange Reactions as a Function of Time on Two Missouri Soils.

Time	Baxter S. L. fraction exchanged	Sarpy Sandy Loam fraction exchanged
.1 hr.	83%	46%
1.0 hr.	94%	57%
12	94%	65%
168	97%	77%
336	96%	81%

The rapid reaction of the added phosphate with the Baxter soil and the small amount of change after one hour indicated that in this soil there is only one kind of phosphorus available for exchange reactions. The results with the soil reveal at least two types of exchange reactions. The added active phosphorus on the Baxter soil appeared to reach an equilibrium after one hour. Even after 336 hours this equilibrium had not been reached on the Sarpy soil.

Fried* determined the exchangeable P_2O_5 by treating a soilwater mixture with radioactive phosphorus and equilibrating for 48 hours. He also tested the response of the soils in the greenhouse when plants were grown on the soils treated or untreated with phosphorus. The results of this experiment are shown in Table II. In some later work on 35 soils showing less than 180 lbs. exchangeable P_2O_5, only 3 did not give plant response to added phosphorus. Of 22 soils with an exchangeable phosphorus level of more than 240 lbs. P_2O_5/A only 3 responded to treatments of applied phosphorus.

Table 2. Exchangeable Soil Phosphorus as Determined by Equilibration with p^{32} and the Response of Soils to Applied Phosphorus in a Greenhouse Experiment. Fried*

Exchangeable P_2O_5/lb. /A	No. of soils responding	No. of soils not responding
0-60	2	0
61-120	11	1
121-180	19	2
181-240	8	9
above 240	3	19

Studies at Missouri have shown that the drying of soils greatly reduced the concentration of p^{31} in the soil solution. The results (Table III) show that the added soluble phosphorus did not stay in solution. The amount remaining in solution after 1 drying and 1 rewetting cycle varied from only .73% as in the Baxter S. L. to 9.37% in the Sarpy Sandy L. The isotope exchange phosphorus varied from a low of 269 to a high of 735 lbs. per acre. According to Fried all of these soils would represent high phosphorus fertility levels and would give only limited response to added fertilizer phosphorus.

*Fried M. Measurement of Plant Nutrient supply of Soils by radioactive isotopes. Am. Assn. Adv. Sci. Pub. 49.

Table 3. Exchangeable Soil Phosphorus as Determined by p^{32} Equilibration On Soil Samples Which Had Been Treated With Soluble p^{31} and Dried After Equilibration with p^{31}.

Soil Sample	mgm. P/60 ml of .01 M. CaCl	% of added soluble P in solution	Exchange Phosphorus P_2O_5 lbs/A
Baxter s l	.016	.73	269
Lindley s l	.021	.97	273
Knox	.161	7.46	735
Sarpy sandy l	.204	9.37	545
Sharkey clay	.061	2.76	565

Attempts to measure the anion exchange capacity of soils and to express the results in the terms of cation exchange capacity have given inconsistent results. It is apparent that so called anion ex-change phosphate does not react with soils or behave in the same way cations do.

It does not appear logical to consider the isotopic exchange soil phosphorus as a uniform fraction of soil phosphorus as we would isotopic exchangeable sodium. It is more or less a heterogeneous fraction. We cannot expect, therefore, that the isotopically exchangeable phosphorus will be an exact measure of the phosphorus available to a plant.

The use of Isotopes in soils studies will allow us to better understand:

1. What happens to phosphorus when added to soil.

2. The nature of high phosphorus fertility in soils.

3. Which species of plants do best on soils of high soil solution phosphorus concentration, and which plants do best on soils containing high levels of isotopic exchange phosphorus.

4. How drying will influence different soils of Missouri in relation to the amount of phosphate in the solution phase.

NUTRITION OF SOYBEANS

G. H. Wagner, Assistant Professor of Soils

Much attention has been given to the nutrition of soybeans. This concentrated effort has shown the many gaps in the knowledge of the physiology of this crop. It has not been possible to determine where in the life cycle of the soybean that a shortage of soil nutrients is limiting productivity.

