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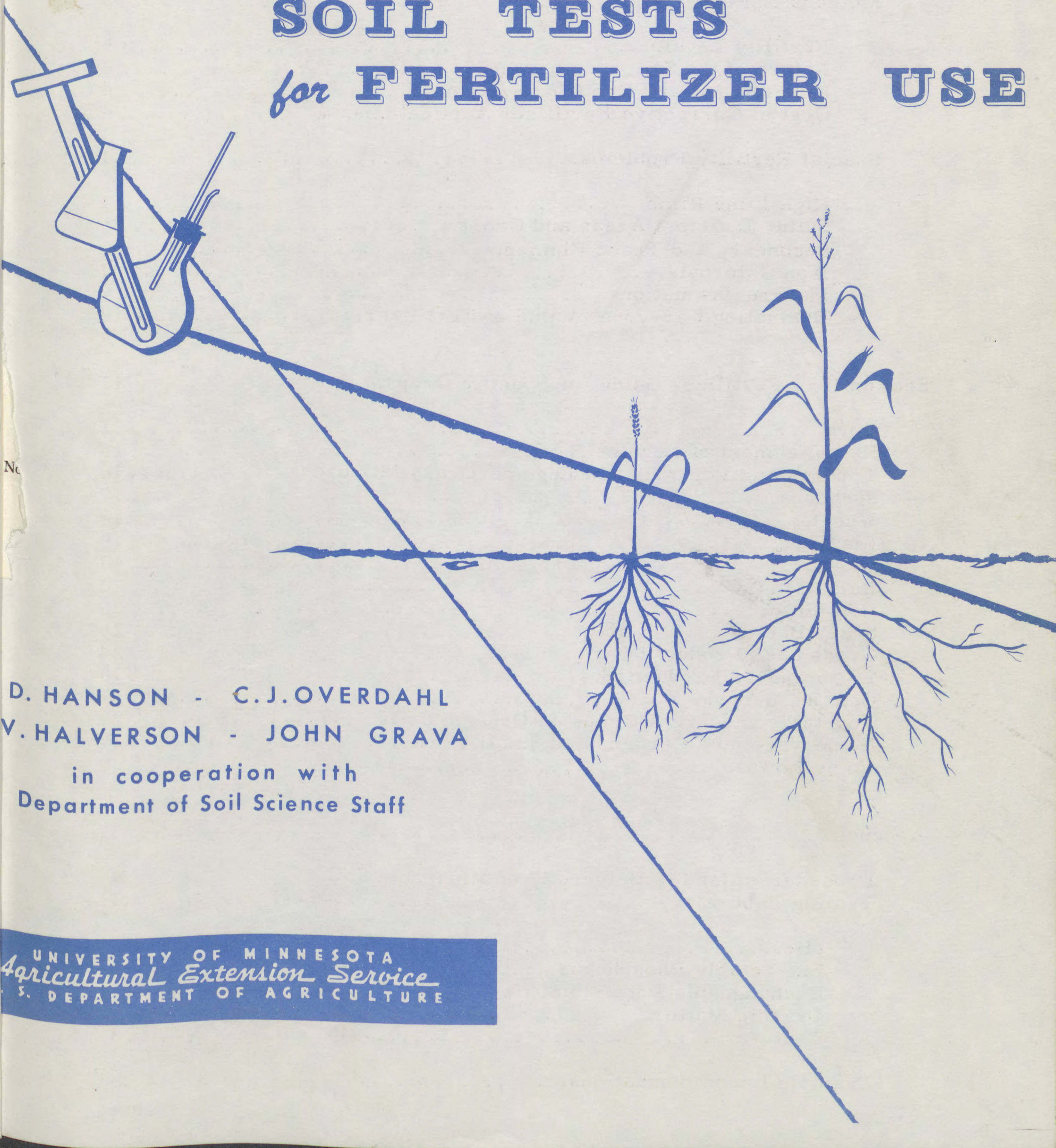
Interpretation of MINNESOTA SOIL TESTS *for* FERTILIZER USE



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UNIVERSITY OF MINNESOTA
Agricultural Extension Service
. S. DEPARTMENT OF AGRICULTURE

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Interpretation of Minnesota Soil Tests for Fertilizer Use

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The use of commercial fertilizers is an important part of the large crop production industry in the state. From 1956 to 1959, Minnesota farmers produced each year an average of about $800 million worth of crops. Fertilizer application is becoming increasingly essential in the production of these crops. During 1963, 614,621 tons of commercial fertilizer were applied to Minnesota soils and provided 80,211 tons of nitrogen, 114,227 tons of phosphate, and 77,448 tons of potash. Even with this amount of fertilizer, recent estimates are that there is an annual deficit of 250,000 tons of nitrogen and 65,000 tons of potash removed and not replaced in Minnesota soils. Increased use of fertilizer, correctly selected, is necessary by farmers to maintain the competitive position of Minnesota's agriculture.

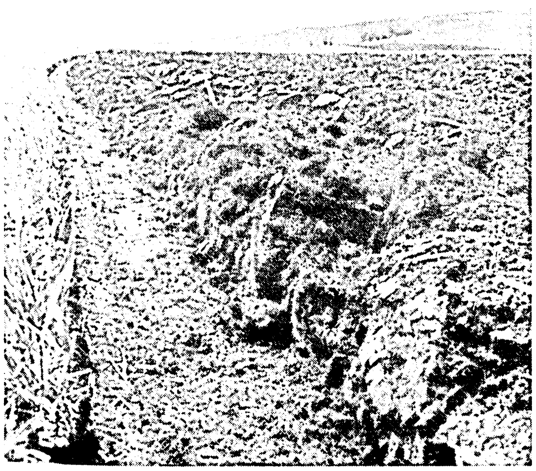


Figure 1. The surface plow layer is the foundation of agricultural production. Its fertility and method of management can determine the efficiency of the whole farm business. Sound soil tests and interpretation are essential to this management.

One of the important responsibilities of the Soils Department and the Extension Service of the Institute of Agriculture is to provide farmers with reliable information on the use of commercial fertilizers and soil amendments. The soil test is used in providing this information. The purpose of this bulletin is to provide the information necessary to develop specific fertilizer recommendations for farmers based on University of Minnesota Soil Testing Laboratory analyses and related Soils Department research.

SECTION I

PRINCIPLES OF SOIL TESTING and FERTILITY

FUNCTION OF THE SOIL TEST

The purpose of a soil test is to provide basic information essential in evaluating the fertility status of a cropping unit of land. Soil test information is then used along with an evaluation of specific crop requirements, past cropping history, and physical soil characteristics in determining the amount and combination of nutrients needed for a certain crop or cropping sequence.

UNIVERSITY OF MINNESOTA SOIL TESTING SERVICE ORGANIZATION

The Soil Testing Service at Minnesota has two primary objectives: (1) providing laboratory soil analyses and (2) interpreting results and recommending the necessary plant nutrients. A staff member of the Department of Soils directs the laboratory and the interpretation and recommendation phase is the responsibility of Extension Soils Specialists and County Extension staffs. These recommendations are based on soil fertility research conducted by the Department of Soils.

Soil samples are submitted to the Soil Testing Laboratory either directly by farmers and dealers or through County Extension offices. A period of about 10 days is required from the time the samples arrive in the laboratory until the results are mailed to the county agents. The County Extension Agent then prepares the individual fertilizer recommendation and mails or delivers it to the farmer. A copy of the laboratory report and recommendations is available for others such as fertilizer dealers, if requested on the information sheet.

There are five individual soil properties measured in a routine soil test. These are: pH, extractable phosphorus, exchangeable potassium, percent organic matter, and texture. The laboratory uses modern analytical instruments and is staffed by trained personnel.

A detailed description of the laboratory methods used is given in the appendix.

INTERPRETATION OF SOIL TEST INFORMATION

To interpret the values obtained from the procedures outlined, you need to understand what these values mean. A common misunderstanding is that the values reported in the analysis are absolute amounts of available nutrients. This is not the case. The test value is an index to the relative availability of phosphorus in the soil.

Table 1. Available soil phosphorus as determined by chemical tests*

Fertilizer	Total P_2O_5 applied+	Bray's 2 extractable P	Bray's 1 extractable P	Thornton's method for available P	"A" ++ values P
	lbs./acre	lbs./acre	lbs./acre		lbs./acre
None	---	25	18	Med. -	34
Concentrated superphosphate	240	48	41	Med. +	59
Rock phosphate	600	104	21	Very high	34

* Caldwell, A.C. et. al. SOIL SCIENCE SOC. AMER. PROC. 20:25-28, 1956.
+ Fertilizer applied in equal amounts over a period of 6 years.
++ Legume hay, second sampling. Kenyon silty clay loam, Mower Co. - pH 5.4-6.3.

A 10-pound test for phosphorus, for example, does not mean that there are 10 pounds of phosphorus available for a crop during the growing season. One crop, such as corn, may remove 30 pounds of phosphorus while oats on the same soil would remove 9 pounds per acre. The laboratory test values become meaningful only when they are calibrated with the availability of a nutrient to growing plants. This is done in controlled soil test correlation experiments.

The designation of the relative level of the soil test values, i.e. high, medium, and low, is the result of summaries of experimental data which give the average yield increases from a specific nutrient on different soils having different tests.

Preliminary to calibration of a test, the selection of the soil test method is based on greenhouse, field, and laboratory experiments. Table 1 shows a comparison of four phosphorus tests from a soil receiving different fertilizer applications.

Table 2. Interpretation of phosphorus and potassium contents of Minnesota soils

Relative level	Extractable phosphorus* (P)	Exchangeable+ potassium (K)
	lbs./acre	lbs./acre
Very low	Less than 6	Less than 60
Low	6 - 10	60 - 90
Medium	11 - 20	91 - 220
High	21 - 30	221 - 260
Very high	More than 30	More than 260

* As determined by using Bray's No. 1 extracting solution.
+ As determined by using neutral 1N ammonium acetate extracting solution and Perkin-Elmer Flame Photometer.

The amount of phosphorus extracted by the Bray's No. 1 method corresponds well with "A" values. The "A" value measures "biological" or "plant" available phosphorus and is used as a standard for evaluating chemical tests.

Selection of the Bray's No. 1 phosphorus extractant was based on this and similar information. Because Minnesota has large areas of calcareous soils that are low in available phosphorus, the stronger acid extractants (Bray's No. 2 and Thornton's method) are not suitable because they give relatively high phosphorus readings on these phosphate responding soils.