The soybean differs from non-legumes in that it uses nitrogen from the air, made available by root nodule bacteria living in symbiosis with it. This symbiosis depends on an extremely complex relationship that exists between a host plant and a strain of bacterium. Furthermore, the plant-bacteria relationship is associated with soil fertility. It has been observed, for example, that a calcium deficiency in the soil affects the activity of the nitrogen-fixing bacteria and as a result may be reflected in a nitrogen deficiency in the plant. Such a relationship was observed in 1960 at the McCredie Experiment Field. Where the calcium treatments were either inadequate in amount or the material was too coarse to have reacted sufficiently in one season, the plants showed distinct nitrogen deficiency symptoms by July. There was little or no nodulation and the soil was still acid and calcium deficient. This deficiency of calcium, and the accompanying nitrogen shortage of the plant, resulted in a yield deficit of two to three bushels of soybeans per acre.

Many Missouri soils are deficient in phosphorus. It is important to correct deficiencies if optimum yields of soybeans are to be obtained. A shortage of lime may reduce the availability of phosphorus and decrease the amount of this element absorbed. Where levels of potassium are low, additions of this element in fertilizers have been effective in increasing yields when the fertilizer is plowed down or applied with planters that keep the treatments in bands separate from the seed. Germinating soybean seeds are sensitive to fertilizer salts and the treatment should never be placed in contact with the seed.

In an experiment at the southwest research center the application of 100 pounds of P_2O_5 in bands near the row gave striking response. In 1959 the yield was increased from 13 to 27 bushels per acre and in 1960 from 21 to 31 bushels. Rock phosphate was as effective as superphosphate. This indicates the value of rock phosphate as a low cost material which can be used with good results on soybeans. The practice of applying a small amount of rock phosphate in the row does not, of course, correct soil deficiencies and should not be expected to benefit subsequent crops. The usual broadcast application at a rate which will correct the soil deficiency is the recommended practice. For soils highly deficient in phosphorus an ideal time to use rock phosphate in the cropping system is just ahead of a soybean crop.

It has been found that on some very acid soils there has been a response to molybdenum. In tests throughout the state where the soil has been properly limed soybeans have not responded to molybdenum treatments. In fact, in one experiment in Southeast Missouri on a Dexter sandy loam soil where lime was adequate, molybdenum applied with the inoculant on soybean seed resulted in stunted plants and a yield reduction of six bushels per acre as compared with the inoculated seed which was not treated with molybdenum.

A number of theories have been proposed concerning the failure of soybeans to respond to fertilizer treatments as much as some other crops. One of these has developed from the suggestion that perhaps the fertility of the soils in the countries from which soybeans were introduced might have had an effect, over evolutionary time, on their present response to fertilizer. The parent plants of the soybean varieties which we grow today have come from oriental countries where cultivation for thousands of years has reduced the fertility of the soil to a low level. The possibility that such a yield-restrictive influence does exist has prompted some soybean breeders to attempt to develop soybean varieties which will be more responsive to fertilizers.

Some work done at Missouri relates to the limitations of soybeans to nitrogen treatments. In these tests a non-nodulating variety of soybeans has been used to study the effects of nitrogen fertilization.

This non-nodulating soybean does show greater response to nitrogen fertilizers than the Clark variety, but only in a nitrogen-deficient soil. In three seasons of testing the production by nitrogen-treated non-nodulating soybeans was better than the yields of well nodulated Clark beans which had received no nitrogen treatment. In 1960 the maximum response from chemical nitrogen applied to the non-nodulating soybeans was four bushels per acre where 100 pounds per acre of nitrogen were used. There appears to be a small nitrogen response for the Clark variety, but it is of questionable significance.

In 1958 when the available nitrogen of the soil was more limiting and the weather conditions seemed ideal for high soybean yields, the nitrogen response of the non-nodulating soybeans exceeded five bushels per acre, but even with nitrogen added the yields were nearly five bushels below that of the well nodulated Clark soybeans which had received no nitrogen treatment.

In 1958, when the maximum nitrogen response was obtained, the non-nodulating beans had a lower crude protein content and a higher oil content than the Clark beans. The nitrogen treatments had only a small influence in changing this composition of the non-nodulating beans to approach that of the Clark beans. The crude protein and oil content of the Clark beans were unaffected by the nitrogen treatments. In 1959, there was no difference in the seed composition of the two varieties and the nitrogen additions had no significant effect on the composition of either.

From the results obtained so far, we must conclude that nitrogen fertilizers may not be used as a practical means of increasing the yield or the quality of the Clark variety of soybeans, nor is it practical to grow a non-nodulating sister strain and use nitrogen fertilizers in an attempt to increase yields over those associated with the well nodulated recommended varieties.

This does not mean, of course, that the recommended varieties of soybeans do not use soil nitrogen. Even a thoroughly inoculated crop gets part of its nitrogen requirement from the soil. For the cropping systems in which soybeans are gorwn in Missouri this requirement is usually met by residual nitrogen from the treatment of a previous crop, or from that released through the breakdown of soil organic matter. When additional fertilizer nitrogen is added to the soil it may also be taken up by the soybean crop, but such a practice does not supplement the nitrogen-fixing activity of the bacteria. Rather it renders the services of these bacteria unnecessary.

The attempts to charge the nitrogen-fixers for consumption of the energy equivalent of six bushels of beans per acre from a crop that yields 20 bushels has yet to be justified. We must conclude that this energy is only a surplus product of the plant's reproduction processes and can, therefore, be handed over with no charge to the bacteria.

It is generally accepted that the soybean is one of our more complex farm crops from a physiological point of view. The soybean in the seedling stage is somewhat sensitive to salt injury from heavy dosages of inorganic nutrients and when more mature fails to be stimulated by direct fertilization of many soils with inorganic nutrients. Nevertheless, soybean yields are obviously related to certain soil factors.

There is some evidence from limited field studies and observations by farmers that soybean yields are influenced by the composition of the residues of the crop preceding the soybeans. Preliminary studies employing radioactive phosphorus show that soybean plants take up phosphorus more readily from the organic decomposition products of barley plants than from mineral phosphates. Since the barley plant is a heavy feeder on mineral nutrients, perhaps it incorporates these nutrients into organic combinations which make the plant food more readily available to the following soybean crop.

In another test of this same general thesis, corn stalk residue from an abundantly fertilized field is being compared with the residue from a soil of low fertility as a treatment for soybeans. From the results of 1959 and 1960, we have been unable to show any significant difference between these differently treated residues.

One other thesis we are investigating involves the use of foliar treatments of organic materials which may serve as "growth substances" to step up the metabolic processes involved in soybean grain production. From the results of three years of study we have evidence that application at the bloom stage with certain materials may prove beneficial. Showing most promise is methionine, and perhaps other amino acids and gibberillic acid.

The yield differences are only of the order of one bushel per acre and are not statistically significant. However, these results are consistent for three different growing seasons and may be worthy of further study. It is the objective of this study to search for growth-promoting substances which would release the restriction of nature over response to mineral nutrients.

So far in our studies of the nutrition of soybeans we have learned that fertilizing the soil can help to increase yields of this crop. It must be conceded, however, that response to fertilizers may not be immediate and often may be realized two or three years after soil nutrient shortages are corrected. Nevertheless, soybeans are large users of plant nutrients. They make heavy demands on the soil for calcium, magnesium, phosphorus, and potassium. When good yields are produced, the nutrients removed are equal to or greater than those for a corresponding crop of corn. Therefore, unless the fertility of the soil is maintained, soybean cropping will deplete the soil of valuable nutrients.

RESPONSES OF CORN TO INCREMENTS OF PHOSPHORUS IN RELATION TO RESULTS OF CHEMICAL TESTS OF SOILS FOR PHOSPHORUS

C. M. Woodruff and J. D. Mikulcik, Department of Soils

One of the propositions that the corn producer must consider is the quantity of phosphorus he will apply to his soil. When legumes were used as sources of nitrogen for corn, the desirability of fertilizing so as to increase the phosphorus contents of soils to levels suitable for legumes was a dominant factor in the consideration. Chemical tests of soils for phosphorus in Missouri were calibrated upon this basis. But with the advent of synthetic nitrogen, cropping practices changed so that corn has come to be grown regularly on many soils. The placement of phosphorus in bands near the seed at planting time has proved to be a very effective means of supplying phosphorus to corn. Banded phosphates now provide the readily available sources of phosphorus formerly supplied by the rapidly decomposing residues of legume crops.