Table 2 shows the general interpretations of phosphorus and potassium test values for Minnesota soils.

The low test levels are reserved for conditions where the chances of getting a profitable increase from fertilizer recommended are overwhelmingly in favor of a farmer. The amount of increase from fertilizer on two different fields with the same test level probably will not be the same because factors other than fertility may influence the results, but the chances are that both increases will be profitable. On fields with high soil test levels the odds are against receiving a profitable increase for heavy fertilization.

For some crops moderate rates of fertilizer are recommended even at high levels because the indicated soil fertility is often not available early in the growing season.

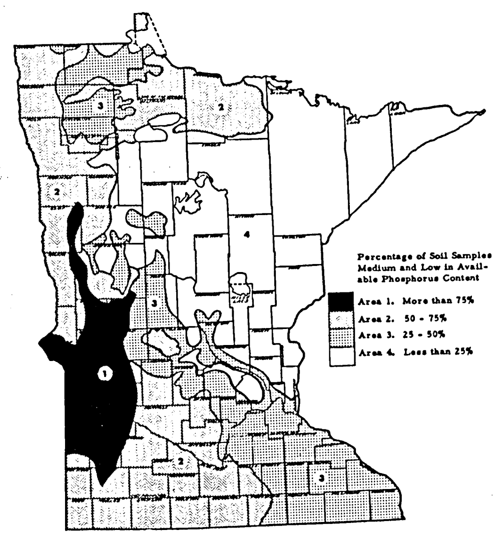


Figure 2. Phosphorus levels of Minnesota soils.

Relationship of Soil Tests and Soil Characteristics

In general there are rather consistent relationships between the parent material, soil morphological characteristics, geographic location, and the average fertility status. For example, the following relationships usually are true unless the soil has been altered by heavy fertilization or by lime.

Acid medium and sandy textured soils developed from outwash are usually low in organic matter, medium to high in phosphorus, and medium to low in potassium.

Clay loam Clarion-Webster and Barnes-Aastad prairie soils in the south and west are usually medium to high in organic matter, low to medium in phosphorus, and medium to high in potassium.

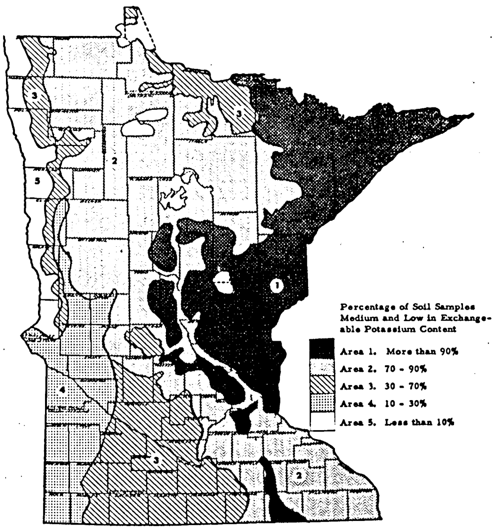


Figure 3. Potassium levels of Minnesota soils.

Silty clay and clay lacustrine prairie soils of the Red River Valley are predominantly medium to low in phosphorus and high in potassium.

Because of the extreme differences in soils in the state it is recognized that there is reason to interpret soil tests in relation to the type of soil. For example, a 40-pound test for phosphorus on a calcareous clay loam soil probably means more available P than if the 40-pound test were an acid sandy soil. This is because part of the high test from acid soils represents unavailable iron and aluminum phosphates.

One of the goals of the soil test correlation program and other Soils Department research is to evaluate the differences in soil tests from different soil areas and incorporate this information in fertilizer recommendations.

Now the same value is given to the phosphorus and potassium analysis regardless of soil type until more information is obtained.

METHODS OF FERTILIZATION

As a result of many new developments in fertilizer technology and soil fertility research, the opportunity for alternative methods of using fertilizer has been markedly increased in recent years.

One of the main decisions in soil management is to what extent the soil is fertilized in contrast to what extent the crop is fertilized. Fertilizing the soil means broadcasting rather large amounts of fertilizer which is designed to build up the available nutrient level of the soil. Fertilization of the crop refers to applying a relatively lower rate near the seed at planting time.

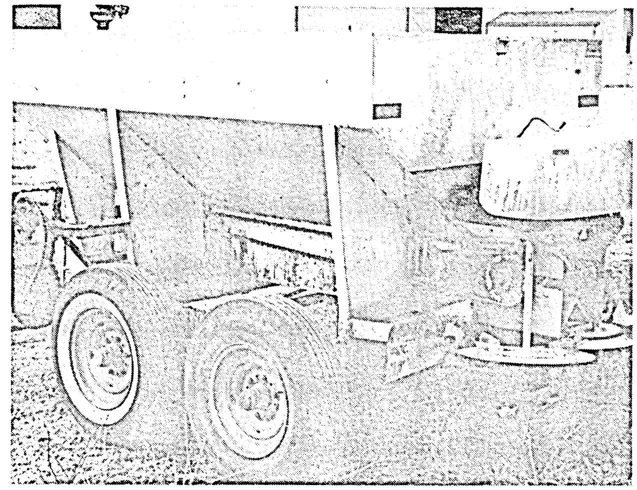


Figure 4. Trailer for broadcasting

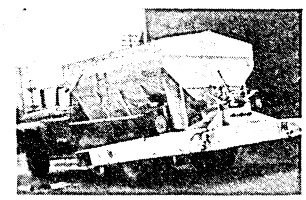


Figure 5. Bulk truck for direct application. New equipment for fertilizer application is constantly being developed. Recommendations should take into account the equipment available.

It is difficult to decide whether to use phosphate and potash in moderate annual applications or heavier broadcast treatments applied less often. Nitrogen is less stable in the soil, and its application rates are specifically adjusted to the kind of crop and crop sequences with less attention to soil buildup over a period of time. Nitrogen, therefore, is usually applied annually for nonlegume crops.

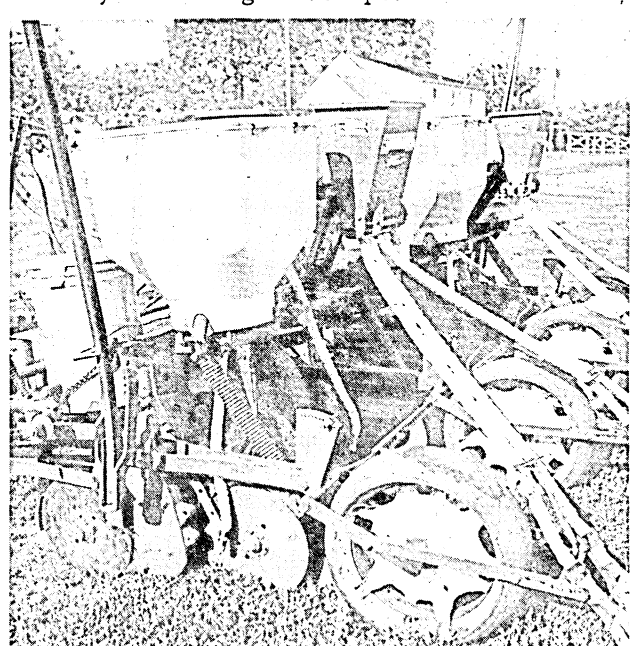


Figure 6. Corn planter with insecticide, herbicide, and fertilizer attachments.

Important factors to consider in choosing the method and the amount of phosphate and potash application are:

1) Fertility level as determined by soil test.
2) Nature of the soil.
3) Kind of crop and cropping system.

A discussion of these factors follows.

Fertility Level

Whenever phosphate and potash application in 1 year exceed approximately 60 pounds and 100 pounds per acre respectively, we are in effect using a corrective or buildup program. Even lesser rates will contribute to increased fertility levels, but the lower the rate the more gradual the buildup.

These applications are needed on low fertility fields to make efficient crop production possible. A rapid buildup is desirable where soil test levels are below 6 pounds per acre for phosphorus and 90 pounds per acre for potassium. Occasionally there are requests from farmers with unlimited capital for immediate buildup recommendations.

Table 3 is a guide for corrective phosphate and potash application designed for immediate and practical buildup of the soil fertility and test level.

Table 3. Guide for corrective fertilizer application

P soil test	P_2O_5 per acre	K test level	K_2O per acre
4-6	140	60-90	180
0-3	240	0-59	240

(These amounts should be modified according to factors discussed under "Nature of the Soil" and "Kind of Crop and Cropping System"

When such applications are made, no additional phosphate or potash fertilizer would be required for the first crop except for a low rate of a 1-4-4, 1-4-2, or 1-4-0 ratio fertilizer for corn. The need for subsequent broadcast fertilization would depend on soil test indications.

Nature of the Soil

Certain soil characteristics may modify the above recommendations. The two most important characteristics are texture and soil reaction. Texture is important especially for potash recommendations since potassium will leach in sandy soils; and heavy applications are, therefore, not efficient. Leaching is not a problem with phosphorus, but extreme (low or high) pH values will increase fixation of available phosphorus to unavailable forms.

Therefore, whenever the pH is above 7.8 or below 5.6, applications recommended in table 3 should not be used. For potash the heavy broadcast application in table 3 should not be used on loamy sands or sand textured soils.

In cases where the pH is below 5.6, lime should be applied as recommended except for special crops. When lime is applied and the P test is below 6, the corrective phosphate applications can be followed with reasonable assurance of high efficiency.

Certain soils should not receive heavy corrective fertilizer applications because of low yield potential. Such situations would be those of poor drainage, flooding hazard, steep slope, or droughtiness.

Kind of Crop and Cropping System

The corrective or buildup fertility program is more critical for some crops than others. Among the crops where low fertility should be immediately corrected are the high value crops such as vegetables, sugar beets, and potatoes. Legume hay crops should also have corrective applications since low fertility levels are a main cause of winterkill, stand failure, and low yields.

If corn and soybeans are the predominant crops in the rotation, corrective fertilizer applications are usually recommended when yield potentials are above 85 bushels of corn per acre and soil tests are low.

Corrective, heavy fertilizer applications should not be recommended when the main crops are small grains. For these crops phosphorus is usually the limiting element rather than potassium, and efficient yields can be raised with moderate phosphate rates placed with the seed.

Cost of Corrective Fertilizer Applications

When heavy corrective applications are made, the cost should not be considered a cost charged to one crop. It is rather in the nature of a capital improvement such as drainage or liming so it should be capitalized over a period of several years.

SPECIAL FERTILITY PROBLEMS

High Lime Rims

The nearly level soils in the Clarion-Webster and Barnes-Aastad soil association areas often have a surface accumulation of lime. This condition has developed in the process of evaporation of drainage water that collects in these areas. A probable explanation is that there has been a differential rate of evaporation and $CaCO_3$ precipitation around the outside edge of the pond water. In some of these sites up to 25 percent of the soil weight in these rims is $CaCO_3$.

This abnormal soil condition causes certain soil fertility problems. In general, the plants on these areas, unless fertilized, are phosphorus and potassium deficient. This is especially true of corn, but other crops are also affected.

Recommendations to help correct problems associated with high lime or "alkali" soils include drainage, fertilization, and selection of less or nonsensitive crops.

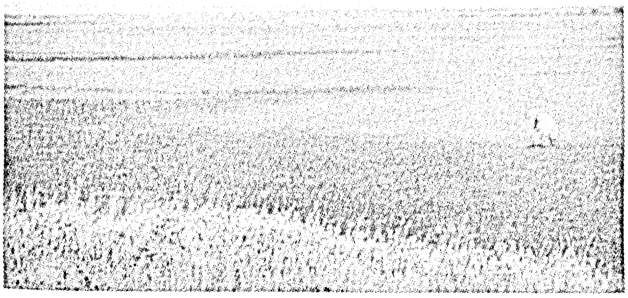


Figure 7. High lime rims cause special fertility problems.

Adequate drainage should be taken care of first; however, a number of years of improved drainage are necessary to help correct the situation. The phosphorus status can be checked with soil tests from the specific high lime locations and the standard recommendations followed. Normally phosphate causes a very good response on alfalfa and corn on these soils.

Because of the extremely wide ratio of exchangeable potassium to calcium in the surface soil, additional fertilizer potassium is usually needed.[1] This condition of a relatively large amount of calcium available to the plant root compared to potassium causes an imbalance in the plant.

In the case of corn there are indications that broadcast treatments of potash fertilizer have not adequately supplied potassium. Therefore, a combination of 100 to 120 pounds of K_2O broadcast plus small amounts of potash applied near the row at planting time is suggested on these soils. Row or starter potash should be from 10 to 20 pounds per acre. This is recommended on all potassium tests below 300 when the high lime situation exists. Level land and a pH above 7.4 can be used to identify such cases. When K tests are above 300, use only the row starter fertilizer.

Small grains are more tolerant of these calcareous rims but will respond to phosphate. The fertilizer guide tables can be followed for small grains and alfalfa.

Sulfur Deficient Areas and Crops

Sulfur is an essential secondary element for plants. In most areas of the state it is present in adequate supply either in the soil or in precipitation.

However, there is a considerable area in north central Minnesota where sulfur response to alfalfa and other legumes and in some cases to oats has been measured. At the present time a routine test for sulfur is not available so recommendations are based on the soil area and crop.[2]

[1] Overdahl, C. J. "Potassium Problems." Soils Fact Sheet No. 6. University of Minnesota.
[2] Overdahl, C. J. and Caldwell, A. C. "Sulfur for Minnesota Soils." Soils Fact Sheet No. 5. University of Minnesota.

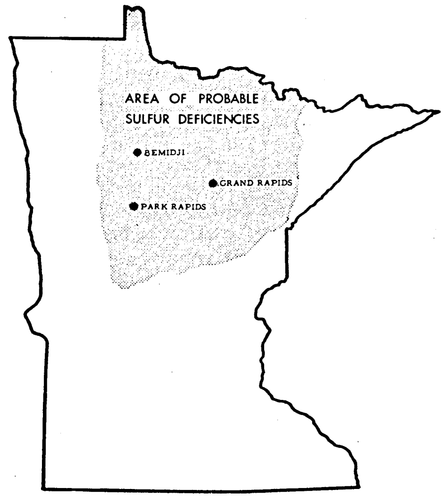


Figure 8.

Since yield responses have been inconsistent on small grains, alfalfa and clovers are the only crops on which sulfur is recommended. If potassium, phosphorus, and lime have been adequately supplied but legume growth is still poor, gypsum (calcium sulfate) should be applied. This should be at the rate of 300 pounds per acre or an equivalent amount of some other sulfur-bearing material.

The soils on which sulfur response would be expected are Nebish, Rockwood, Brainerd, NoKay, Menahga, and Chetek. These recommendations apply to the following counties:[3]

East Polk	Cass
Clearwater	Crow Wing
Beltrami	Morrison
Becker(east one-half)	Itasca
Otter Tail (northeast)	St. Louis (west tier of township)
Wadena	
Hubbard	Aitkin
	Mahnomen (two townships)

Secondary and Trace Elements

Although most attention is given to the use of nitrogen, phosphorus, and potassium, there are 13 other elements that are just as essential to plant growth. Table 4 lists these elements according to the source and the relative amount used by plants.

Table 4. Essential nutrient elements and their sources

Used in relatively large amounts			Used in relatively small amounts	
Mostly from air and water	From soil colloids		From soil colloids	
Carbon	Nitrogen	Calcium	Iron	Copper
Hydrogen	Phosphorus	Magnesium	Manganese	Zinc
Oxygen	Potassium	Sulfur	Boron	Molybdenum
				Chlorine

[3] Refer to current ASC Conservation Guide.

Of these, calcium, magnesium, and sulfur are the secondary elements, and iron, manganese, boron, copper, molybdenum, chlorine, and zinc are the minor elements based on the relative amounts needed by plants.

Although increasing attention is being given to the need for fertilization with these elements, there is evidence that relatively few of Minnesota's 20 million crop acres are now deficient. Lack of the major nutrients and less than optimum physical and moisture conditions are much more important yield limiting factors.

However, on the soils where parent materials have not supplied sufficient available secondary and minor elements, crop yields are substantially reduced; and it is a serious problem for the individual farmer.

Calcium and magnesium are largely taken care of by the lime recommendation. Most of the agricultural limestone used in Minnesota is a dolomite rock that contains both magnesium and calcium carbonate.

Sulfur recommendations are based on area and crop as discussed previously.

Recommendations on minor or trace elements will depend on the variety of a specific crop and soil situations. At the present time there are no routine soil tests available for these nutrients. Research is being conducted to better establish minor element fertilization needs and diagnostic techniques useful in predicting these needs.

In evaluating the possibility of a minor element problem it is important to consider a major nutrient deficiency, insufficient or excessive moisture, diseases, or insect problems. Following is a guide to the general conditions associated with minor element deficiencies and the range of suggested rates of application. It is suggested that new minor element recommendations for large acreages be called to the attention of soils specialists or soils department staff.

Boron

Function in plant	Soil characteristics usually associated with deficiency
Affects the flowering and fruiting process, cell division, and pollen germination; is a constituent of membranes and acts as a buffer.	Mineral soils low in organic matter and medium or sandy in texture. Deficiencies noted have been in southeast, northeast, and central Minnesota. Organic soils unless previously fertilized with boron.

Crops of possible deficiency in Minnesota	Deficiency symptoms	Suggested rates when B is used
Plants most sensitive to deficiency -- alfalfa, sweetclover, sugar beets, caggage, celery, apples, cauliflower, rutabagas. Tolerant crops to deficiency -- barley, corn, wheat, oats, soybeans, strawberries, potatoes.	Alfalfa--orange-colored top leaves, terminal bud dead. Multibranching at top of plant. Root crops- heart rot of roots. Corn - short plants and poorly filled or barren ears.	Alfalfa and vegetables-- 20 pounds per acre of borax or 2 pounds of boron. Corn - 5 to 10 pounds of borax; not more than 10 pounds per acre. Boron containing materials should be broadcast.

Manganese

Function in plant	Soil characteristics usually associated with deficiency
A constituent of respiratory enzymes. May be concerned with nitrogen metabolism; assists with the synthesis of chlorophyll.	Alkaline reaction, deficiency more likely on organic than on mineral soils.

Crops of possible deficiency in Minnesota	Deficiency symptoms	Suggested rates when Mn is used
Potatoes, oats, alfalfa, soybeans, onions, and peas. Few established cases of Mn deficiency have been reported in Minnesota.	A chlorosis between the veins of net-veined leaves; on leaves with parallel veins, general chlorosis or "gray speck" on oats.	25 to 100 pounds per acre of $MnSO_4$. If soil is very high in pH (7.5+), higher rates can be used.

Iron

Function in plant	Soil characteristics usually associated with deficiency
A catalyst in production of chlorophyll.	High-lime, low-lying mineral soils in south central and western Minnesota. Excessive phosphate, bicarbonate, and heavy metals contribute to iron deficiency.

Plants of possible deficiency in Minnesota	Deficiency symptoms	Suggested rates when Fe is used
Soybeans, flax, corn, gladioli, roses, spiraea, flowering crab, strawberries, apple, plum, maple, elm, boxelder, larch, and birch.	Yellowing of intraveinal leaf tissue with veins remaining green.	One percent $FeSO_4$ as spray on foliage or 5 to 10 pounds per acre of chelates DTPA or APCA as soil treatment (Chel-330 Fe or chel-138 Fe).

Copper

Function in plant	Soil characteristics usually associated with deficiency
Not well established except that it is a constituent of many enzymes. Is concentrated in rootlets and chloroplasts.	Deficiency most likely on organic soils with pH below 5.5.

Crops of possible deficiency in Minnesota	Deficiency symptoms	Suggested rate when Cu is applied
Lettuce, onions, spinach, carrots, alfalfa, grasses, and oats. Deficiencies have been noted on organic but not mineral soils.	Not readily apparent on most crops. Tips of small grain leaves are white or yellow.	On mineral soils 5 to 25 pounds per acre of $CuSO_4$; on organic soils 20 to 30 pounds of $CuSO_4$.

Molybdenum

Function in plant	Soil characteristics usually associated with deficiency
Essential for N fixation by micro-organisms and nitrogen transformation processes in plants.	Characteristics not well defined. Low organic matter and acid pH are likely. Liming can correct deficiency. A recent greenhouse experiment with Anoka, Barnes, Nicollet, Fayette, and Hegne soils showed no Mo response on alfalfa.

Crops of possible deficiency in Minnesota	Deficiency symptoms	Suggested rate when Mo is used
Alfalfa--Response reported on one experiment at Rosemount.	Alfalfa leaves are pale green and leaf margins appear gray, limp, and wilted. Upper leaves are affected first.	Eight ounces of Mo per acre as $(NH_4)_2 MoO_4$. This can be applied as a spray or as a seed treatment.