The effectiveness of band placements of phosphorus have been demonstrated amply by results obtained during the past three years from investigations of the subject on the experimental field at McCredie, Missouri. Heavy broadcast applications of acid processed phosphorus (800 lbs. per acre of P_2O_5 as dicalcium phosphate) were mixed thoroughly with acid and limed soils in the spring of 1958. Similar acid and limed soils to which no phosphorus was added served as references for determining the effectiveness of banded phosphorus. Corn was planted across the four plots in paired rows, one with no phosphorus in the fertilizer band, the other with 50 pounds per acre of P_2O_5 banded near the seed (40 lbs. of P_2O_5 were used in 1960).

The increases in yields attributable to the banded phosphorus were equally as good as those obtained by the combinations of broadcast and banded phosphorus for each of the three years of the investigation. (Table 1). The maximum difference in favor of the combination of treatments was 5 bushels per acre on the limed plot in 1958, but this difference was less than the experimental error of the measurement. The increased yield from the combination of treatments on the acid soil was less than that for the banded treatment alone in 1958 and the difference was significant. The ears of corn were light and chaffy, suggesting some adverse effect in the physiology of the plant that was associated with large amounts of phosphorus in the acid soil. This effect was not apparent in the two succeeding years, but appeared in three cases for other soils in 1960.

The increases in yields produced by the large amount of phosphorus incorporated into the soil were less than those obtained from the banded phosphorus in both 1958 and 1959. These results suggested that banded phosphorus might prove desirable on soils normally containing large amounts of phosphorus. Significant responses to banded phosphorus as judged by more rapid early growth of corn had been observed on phosphorus rich alluvial soils along the Missouri and Mississippi Rivers. For these reasons the effects of banding phosphorus on alluvial soils were included in the field trials which were conducted in 1960.

Prior to 1960, no information had been obtained concerning the most desirable amount of phosphorus to band with corn at planting time. It was expected that this quantity should depend to some degree upon the availability of phosphorus in the soil. A series of experiments designed to evaluate the responses of corn to different rates of banding phosphorus also provided an opportunity to evaluate different methods of testing soils for phosphorus. Four methods were chosen for evaluation.

1. Extraction with 0.1N HCl and 0.03N NH_4F as developed by Bray.
2. Extraction with 0.025N HCl and 0.03N NH_4F as developed by Bray.
3. Extraction with sodium bicarbonate as developed by Olsen.
4. Equilibration with 0.01M $CaCl_2$ as developed by Asylng.

The first of these methods is that used by the soil testing laboratories in Missouri. Its feature is a sufficient concentration of acid to dissolve phosphorus from the apatite of rock phosphate. The second method is one now used extensively in adjoining states. Its feature is a low enough concentration of acid to avoid the dissolution of the more stable minerals forms of phosphorus. The merit of the third method is an alkaline extraction applicable particularly to calcareous soils of the West. The last method is one which reflects the phosphorus potential of the soil or the concentration of phosphorus in the soil solution. Its use has been found to provide an excellent reflection of the nutritional status of soils for the growth of plants in pots in the greenhouse.

Plan of the Investigations Conducted in 1960.

To determine the most appropriate rate of banding phosphorus for corn, four rates were chosen, 0, 20, 40, and 80 lbs. of P_2O_5 per acre. The range was considered adequate to cover the requirements on even the most deficient soils. These were applied as a single strip of four rows across a field of 40 acres. Nitrogen, and potassium where needed were spread separately. When the corn was one to two feet tall, the four row strip was divided into 25 to 30 plots each 50 feet long. The corn was thinned to provide equal numbers of plants in each of the four rows on a plot. Thus a measure of the precision of the data was obtained. Numbers of plants per acre were of the order of 12,000 to 15,000 except at Mt. Vernon where 8,500 were used. Composite samples of soil were obtained from each plot providing from 25 to 30 samples for each location.

The investigations were conducted at thirteen locations in the state, four on upland soils and nine on alluvial soils. Two fields were used at one location and four plots were used at each of two locations providing a total of twenty experiments as set forth below. Except for the plots on the experiment station fields at McCredie, Columbia, and Mt. Vernon, the experiments were conducted on fields of cooperating farmers who graciously provided the equipment and tended the plots.