Zinc

Function in plant	Soil characteristics usually associated with deficiency
Necessary component of several enzyme systems. It is needed for formation of auxins which are growth promoting substances.	Zinc deficiencies appear to be associated with alkaline soil in this area.

Crops of possible deficiency in Minnesota	Deficiency symptoms	Suggested rate when Zn is applied
Most sensitive crops--corn, lima beans, flax, soybeans. Moderately sensitive--potatoes, tomatoes, onions, sugar beets. Deficiencies have been observed on a number of limy soils.	Chlorosis of interveinal tissue, particularly lower leaves. Causes striping of corn leaves; plants are stunted with severe deficiency.	15 to 25 pounds of $ZnSO_4$ per acre can be used on trial basis either broadcast or in the row. Nitrogen-containing fertilizer should be used with zinc application.

Iron Chlorosis

Some fields of soybeans and flax in southern and western Minnesota are subject to an available iron deficiency called iron chlorosis. The problem is characterized by yellow leaves on these crops as well as some ornamental plants. The field crop problem is usually most severe in the month of June and is largely restricted to high-lime, low-lying soils.

Extensive research has shown that the reasons for the iron deficiency are very complex and involve a number of soil and soil-climate characteristics. Chelated iron compounds, organic iron carriers, have been effective in correcting the iron deficiency. However, the 10-to 20-pound rates of the materials that are needed are too expensive for general use on field crops. Two materials that have been effective are chelates DTPA and APCA (Chel-330 Fe and Chel-138-Fe) which can be applied as a broadcast on a trial basis at the 10-pound-per-acre rate. There is some indication that these materials can be used effectively as a seed treatment for soybeans which also may be tried on a small acreage. The most practical recommendation is to use a 1 percent ferrous sulfate solution spray on the foliage of the affected plants. Such treatments have to be repeated about every 10 days until the chlorosis disappears.

Manure Evaluation

One of the difficulties in making fertilizer recommendations is to properly evaluate manure recently applied to a field in question. This is because of the variability in the amount and availability of nutrients in the manure and the general lack of specific information as how much manure has been or will be applied.

For routine soil test recommendations where there is no chance to talk to the farmer the most practical method is to credit each ton of manure with 6 pounds of nitrogen and 10 pounds of potash. This amount should be deducted from the needed total indicated on the guide tables for a given soil test. However, do not eliminate the first 10 to 20 pounds of row potash for corn even though the total potash need might be satisfied from the manure applied. The phosphate applied in manure may vary from 3 to 6 pounds per ton but is ignored in calculating the fertilizer to be applied for row crops and small grains. This is because the amount of phosphate is usually not high and the placement is not as effective as the phosphate applied as commercial fertilizer. Also, the manure phosphorus is not readily available. Where placement is not as critical, such as for legumes, the phosphate can be credited at the rate of 5 pounds per ton.

In cases where more information is available about the kind of manure applied the following information will be helpful in evaluating the fertility value of manure.

Decomposition of manure must occur before nitrogen and phosphorus are released, but is not necessary for the release of potassium. For this reason it is estimated that 30 to 60 percent of nitrogen and phosphorus is released to the crop in the year the manure is applied. All of the potassium, 8 to 10 pounds per ton, is considered available the first year.

Well rotted manure from feed bunk areas or cattle sheds will have about 60 to 70 percent of the N and P available while the 30 to 40 percent figure is more appropriate for dairy barn manure with bedding.

Poultry manure has a higher nutrient value than swine and cattle manure. A value of 25 pounds of nitrogen, 15 pounds of phosphate, and 10 pounds of potash per ton should be used.

Evaluating Carryover Value of Fertilizer

In general past fertilization with phosphate and potash will be reflected in higher soil test values for P and K so no adjustment has to be made in the recommendations.

There are three situations, however, where some estimates have to be made of the amount of nutrient carryover or credit for past fertilization. These are:

1) Applications of greater than 60 pounds of P_2O_5 and K_2O have been made within 12 months of the crop for which recommendations are being made. In this case the fertilizer is not likely to have been adequately mixed with the soil measured by the soil test.

2) A recommendation is to be made from soil test information from samples taken before fertilization. This would usually be a case where a second or third year crop after testing was to be fertilized.

3) Situations where a crop failure occurred the previous year and an estimate is to be made of the value of carryover to determine the next year's fertilization.

A number of soil and climatic factors affect the absolute amount of carryover fertility. Such factors which would tend to decrease fertilizer carryover would be above-average rainfall, coarse-textured soil, acid soils, high yields, and erosion.

As a general guide for carryover fertility, it can be considered that 20 percent of the N, 20 percent of the P_2O_5, and 50 percent of the K_2O can be credited for the second crop if rates of 60 pounds per acre or greater were used. When a crop failure occurred, which would be most applicable for corn, the credit for N and P_2O_5 can be doubled. See table 5.

Table 5. Guide for credit of carryover of past fertilization *

Nitrogen	Rate of N applied per acre	Carryover after normal crop lbs. N per acre	Carryover after crop failure lbs. N per acre
	40	0	0
	60	10	20
	80	15	30
	100	20	40
Phosphate	**Rate of P_2O_5 applied per acre**	**Carryover after normal crop lbs. P_2O_5 per acre**	**Carryover after crop failure lbs. P_2O_5 per acre**
	40	0	0
	60	10	20
	80	15	30
	100	20	40
Potash	**Rate of K_2O applied per acre**	**Carryover after normal crop lbs. K_2O per acre**	**Carryover after crop failure lbs. K_2O per acre**
	40	0	0
	60	30	30
	80	40	40
	100	50	50

* Do not eliminate all starter fertilizer for corn or drill-placed phosphate because of the carryover contribution.

Note: The figures are rounded off to the nearest 5 pounds.

SECTION II

FERTILIZER GUIDE for SPECIFIC CROPS

The guide tables in the following section are organized to vary the amount of plant nutrients according to: 1) soil test levels of organic matter, phosphorus, and potassium; 2) yield goal; and 3) previous soil management.

The final recommendation should follow the guide figures quite closely but some changes can be made. Adjustments, for example, should be made in order to recommend a minimum number of grades for one farm. When a change in amount of plant food is made, it is usually in the farmer's interest to recommend more than the crop guide indicates rather than less because the additional residual effect will be profitable.

It is important to avoid making different recommendations for soil tests from the same field.

The guide figures give nutrient amounts that are expected to result in the greatest average return per acre over a period of years. Some of the nutrients recommended, particularly in the case of the low category for P and K, are intended to gradually increase the supply of the nutrients for succeeding crops. A rapid buildup program with corrective treatments is discussed earlier in the bulletin.

In the case of a person with limited capital who must have the greatest return per dollar invested in fertilizer, the amount of phosphate or potash can be decreased to that recommended for the medium categories where soil tests are low. The greatest return per acre should result by following the recommendations.

Changes from the guide recommendations should not be made without discussion with the operator. In most cases, if capital is limited, fewer acres at the recommended rate should be fertilized rather than a lower rate per acre. At least part of the field should be fertilized at the proper rate for comparison with lower rates.

Certain assumptions are made in arriving at the recommended nutrient rates concerning other crop and soil management practices. These practices would include: soil drainage, weed control, planting rate, adapted variety and hybrids, and water and erosion control. In the case of corn these variables are handled by having different fertilizer recommendations in three yield goal categories.

For other crops management, practices are those recommended by the Minnesota Agricultural Extension Service.

CORN

Proper fertilization of corn is particularly critical because of relatively high cost of corn production and the high potential yield increase from applied nutrients. Yield increases of 50 bushels are not uncommon and quality often is improved with adequately fertilized corn being higher in protein and phosphorus and lower in moisture.

Of the three primary nutrients, nitrogen deficiency probably causes the greatest loss of potential yield. With a total requirement of about 150 pounds of nitrogen for 100 bushels, 120 pounds of which is needed during the 2-month midseason period, soil released nitrogen is usually not adequate for efficient yields.

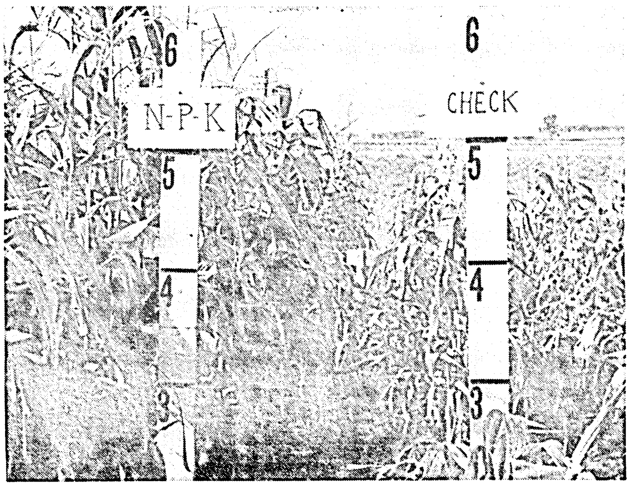


Figure 9. Field soil test correlation plots have been used to determine fertilizer recommendations.

Nitrogen

The recommended rate of nitrogen for corn varies with the yield goal, relative amount of soil organic matter, and nature of the preceding cropping soil management. Unless corn follows a legume crop or the field has been manured, the total amount of nitrogen recommended is usually in excess of 40 pounds per acre. At this or a higher rate it is usually economical to apply most of the nitrogen as a straight material.

The effect of different times of application and differences in nitrogen sources has been extensively investigated. This research shows that nitrogen can be applied either in the fall, in the spring before planting, or as an early sidedress on most soils with little difference in efficiency. The exception is on sandy soil (loam or coarser) where sidedressing is recommended because of substantial losses by leaching. There is also some evidence that surface applied nitrogen on soils that become extremely wet for an extensive period undergoes some loss by a volatilization to the atmosphere.

For this reason incorporation of the nitrogen in the soil, regardless of the form, is good insurance against loss where soil surfaces tend to be frequently wet.

It is common to apply nitrogen before plowing corn stalks to hasten the decay process. Although stalk decomposition may be hastened by a fall nitrogen application, subsequent corn yields are about the same with fall or spring application. Therefore it is most efficient to apply all of the needed supplemental nitrogen at one time--fall, spring, or sidedress--rather than a higher cost split application. With row fertilizer placed 2 inches to the side and below the seed high nitrogen grades can be used to supply the total nitrogen need at planting time.

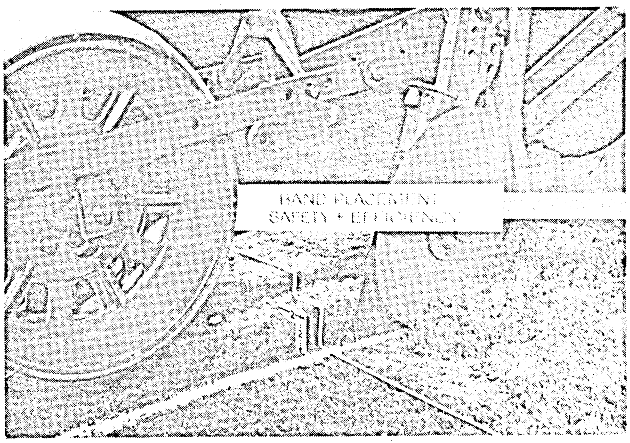


Figure 10. The trend today in fertilizer placement for row crops is toward single band placement, as shown above--a safe, efficient way to place planting fertilizer. The single band is about 2 inches to the side, 2 inches below the seed. It is safe because the fertilizer salts do not contact the germinating seeds or tender seedlings ....efficient because the fertilizer is placed where the feeder roots can soon reach the plant nutrients and the band is down where the soil is more likely to be moist.
Courtesy: American Potash Institute

There is a wide selection of nitrogen materials. These include the following:

Nitrogen	Form	Percent N
Ammonium sulfate	Solid	21
Ammonium nitrate	Solid	$33\frac{1}{2}$
Low pressure solutions	Liquid	21 to 32
Pressure solutions	Liquid	28 to 41
Urea	Solid	45
Anhydrous ammonia	Liquid(stored) Gas (applied)	$82\frac{1}{2}$

Tests have shown that applying these materials has essentially equal effects on corn yield per pound of nitrogen. The choice by the buyer will depend on the convenience of application and price. In general, the materials that are applied below the soil surface, pressure solutions and anhydrous ammonia, become cheaper per pound of nitrogen as rate per acre is increased when the cost of application is included.

Phosphorus

Corn growth and yield response to phosphate fertilizers in Minnesota have been frequently measured, and the use of phosphate fertilizer on corn is widely accepted. The commonly observed "starter effect" is largely the stimulating effect of phosphorus on early growth. Even though the amount of phosphorus used by young corn plants is small (1 pound of P_2O_5 per acre in first month), lack of an early available supply in the immediate root area inhibits plant development throughout the season. For this reason at least 20 pounds of P_2O_5 placed near the seed is recommended for all soils that test below 100 pounds of P per acre.

When higher rates than 40 pounds of P_2O_5 are applied for corn, the recommendation is usually to apply a portion of the fertilizer as starter and larger amounts as a broadcast application. Broadcast phosphate, especially if plowed down, has the advantage of being in a good position for late season use; and application costs and labor are minimized. However, recent research has shown good utilization of higher rates of phosphate in row placement so the choice of method of application above 20 pounds in the row depends largely on the difference in time, labor, and application cost.

Yield increases from phosphorus fertilizers in general are quite consistent but not as large as those from nitrogen. Also, applied phosphorus does not move out of the soil and, therefore, may be available for succeeding crops.

Table 6 gives a summary of average yield increases from phosphate fertilizer on corn when nitrogen and potassium were adequate.

Table 6. Yield increase from 100 pounds of P_2O_5 on soils of different soil tests *

Soil test range		Corn yield increase	Number of fields
20 to 200+	High	3.8	53
10 to 19	Medium	4.5	50
6 to 9	Low	10.0	30
0 to 5	Very low	19.5	15

* Data from 1959 and 1960 soil test correlation plots.

Potassium

The need for potassium for corn in Minnesota is increasing both in respect to soil areas and the rate per acre. This is because of more precise information on the location of potassium deficient soils, higher potassium requirement with higher yields, and the continual depletion of native available soil potassium.

The potash yield response on potassium deficient soils is substantial, often greater than 20 bushels per acre. In the medium soil test category, 90 to 200 pounds per acre, the yield response is quite variable. Soil moisture and temperature are very important in the release of available soil potassium with availability decreased with moist conditions and increased availability with drying. Therefore, seasonal differences in potash response is often noted, especially on fine textured soils.

In addition to the yield effect, applied potash tends to increase resistance to lodging and improves grain quality.

Potash placement is not so critical as phosphate because potassium is more mobile in the soil. However, indications are that row placement of amounts less than 30 pounds per acre is more desirable than broadcast placement. Also, when soils are poorly drained or high in lime, 15 to 20 pounds of K_2O in the row provides potassium when soil potassium is slowly available.

Table 7 gives a summary of yield response to potash fertilizer on soils of various levels of exchangeable potassium.

Table 7. Yield increase with 100 pounds per acre of K_2O *

K soil test level		Corn yield increase	Number of fields
221 to 600+	High	3.1	34
151 to 220	Medium-High	3.8	36
91 to 150	Low-Medium	4.6	54
0 to 90	Low	15.1	20

* Data from 1959 and 1960 soil test correlation plots.

Table 8. Corn (yield goals of 60 to 80 bushels)

Soil test organic matter	Nitrogen: Previous management* N-def.	N-inter.	N-suff.	Phosphorus +: Soil test phosphorus	Phosphate P_2O_5	Potassium: Soil test potassium	Potash K_2O
	nitrogen ++ recommended lbs./acre				recommended lbs./acre		recommended lbs./acre
High	50	30	10	100 to 200+	0	301+	0
Medium and low	60	40	10	21 to 99	20	220 to 300	20
				0 to 20	40	91 to 220	40
						0 to 90	80

* Key to nitrogen categories (crops grown before corn):

Nitrogen deficient	Nitrogen intermediate	Nitrogen sufficient
Corn	Soybeans	Pure stand alfalfa or clover
Potatoes	Any crop preceded by legume	Black or legume summer fallow
Sugar beets	Small grains with green manure	10 or more tons per acre of manure (credit manure with 6 pounds of N and 10 pounds of K_2O per ton)
Grass sod	++Nitrogen-fertilized, drought-stricken crop	Organic soils, peat, and muck
Small grain without green manure	Corn with above 80 rate of nitrogen applied	
	N deficient crops plus manure	

\+ If the split-boot fertilizer attachment is to be used, limit the total of N and K_2O to 40 pounds per acre. Any amount of fertilizer can be applied in the row if placed 2 inches below and 2 inches to the side of the seed. However, broadcasting part of the fertilizer has the advantage of being in a better position for carryover effect. If no fertilizer is row applied, increase the 20-pound rate to 40 and the 40-pound rate to 60 pounds per acre.

++ Do not give credit for past nitrogen fertilization on loamy sands and sands.

Table 9. Corn (yield goals of 80 and 110 bushels per acre)

	Nitrogen			Phosphorus +		Potassium	
Soil test organic matter	Previous management* N-def.	N-inter.	N-suff.	Soil test phosphorus	Phosphate P_2O_5	Soil test potassium	Potash K_2O
	nitrogen ++ recommended lbs. /acre				recommended lbs. /acre		recommended lbs. /acre
High and Medium	70	50	10	21+	20	300 to 600+	0 or 20 (see ++)
				11 to 20	40	221 to 300	20
				6 to 10	50	151 to 220	40
Low	100	70	15	0 to 5	80	91 to 150	60
						0 to 90	120

* Key to nitrogen categories (crops grown before corn):

Nitrogen deficient	Nitrogen intermediate	Nitrogen sufficient
Corn	Soybeans	Pure stand alfalfa or clover
Potatoes	Any crop preceded by legume	Black or legume summer fallow
Sugar beets	Small grains with green manure	10 tons of manure (credit manure with 6 pounds of N and 10 pounds of K_2O per ton)
Grass sod	Nitrogen-fertilized, drought-stricken crop	Organic soils, peat, and muck
Small grain without green manure	Corn with above 100 rate of nitrogen applied	
	N deficient crops plus manure	

\+ If the split-boot fertilizer attachment is to be used, limit the total of N and K_2O to 40 pounds per acre. Any amount of fertilizer can be applied in the row if placed 2 inches below and 2 inches to the side of the seed. However, broadcasting part of the fertilizer has the advantage of being in a better position for carryover effect. If no fertilizer is applied as starter, increase the 20-, 40-, and 50-pound rates by 20 pounds per acre.

++ Level, fine textured soils with pH above 7.3 should have 10 to 20 pounds of K_2O in the row with this test. These textures are silty clay loam, clay loam, silty clay, and clay.

Table 10. Corn (yield goals of 110 to 140 bushels per acre)

	Nitrogen			Phosphorus +		Potassium	
Soil test organic matter	Previous management* N-def.	N-inter.	N-suff.	Soil test phosphorus	Phosphate P_2O_5	Soil test potassium	Potash K_2O
	nitrogen recommended lbs. /acre				recommended lbs. /acre		recommended lbs. /acre
High and Medium	100	80	30	21+	30	301 to 600+	20
				11 to 20	60	221 to 300	30
				6 to 10	80	151 to 220	60
Low	130	100	40	0 to 5	100	91 to 150	100
						0 to 90	140

* Key to nitrogen categories (Crops grown before corn):

Nitrogen deficient	Nitrogen intermediate	Nitrogen sufficient
Corn	Soybeans	Pure stand alfalfa or clover
Potatoes	Any crop preceded by legume	Black or legume summer fallow
Sugar beets	Small grains with green manure	10 tons of manure (Credit manure with 6 pounds of N and 10 pounds of K_2O per ton)
Grass sod	Nitrogen-fertilized, drought-stricken crop	Organic soils, peat, and muck
Small grain without green manure	Corn with 100 rate of nitrogen applied	
	N deficient crops plus manure	

\+ If the split-boot fertilizer attachment is to be used, limit the total of N and K_2O to 40 pounds per acre. Any amount of fertilizer can be applied in the row if placed 2 inches below and 2 inches to the side of the seed. However, broadcasting part of the fertilizer has the advantage of being in a better position for carryover effect. Always recommend a complete starter fertilizer for this yield goal.

ESTABLISHMENT OF LEGUME HAY
(Alfalfa, Clovers, and Grass Mixtures)

Legume hay continues to be important as a source of high quality forage for livestock and as the foundation of soil conserving rotations.