Corn heights were measured and tillers were counted at the time the plots were thinned to constant stands. Percentages of silked ears were determined during the silking stage. Ear counts were obtained when the corn was harvested.

Results of Investigations:

General Observations:

Row applications of phosphorus increased the rates of growth of the plants during the early stages of development in all cases, and hastened the appearance of silks. The tillering of the corn was increased significantly only at the highest rate of treatment with phosphorus. The numbers of ears harvested did not vary significantly with respect to the quantities of phosphorus applied in the band except at Palmyra, McCredie, Henrietta, and Poplar Bluff. At these locations there was a progressive increase in numbers of ears per acre with increasing amounts of phosphorus that were applied. The increase was of the order of 1000 to 2000 ears out of a total of 12,000 ears per acre for the 80 lbs. of P_2O_5 in the band.

Results of Soil Tests and Final Yields of Corn:

The results of the soil tests must be judged in terms of the kind of test employed and the standards which have been established for interpreting the results. Usually the values obtained by the tests are classified in three categories, namely, 1. Values below which response to treatment is likely or certain. 2. Values for which response is probable or uncertain and 3. Values above which response is unlikely. Some suggestions of the limits that are used for the respective tests are as follows:

Method	Response Likely	Probable Response	Response Unlikely
1. Strong Acid Extraction	-- Below 50 lbs P_2O_5	50 to 100 lbs P_2O_5	over 100 lbs P_2O_5
2. Weak Acid Extraction	-- Below 20 lbs P_2O_5	20 to 30 lbs P_2O_5	over 30 lbs P_2O_5
3. Sodium Bicarbonate	-- Below 25 lbs P_2O_5	25 to 50 lbs P_2O_5	over 50 lbs P_2O_5
4. Calcium Chloride	-- Below 0.25 μM/l	0.25 to 0.50 uM/l	over 0.50 μM/l

The strong acid extraction as used in Missouri is not interpreted as a guide to the banding of phosphorus for corn. It is used as a guide to building the basic level of phosphorus in a soil to a point that will support legume and meadow crops which are not fertilized directly. Banded applications of 30 lbs. of P_2O_5 per acre are suggested for corn irrespective of the results obtained with this soil test.

The response levels for the calcium chloride equilibration are those suggested for final yields of corn. In terms of the rates of growth of corn plants during their early stages of development some response to treatment may be expected for test values up to 10 micromoles per liter.

In view of the considerations and suggestions outlined above the results of the soil tests by the different methods may be appraised in terms of the responses to treatments that were obtained in this investigation. The data are presented in Table 2. Each figure reported represents an average of approximately 25 determinations. About 2,000 analyses were made of soil samples and a corresponding number of yield determinations were made. The precision of the data for yields is of the order of 5 to 7 bushels per acre at the 1% level of significance and 3 1/2 to 5 bushels per acre at the 5% level of significance.

Discussion of Results:

1. Edina Soil at Palmyra, Missouri (A soil similar to Putnam Soil)

The results of all four of the soil tests were very near or within the range of accepted values for which a response would be considered probable. An excellent response was obtained to 20 lbs. of P_2O_5 in the fertilizer band. However, larger amounts depressed the yield from that obtained with only 20 lbs. of P_2O_5. This depression in yield is worthy of note since in all previous work with phosphorus on soils suitably supplied with other nutrient elements no such depressions in yield by large amounts of phosphorus were observed.

2. Putnam Soil At McCredie, Missouri

The results of each of the four soil tests on both the acid and limed plots suggested that a response to fertilization with phosphorus should be obtained where no phosphorus had been added previously and that very little or no response could be expected where the heavy basic treatment (800 lbs. P_2O_5) had been applied two years previously. The yields of corn obtained were in agreement with these interpretations. In assessing the economics of the responses obtained it may be pointed out that approximately one bushel of corn per acre will pay for ten pounds of P_2O_5 as fertilizer. The 80 lb. rate provided good returns on the untreated plots of this series.

3. Putnam Soil at Columbia.

This soil had received 2,000 pounds of rock phosphate per acre in 1950 and 100 lbs. of P_2O_5 per acre as super phosphate annually for twelve years prior to 1960. Results of the soil tests reflect adequate supplies of phosphorus in the soil. The wide difference between the results obtained by the two acid extractants also reflect the presence of the apatite that had been added as rock phosphate. The corn did not respond to the banded phosphate indicating that the level of availability in the soil was adequate.

The yields in 1960 at both Columbia and McCredie where phosphorus was banded were contrary to those obtained in both 1958 and 1959 at McCredie when good responses to banded phosphorus were obtained where 800 lbs. of P_2O_5 had been mixed with the soil. The rainfall during 1958 and 1959 was sufficient during July and August to keep the corn roots concentrated in the upper soil horizons. Very little rain occurred during July and August of 1960. Corn roots penetrated to a depth of four feet. The profile of the Putnam soil contains an abundance of phosphorus beneath the clay pan. Undoubtedly this phosphorus becomes effective in seasons characterized by a deficienty of rain when corn is filling the ears.

4. Baxter Soils at Mount Vernon

The four plots used at Mount Vernon had received 0, 100, 300, and 900 lbs. of P_2O_5 as triple super phosphate mixed with the soil the previous year. The soil of the untreated plot would be judged deficient in phosphorus by the results of each of the soil tests. A good yield response was obtained to the banded phosphorus. The results of the soil tests of the plot that had received 100 lbs. of P_2O_5 per acre reflected an adequate supply by the weak acid extraction and a probable response by both the strong acid extraction and the calcium chloride equilibration. A maximum yield was obtained with no banded phosphate and significant depression in yields occurred with banded phosphate.

Adequate amounts of available phosphorus were indicated by the results of the soil tests for the remaining two plots which had received 300 and 900 lbs. per acre of P_2O_5 respectively and banding of phosphorus depressed the yields significantly. The heavy basic treatment also depressed the yield from those obtained with moderate basic treatments.

The depression in yields by large additions of phosphorus to the Baxter Soil were associated with a disturbed physiology of the female organ of the plant. Strong vigorous stalks with broad healthy leaves were produced but the shoots were deformed and poorly developed. It is suspected that phosphorus interacts adversely with one of the essential minor elements, which might easily be deficient in this highly weathered soil of the Ozarks.

5. Alluvial Soils of the Missouri, Mississippi and St. Francis River Basins.

Results of the soil tests by each of the four methods employed reflected ample to surplus amounts of phosphorus in the soils at all the locations on alluvial soils. Significant depression in yields as a consequence of banding phosphorus occurred for the soil at Watson, Missouri. No significant response either favorably or adversely occurred at New Franklin, St. Charles, and St. Genevieve even though the levels of available phosphorus as reflected by the results of soil tests were extremely high. At Henrietta, Carrollton, Alexandria, Malden, and Poplar Bluff good response to the banding of phosphorus were obtained. Generalizing from the data, it would seem that 20 to 40 lbs. of P_2O_5 per acre was adequate in most cases.

Summary and Conclusions:

1. From the data obtained it was evident that a low test value for soil phosphorus by any of the four methods of testing that were employed was indicative of a response to banded phosphorus.

2. The evidence, although not conclusive, suggests that for soil testing low in phosphorus, the rates of banding phosphorus should be moderate to high. 40 to 50 lbs. of P_2O_5 per acre, or enough to replace that removed by 100 bushels of grain would appear to be appropriate. Large amounts would appear to be inducive to tillering which in most cases is considered to be undesirable.

3. For soils testing medium and high in phosphorus, by any of the tests that were used, there appears to be no certainty concerning the yield response to be

expected by banding phosphorus. In view of the numbers of good responses obtained with the minimum treatment employed it would seem appropriate to use 20 to 25 lbs. of P_2O_5 as a starter for corn on soils testing high in phosphorus unless practical field trials over a period of years show the treatment to be unnecessary.

Regardless of the fact that the results of the chemical tests for phosphorus were high for the alluvial soils, the rates of growth of the corn plants were increased markedly by the banding of phosphorus on all these soils.

4. In view of the excellent yields of corn obtained in most cases from soils containing surplus amounts of phosphorus, adverse effects on corn yields of banding large amounts of phosphorus such as those which occurred at Palmyra, Mt. Vernon, and Watson should be investigated to determine the causes for such effects. They suggest a deficiency of some element other than the major fertilizer and lime elements. The applied phosphorus may have only intensified the effects of the deficiency thus providing a possible means of ascertaining the existence of a deficiency in a soil that otherwise would be a borderline case for diagnosis.