Alfalfa is the preferred species of hay in all areas of the state. Nutrient requirements are substantial; a 4-ton yield will require 180 pounds of N, 40 pounds of P_2O_5, and 180 pounds of K_2O. The N is largely obtained from the air while the phosphorus and potassium needs must be supplied by fertilization or by soil reserves.

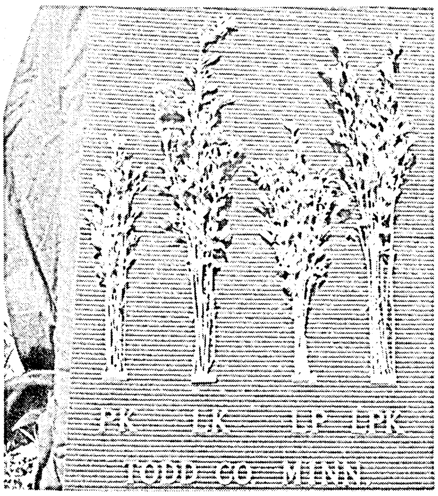


Figure 11. The combination of adequate lime, phosphorus, and potassium is necessary for alfalfa. Lime and potassium are often deficient in central Minnesota.

Fertilization of alfalfa and other forage legumes should consist of an initial application at seeding and annual topdressing as needed to maintain yields and stand. The initial application at recommended rates will be sufficient for the year of establishment and the first production year. During the second and later years of production a maintenance application based on the initial soil tests and table 12 should be followed.

Yield response to phosphate and potash is consistent on soils testing medium and low in these nutrients. This is illustrated in the results of a 10-year experiment at Rosemount where 31 different combinations of nutrients, rates, and times of application were compared. The soil was a Port Byron silt loam testing 110 in potassium, 14 in phosphorus.

Results of Selected Treatments *
Alfalfa Fertility Study - Rosemount

Annual treatment	Yield--annual average	Annual average increase
	tons/acre	tons/acre
Check	3.13	----
0+40+0	3.83	0.70
0+40+40	4.70	1.57
10+40+40	4.06	0.93

* MacGregor, J. M. The Effect of Rate, Time, and Kind of Fertilizer on Yield of Alfalfa at Rosemount. Soil Series 51. 1959.

Table 11. Establishing new seedings (alfalfa, clover, and legume-grass mixtures)
Nutrients to be applied, pounds per acre

Companion crop	Nitrogen: Previous management* N-def.	N-inter.	N-suff.	Phosphorus: Soil test phosphorus	Phosphate P_2O_5	Potassium: Soil test potassium	Potash K_2O Textures-silt loam and finer	Potash K_2O Textures-loam and coarser
Oats +	30	20	0	30+ ++	0	220+	0	0
Flax	30	20	0	20 to 29	30	150 to 219	60	60
Barley	30	20	0	10 to 19	60	90 to 149	90	120
Wheat	50	30	0	0 to 9	100	0 to 90	120	240
None	0	0	0					

* Key to nitrogen categories:

Nitrogen deficient
- Corn
- Potatoes
- Sugar beets
- Grass sod
- Small grain without green manure

Nitrogen intermediate
- Soybeans
- Any crop preceded by legume
- Small grains with green manure
- Nitrogen-fertilized, drought-stricken crop
- Corn with above 100 pound rate of nitrogen applied
- N deficient crops plus manure

Nitrogen sufficient
- Pure stand alfalfa or clover
- Black or legume summer fallow
- 10 or more tons per acre of manure (Credit manure with 6 pounds of potash per ton)
- Organic soils, peat, and muck

\+ Recommend no nitrogen if a lodging problem is indicated or known.

++ With P tests above 30 pounds recommend 30 pounds of P_2O_5 per acre only in the following soil association areas: Zimmerman-Isanti-Peat, Milaca-Brainerd-Hibbing, Menahga, Nebish-Redwood.

Table 12. Topdressing established legume and legume-grass mixtures*

Soil test phosphorus	Phosphate P_2O_5, lb. /acre apply annually	Soil test potassium	Potash, K_2O lb. /acre apply annually — Textures: Silt loam and finer	Loam and coarser
30 to 200+	0	220 to 600+	0	0
20 to 29	30	150 to 219	30	60
10 to 19	60	90 to 150	60	90
0 to 9	100	0 to 90	120	180

* Nitrogen at rate of 30 to 50 pounds per acre should be used when stand is primarily grass.

\+ With P tests above 30 pounds recommend 30 pounds of P_2O_5 per acre only in the following soil association areas: Zimmerman-Isanti-Peat, Milaca-Brainerd-Hibbing, Menahga, Nebish-Rockwoo

TOPDRESSING LEGUMES AND LEGUME-GRASS MIXTURES

The correct ratio and rate of phosphate and potash for alfalfa and other legumes makes possible more consistent dollar returns than with most other crops. Weather hazards are considerably less for forage crops than for seed producing crops.

Topdressing of legume forages can be done anytime of the year, but early spring or fall is preferred for maximum response.

Fertilizers containing at least 2 percent boron may be needed for alfalfa in some areas in the state. If boron deficiency is observed, and this is more likely on the loamy sand and sandy loam soils of Anoka, Benton, Sherburne, Isanti, Stearns, Mille Lacs, Pine, Aitkin, Kanabec, Morrison, Todd, Wadena, and Crow Wing Counties, a boron containing fertilizer should be recommended. A word of caution is necessary regarding boron in fertilizer that may be used on boron sensitive crops such as corn. Corn may need boron, too; but it is more sensitive to heavier application rates than is alfalfa. Use boron on corn only on a trial basis. (See page 6).

Sulfur recommendations are appropriate in the areas described on page 5.

Grass Pastures and Hay

Marked increase in forage production can be obtained with adequate fertilization of grasses. Addition of each of the three major nutrients is often required for efficient production, but nitrogen is usually most important.

An example of the effect of nitrogen on grass production is given in table 13. This experiment was conducted at Grand Rapids on a mixed native grass pasture, and yields were measured by the feed value to a dairy herd.

Table 13. Effect of nitrogen on TDN and equivalent hay production

Pounds of N* applied per acre	TDN+ per acre	Equivalent tons of hay per acre
0	1,500	1.5
50	2,600	2.6
100	3,600	3.6
200	4,300	4.3

* Adequate phosphate and potash was added to the entire area.

\+ Total digestible nutrients.

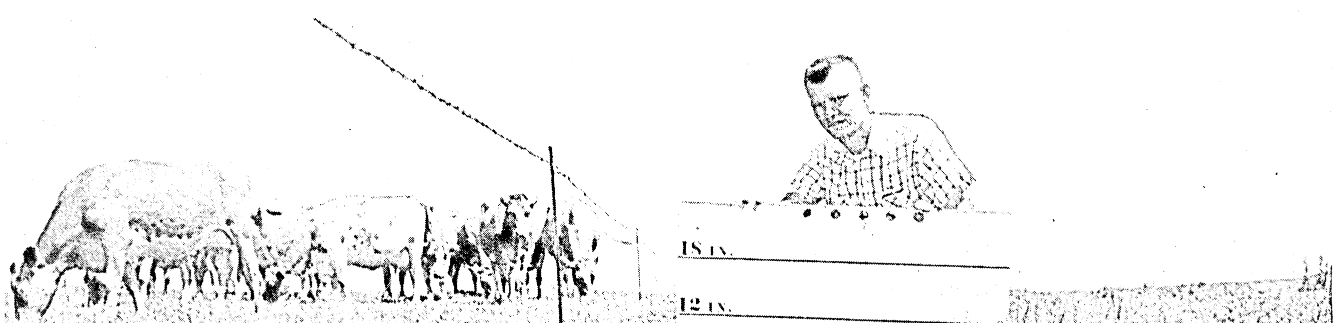


Figure 12. Good pasture management must include soil fertility. Ration-a-day grazing is used here on nitrogen fertilized grass.

Table 14. Permanent grass pasture and hay

Nitrogen		Phosphorus		Potassium	
Soil * condition	Annual nitrogen application lbs. /acre	Soil test phosphorus	Phosphate, P_2O_5 recommended lbs. /acre	Soil test potassium	Potash, K_2O recommended lbs. /acre
Peat and muck soils	0				
Droughty soils	35	20 to 200+	0	220 to 600+	0
Moderate moisture soils	70	0 to 20	30	150 to 219	30
Adequate moisture soils	100	-------	--	0 to 149	90

* The three soil condition categories are intended to describe the average soil moisture condition. Use estimate of average rainfall and nature of the soil to determine this. Sandy soils or those on steep slopes would be considered droughty regardless of rainfall.

Phosphorus and potassium requirements of grass are very similar to those of legume forages with corresponding yields. However, grasses have not been as responsive to phosphate as legumes.

In addition to yield effects, grasses fertilized with nitrogen are much higher in protein, and some species such as reed canary are more palatable to livestock.

It is important that intensive grazing management systems be used to utilize increased production from fertilized pastures. This would include grazing before heading of the grasses and periodic clipping to prevent grasses from maturing and becoming less palatable.

All forms of nitrogen materials may be used on grass, but spacing of ammonia and liquid injector knives of the soil should not be greater than 16 inches.

Applications of nitrogen can be made as split applications or as one application late in the fall or early spring. Split applications allow adjustment to soil moisture conditions.

On medium productive grass pastures with good spring growth the nitrogen application can be delayed until after the first spring lush growth or early June. This will extend the grazing period.

SOYBEANS

Soybeans are one of the most important crops in Minnesota. In 1960, 2,009,000 acres of soybeans were harvested with an economic value of about $105 million.

As with other crop plants, soybean growth and yield is dependent on the level of soil fertility. Plant food requirements for a 30-bushel yield are 135 pounds of nitrogen, 33 pounds of phosphate, and 60 pounds of potash. Since soybeans are a legume, nitrogen is supplied from the air through symbiotic bacteria. However, presence of the specific bacteria should be insured by inoculation of the seed. Nitrogen deficiency may also result when soils are acid; pH should be brought above 6.2 with lime applications.

Soybeans are grown primarily in rotations involving corn and small grains. Since soybeans are efficient in making use of carryover fertility from fertilizer applied on the preceding crop, previous fertilization should be taken into account in making recommendations.

When soybeans are to follow corn, it is sound management to apply 20 or 30 more pounds of phosphate and potash to the corn and eliminate direct fertilization of the soybeans. An exception may be on the sandy or other extremely potassium deficient soils where broadcast applications of potash are made directly for the soybean crop.

Both phosphate and potash are necessary when the fertility level is low in direct fertilization of soybeans.

Table 15. Typical soybean yield in western Minnesota with fertilization--Morris

Annual treatment	Four-year average 1956-1959 yield	Soil test
Check 0+0+0	24.5	pH - 7.2
N 20+0+0	24.7	p - Low
P 0+40+0	28.5	K - High
K 0+0+40	24.2	----------
NPK 20+40+40	29.1	----------

In addition to yield effect, fertilization hastens maturity and improves quality of soybeans. In most cases where yield is increased, maturity is earlier and moisture content of the grain is lower with fertilization. Potash on potassium deficient soils is especially effective in this respect.

The fertilizer can be applied in the row with proper placement a few inches away from the seed. The tables of recommended rates are based on this method of application. If fertilizer is to be broadcast, the 30-pound rates indicated should be doubled to 60 pounds per acre. The 90-pound rate of potash suggested for a low test level should be adequate for either a broadcast or properly placed row application. Soybeans are very sensitive to potash when it is allowed to come to contact with the seed.

Table 16. Soybeans

Nitrogen		Phosphorus		Potassium	
Organic matter	Nitrogen lbs./acre	Soil test phosphorus	Phosphate P_2O_5 recommended lbs./acre	Soil test potassium	Potash K_2O recommended lbs./acre
Medium and high	0	16 to 200+	0	151 to 600+	0
Low	10	0 to 15	30*	90 to 150	30*
				0 to 90	90

* With split-boot type of application equipment, do not recommend more than 30 pounds of N and K_2O as starter fertilizer. Double the 30-pound rates of P_2O_5 and K_2O if the fertilizer is broadcast. (This does not apply to the 90-pound rate of K_2O.)

WHEAT

With high potassium testing soils usually in the major wheat growing area nitrogen and phosphate have been found to be the most needed nutrients for wheat.

With a trend toward less reliance on legume and summer fallow for nitrogen, nitrogen use is increasing. Profitable yield increases from 20 to 60 pounds of nitrogen in research plots frequently have been recorded. Although many of the wheat area soils are high in organic matter, because these soils are slow to warm up, soil released nitrogen from organic sources usually comes too late in the season for optimum growth.

Below is a summary of wheat yield response to nitrogen over a 3-year period in the Red River Valley. Five experiments are represented; all were conducted on soils having textures ranging from silt loam to clay loam and cropped the preceding year to grain, potatoes, or sugar beets. Selkirk was the wheat variety in all cases.

Nitrogen * lbs./acre	Average yield	Yield increase bu./acre
0	21.1	----
20	31.6	10.5
40	35.7	14.6
80	40.2	19.1

* Adequate phosphate was applied.

Nitrogen can be applied on non-sandy soils either as a plowdown in the fall, in the spring before or at seeding time, or as a topdress on the growing crop. Unless the surface soil is dry, up to 40 pounds of N can be applied with a drill fertilizer attachment.

Soils testing below 150 in K will likely benefit from potassium fertilization in yield and grain quality.

Table 17. Wheat (without legume seeding)

Nitrogen				Phosphorus			Potassium		
Organic matter	Previous management* N-def.	N-int.	N-suff.	Soil test phosphorus	Phosphate, P_2O_5 Drilled	Broadcast	Soil test potassium	Potash, K_2O Drilled	Broadcast
	nitrogen recommended lbs./acre				recommended lbs./acre			recommended lbs./acre	
High	50	20	10	51+	0	0	151+	0	0
Medium				21 to 50	15	30	91 to 150	15	20
or	60	30	10						
low				11 to 20	30	45	0 to 90	30	40
				0 to 10	40	60			

* Key to previous management categories (Crops grown the year before wheat):

Nitrogen deficient
- Corn
- Potatoes
- Sugar beets
- Grass sod
- Small grain without legume

Nitrogen intermediate
- Soybeans
- Any crop preceded by legume
- Small grains with green manure
- Nitrogen-fertilized, drought-stricken crop
- N deficient crops plus manure
- Corn with more than 70 pounds of N
- Small grain with more than 40 pounds of N

Nitrogen sufficient
- Pure stand alfalfa or clover
- Black or legume summer fallow
- 10 or more tons per acre of manure (Credit manure with 6 pounds of N and 10 pounds of potash per ton)
- Organic soils, peat, and muck

FLAX

Direct fertilization of flax does not increase yields as consistently as with the small grains. Recent trials in both Minnesota and North Dakota seldom show an economic increase from phosphate or potash fertilization at the medium or higher soil test level. Soils testing in the low level may give a profitable response.

Nitrogen gives a more consistent yield increase, but weed control should accompany nitrogen fertilization of flax. See Minnesota Extension Folder 191 for recommendations on weed control.

Salt damage to the flax seedling often occurs even with phosphate fertilizer. No more than 25 pounds of P_2O_5 should be applied with the seed. When nitrogen and potash are applied, the fertilizer should be broadcast.

Table 18. Flax (without legume seeding)

Nitrogen				Phosphorus		Potassium	
Organic matter soil test	Previous management* N-def.	N-inter.	N-suff.	Soil test phosphorus	Phosphate P_2O_5	Soil test potassium	Potash † K_2O
	recommended nitrogen lbs. /acre				recommended lbs. /acre		recommended lbs. /acre
				11 to 200+	0	91 to 600+	0
All	30	10	0				
				0 to 10	20	0 to 90	60

* Key to previous management categories (crops grown the year before flax):

Nitrogen deficient	Nitrogen intermediate	Nitrogen sufficient
Corn Potatoes Sugar beets Grass sod Small grains without legume	Soybeans Any crop preceded by legume Small grains with green manure Nitrogen-fertilized, drought-stricken crop Corn with more than 70 pounds of N Small grain with more than 40 pounds of N	Pure stand alfalfa or clover Black or legume summer fallow 10 or more tons per acre of manure (Credit manure with 6 pounds of N and 10 pounds of potash per ton) Organic soils, peat, and muck

† All except 10 pounds of nitrogen and potash should be broadcast.

OATS

Oats responds well to fertilizer. Poor economic returns with oats are often the result of low yields due to weather conditions or low fertility.

Drill applied fertilizer is preferred, but most of the oat acreage is in areas where fertilizer drill attachments are not common. Except for the Tama-Downs and Fayette soils of southeast Minnesota nitrogen deficiency is usually a serious problem. In the southeast area nitrogen fertilization can usually be eliminated if there has been alfalfa within 2 years.

A typical situation regarding the effect of nitrogen and phosphate on oats in the south central and southwest part of the state is shown in table 19.

Table 19. Effect of nitrogen and phosphate on oats on Clarion, Webster, and Moody soils *

Treatment	Yield per acre
0+0+0	42
0+40+0	44
10+40+0	48
20+40+0	51
40+40+0	57

* MacGregor, J. M. "Fertilizing Oats Often Pays in Minnesota," Farm and Home Science. February 1950.

Summary of work from 1956 to 1960 at Waseca show returns over fertilizer cost are usually higher when harvested as silage rather than grain.

Oats can effectively use carryover fertility from corn and soybeans. When nitrogen rates of 80 pounds or greater have been applied the previous year, additional nitrogen is not likely to be needed for oats unless the soil is coarse textured.

Table 20. Oats (without legume seeding)

	Nitrogen			Phosphorus			Potassium		
Organic matter	Previous management* N-def.	N-inter.	N-suff.	Soil test phosphorus	Phosphate, P_2O_5 Drilled	Broadcast	Soil test potassium	Potash, K_2O Drilled	Broadcast
	nitrogen recommended lbs. /acre +				recommended lbs. /acre			recommended lbs. /acre	
High	30	20	10	51+	0	0	150 to 600+	0	0
				21 to 50	15	30	90 to 149	15	30
Medium				11 to 20	20	40	0 to 89	30	40
or	40	30	10						
low				0 to 10	30	40			

* Key to previous management categories (crops grown the year before oats):

Nitrogen deficient	Nitrogen intermediate	Nitrogen sufficient
Continuous corn	Soybeans	Pure stand alfalfa or clover
Potatoes	Any crop preceded by legume	Black or legume summer fallow
Sugar beets	Small grains with green manure	10 or more tons per acre of manure (Credit manure with 6 pounds of N and 10 pounds of potash per ton)
Grass sod	Nitrogen-fertilized, drought-stricken crop	Organic soils, peat, and muck
Small grain without legume	Corn with more than 70 pounds of N	
	Small grain with more than 40 pounds of N	
	N deficient crops plus manure	

\+ Increase nitrogen rate by 20 pounds if crop is to be used for silage except for N-sufficient category.

BARLEY

As in the case of wheat, nitrogen and phosphorus are the nutrients which most consistently improve barley yields. Although nitrogen occasionally contributes to lodging, nitrogen deficiency in barley is widespread.

Phosphorus fertilization is usually necessary for optimum barley yields. Rates recommended are the same as those for wheat. Placement effect is also the same as wheat with a higher efficiency of fertilizer possible with drill placement. Maturity is often earlier on phosphate fertilized barley. Phosphate also contributes to seed quality.

POTATOES

USDA estimates made in October 1960 place Minnesota potato production in sixth place nationally with an acreage of 100,300 and a production of 12,731,000 cwt. In 1959, 69 percent of the state's total production was centered on the lake-laid soils of the six northwest counties immediately adjoining the Red River. Anoka and Hennepin Counties with substantial acreages of irrigated sandy soils contribute 6.6 percent, and production on the organic soils of the Hollandale area in Freeborn county accounted for another 9.2 percent of the seasonal total.

Basis for Recommendations

Potatoes have a high requirement for mineral nutrients. Failure of the soil to supply nutrients in adequate amount will result in reduced yields unless fertilizers are added. Chemical soil tests, past cropping history, and soil texture are used in estimating availability of the major nutrient elements. Ideally, such information should be correlated with the results of extensive field fertilizer trials to provide the best possible basis for fertilizer recommendations. To date only limited correlation work has been accomplished with the potato crop in Minnesota. However, a considerable fund of experience with potato fertilization on Minnesota soils is available. This work currently provides the basis for fertilizer recommendations made by the Department of Soils and the Agricultural Extension Service.