5. Until more evidence on the subject pertaining to the values of the different soil tests in predicting responses to the banding of phosphorus for corn is obtained, it cannot be concluded that one method is more appropriate than another.

Table 1. Yields of Corn from Acid and Limed Putnam Soil with no Applied Phosphorus and Increases in Yields Obtained by Mixing Phosphorus with Soil, by Banding Phosphorus in the Row and by a Combination of Both Mixed and Banded Phosphorus
McCredie, Missouri - 1958 to 1960

Bushels per Acre

Year		1958		1959		1960	
	Banded P_2O_5 - lbs/acre	0	50	0	50	0	40
Acid	No P_2O_5 Mixed	73	+44	48	+24	95	+16
Soil:	800 lbs - P_2O_5 in 1958	+23	+30	+15	+23	+16	+18
Limed	No P_2O_5 Mixed	62	+53	62	+17	111	+ 8
Soil:	800 lbs - P_2O_5 in 1958	+44	+58	+ 8	+19	+13	+10

Increases in yields denoted by a prefix +

LSD .01 approximately 5 bu/acre for effects of banded phosphate

Approximately 10 bu/acre for effects of mixed phosphate.

Table 2. Results of Soil Tests for Phosphorus by Four Methods, Yields of Corn with no Phosphorus Banded in Row and Increases or Decreases in Yields for Different Quantities of Phosphorus Banded in Row at Various Locations in Missouri.

A. Upland Soils

Location	Soil Test Method				Pounds of P_2O_5 Banded in Row			
	Strong	Weak	Sodium	Calcium	0	20	40	80
	Acid	Acid	Bicarb	Chloride	Yield	Increases	or	Decreases
	lbs. P_2O_5 per acre			u m/l of P	bu/ac.	bu/ac	bu/ac.	bu/ac
Palmyra:	57	33	45	0.46	89	+25	+12	+15
McCredie:								
No P - Acid	31	20	10	0.07	95	+15	+16	+22
Limed	30	20	11	0.09	111	+ 5	+ 8	+14
800 P_2O_5 - Acid	183	112	36	0.43	111	- 3	+ 2	+ 1
Limed	224	86	27	0.41	124	- 2	- 3	- 2
Columbia	433	130	110	2.13	98	0	+ 3	+ 3
Mt. Vernon:								
No - P	33	24	33	0.20	56	+10	+ 3	+ 4
100 lbs. P_2O_5	67	44	47	0.32	64	- 1	- 8	- 9
300 lbs. P_2O_5	165	117	76	1.62	66	- 2	- 8	-12
900 lbs. P_2O_5	336	172	124	4.60	58	- 2	- 9	- 8

Table 2 - Continued

B. Alluvial Soils

Location	Soil Test Method				Pounds of P_2O_5 Banded in Row			
	Strong Acid	Weak Acid	Sodium Bicarb	Calcium Chloride	0	20	40	80
					Yield	Increases	or	Decreases
	lbs. P_2O_5 per acre			u m/l of P	bu/ac	bu/ac	bu/ac	bu/ac
Watson:	774	192	126	7.8	128	+ 3	-12	-22
Henrietta:	526	187	161	4.6	108	+ 3	+12	+15
Carrollton:	347	286	87	6.9	104	+17	---	+16
New Franklin:	608	104	124	4.8	146	- 3	- 1	- 6
Alexandria*								
North Field a.	347	118	171	3.1	132	+ 9	+10	+ 2
b.					52	+16	+19	+25
South Field a.	416	96	124	1.9	131	+ 3	- 4	+10
b.					51	+21	+23	+19
St. Charles	488	310	170	6.2	74	- 4	- 2	- 1
St. Genevieve	591	110	144	2.0	115	0	- 2	+ 3
Malden	289	121	109	1.3	87	+ 9	+ 8	+15
Poplar Bluff	154	81	119	1.6	95	+ 4	+12	+ 7

* At Alexandria portions of Fields flooded (a) unflooded (b) flooded.

All banded phosphate applied as mono ammonium phosphate