Table 21. Barley (without legume seeding)

Nitrogen				Phosphate			Potassium		
Organic matter	Previous management* N-def.	N-inter.	N-suff.	Soil test phosphorus	Phosphate, P_2O_5 Drilled	Broadcast	Soil test potassium	Potash, K_2O Drilled	Broadcast
	nitrogen recommended lbs. /acre				recommended lbs. /acre			recommended lbs. /acre	
High	30	10	10	51+	0	0	150 to 600+	0	0
Medium or low	40	20	10	21 to 50	15	30	90 to 149	15	30
				11 to 20	20	40	0 to 89	30	40
				0 to 10	30	40			

* Key to previous management categories (crops grown the year before barley):

Nitrogen deficient

Continuous corn
Potatoes
Sugar beets
Grass sod
Small grain without legume

Nitrogen intermediate

Soybeans
Any crop preceded by legume
Small grains with green manure
Nitrogen-fertilized, drought-stricken crop
Corn with more than 70 pounds of N
Small grain with more than 40 pounds of N
N deficient crops plus manure

Nitrogen sufficient

Pure stand alfalfa or clover
Black or legume summer fallow
10 or more tons per acre of manure (Credit manure with 6 pounds of N and 10 pounds of potash per ton)
Organic soils, peat, and muck

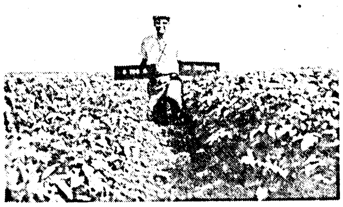
Nutrient Requirements

Dunn and Rost measured nutrient removal by the potato crop at 23 Red River Valley locations and concluded that nutrients in the foliage and tubers of a crop yielding 150 cwt. per acre would approximate 100 pounds nitrogen, 25 pounds phosphate (P_2O_5), 170 pounds potash (K_2O), 44 pounds calcium, 32 pounds magnesium, and 12 pounds sulfur. Forty to 50 percent of the nitrogen and potash, 35 percent of the phosphate, practically all of the calcium, and about half of the magnesium were contained in the foliage and hence returnable to the soil. Higher yields would affect proportionally greater amounts of nutrient removal.

Place of Potatoes in the Crop Rotation

In the Red River Valley area the potato crop usually follows a small grain crop or black or legume summer fallow. On the sandy irrigated areas near the Twin Cities a 2-year rotation of rye and potatoes or continuous cropping to potatoes with a fall planted rye cover crop constitute common practice.

Figure 13. Potatoes respond to high rates of phosphate in the Red River Valley. Nitrogen and potash were also effective on this field.



Fertilizer Experiments

In 1942 Dunn and Rost demonstrated potato yield responses to phosphate fertilizer on the Fargo, Bearden, and Ulen soil types of the Red River Valley. In addition, the sandy Ulen soils responded to potash. No soil test information was available. Treatments and yields were as follows:

Treatments, lbs. /acre N	P_2O_5	K_2O	Potato yield, cwt. /acre (1942) 5 Fargo soils	4 Bearden soils	4 Ulen soils
0	0	0	134	139	100
0	60	0	158	154	133
0	60	120	151	155	153

In 3 years' work at the Red River Valley Potato Research Farm near East Grand Forks, Caldwell and Kramer have consistently demonstrated economical yield responses to high rates of row placed phosphate fertilizers. The soil is a silty clay loam testing low (10 pounds per acre) in phosphorus. On the Pontiac variety in 1958 the maximum economical application rate was not reached at 240 pounds P_2O_5 per acre. The maximum economical rate for the Norland variety was about 200 pounds P_2O_5 per acre. In the 1959 work yields of No. 1 grade Pontiac potatoes increased from 136 cwt. per acre to 192 cwt. per acre to 250 cwt. per acre when 0, 100, and 500 pounds P_2O_5 per acre were used together with moderate amounts of nitrogen and potash. The 60+500+40 treatment yielded an increased return-after-fertilizer cost of $53 per acre over the check figuring potato values at $1 per cwt.

These data would indicate that the potato plant is a "weak feeder" on both soil and fertilizer forms of phosphorus. If the phosphorus composition data of Dunn and Rost are strictly applied, the 250 cwt. per acre yield attained with the 500 pounds per acre P_2O_5 rate would contain no more than 42 pounds P_2O_5 in the vines and tubers.

On soils of moderate to high organic matter content substantial amounts of available nitrogen accumulate following black or legume summer fallow. Economical yield response to high rates of nitrogen applications on such soils is unlikely. Soils with a history of nitrogen depleting crops the preceding season, however, frequently exhibit paying yield responses to nitrogen fertilization.

John Hansen at the North Dakota Station concluded after 3 years' study on soils cropped the previous season to small grains that 60 pounds nitrogen per acre produced maximum marketable yields. Yields at four rates of nitrogen averaged over the 3-year period follow:

Nitrogen lbs. /acre	Marketable yield cwt. /acre
0	139
30	168
60	180
90	179

In 1960 Turnquist and Daellenbach conducted demonstration work with potatoes on a Hammerly silt loam soil in Clay County. Cobbler was the variety. Phosphate at 100 pounds P_2O_5 per acre was row placed throughout. Three rates of nitrogen and four rates of potash were replicated four times, broadcast, and plowed under. Soil test information and yield results were as follows:

pH: 8.2	Extract. P: 1 low	1959
O. M.: 46 percent Med.	Exch. K: 190 med.	crop: soybeans

Table 22. Main effect of nitrogen on yield of marketable potatoes

N rate, lbs. /acre	Yield, cwt. /acre	Increase
0	137.0	----
40	154.7*	17.7
80	159.4*	4.7

* Differ significantly from check.

Table 23. Effect of potash at three nitrogen rates upon yield of marketable potatoes

	Yield, cwt. /acre		
K_2O	O N	40 N	80 N
pounds per acre			
0	133.7	147.6	163.1
40	141.2	149.8	157.7
80	148.7	164.5	148.6
120	124.3	156.7	168.4

Both the 40- and 80-pound nitrogen rates increased yields significantly over check, but the yield associated with the 80-pound rate did not differ significantly from that at the 40-pound rate.

The main effect of potash upon yield was not a significant one; however, there was a tendency for potash to increase yield substantially in the absence of nitrogen while apparent yield depressions occurred with increasing potash rate at the 80-pound nitrogen rate. The interaction did not prove to be significant. A comparison of the chloride and sulfate forms of potassiu at common rates of 100 pounds P_2O_5 per acre and 40 pounds N per acre showed almost identic effects upon yield. From a practical view failur to achieve placement of nitrogen and potash com parable to that affected by standard potato plante fertilizer attachments would appear to constitute valid criticism of this work.

Quality and Maturity Aspects

Differences in season, soil type, and fertilizer treatment can influence the dry matter content of potatoes as indicated in tables 24, 25, and 26. Dunn and Rost studied these variables at 21 locations on three Red River Valley soil types of a 3-year period. Seasonal and soil differences had the most pronounced effect on percent dry matter. Phosphate at 60 pounds P_2O_5 per acre tended to increase dry matter content, but the effect was not significant. Potassium in the chloride form significantly depressed percent dry matter on all soils and in all seasons (except on two Ulen soils in 1953), an effect that was attributed to the chloride ion and accompanied by large increases in chloride content of the tubers. Overall decreases in percent dry matter were substantially less on the potash responsive Ulen soils than on the more potassium sufficient Fargo and Bearden soils. Consistent decreases in percent dry matter failed to occur when potassium was added in the sulfate form. In the more recent work of Caldwell and Kramer potash fertilizers, when accompanied by high rates of phosphorus, have not adversely affected potato quality as measured by specific gravity of the tubers

Recent evidence indicates that potatoes fertilized with potassium sulfate tend to fry darker when processed into chips. This is based on observations the extension horticulturist has made in tests of chipping quality.

Table 24. Effect of soil type on percent dry matter in potatoes in 1942 (after Dunn and Rost), no fertilizers added

Soil type	Percent dry matter on tubers
5 Fargo soils	21.1
4 Bearden soils	23.4
4 Ulen soils	22.9

Table 25. Effect of season and/or differences among soils of one type on percent dry matter in potatoes (after Dunn and Rost), no fertilizers added

Four Bearden soils 1942	Four Bearden soils 1943	Two Bearden soils 1944
23.4	22.2	19.8

Table 26. Effect of fertilizers on percent dry matter in potatoes grown on three Red River Valley soil types in 1943 (after Dunn and Rost)

Treatment	Two Fargo soils	Averages from four Bearden soils	Two Ulen soils
0+0+0	20.7	22.2	21.9
0+60+0	21.1	22.5	22.2
0+0+120	20.1	20.4	21.7
0+60+120	19.7	20.5	21.7

Excessive amounts of nitrogen can delay maturity of potato vines and tubers. At rates giving economical yield increases the effect of nitrogen upon maturity and specific gravity has varied with the soil and season. The Horticulture Department at the North Dakota Station studied the effect of nitrogen rate upon tuber skinning and specific gravity throughout the 3-year period 1956-1958.

In 1956 all nitrogen application rates resulted in less skinning. Specific gravity increased as the nitrogen rate went up to 60 pounds per acre, but the 90-pound rate caused a slight reduction. In 1957 the amount of skinning increased and specific gravity showed a slight but gradual reduction as nitrogen rate was increased. In 1958 neither skinning nor specific gravity were influenced by application of nitrogen in the ammonium nitrate form while tuber set was markedly increased.

In general any treatment which tends to delay maturity of the potato plant will result in lower dry matter of the tubers.

Method and Time of Fertilizer Application

Essentially all fertilizers used on the potato crop in the Red River Valley are applied at planting time through planter attachments. On the sandy irrigated soils of low organic matter and potassium content in the Hennepin-Anoka County area much of the total potash requirement is broadcast before spring plowing and the remainder (together with phosphate and some nitrogen) is row placed with the planter attachment. Nitrogen is usually added in some combination of broadcast preplant, sidedress, and planter attachment application. Potash used on the organic soils of Freeborn County is often split between the preplant broadcast and planter attachment methods of application, while the nitrogen and phosphate requirements are most commonly applied in the row.

In trials conducted by the North Dakota Station, sideband application was significantly more effective than broadcast. Yield and tuber set were increased by nitrogen application at planting time but not by later sidedressings. Caldwell, working on a silty clay loam soil at Grand Forks, found that combined rates of nitrogen and potash exceeding 200 pounds per acre placed in the row resulted in yield decreases.

At rates in common use on Red River Valley soils sideband application of the total fertilizer requirement at planting time would appear to be desirable in most cases. On sandy and organic soils with high potash and/or nitrogen requirements the combined rate of nitrogen and potash should probably not exceed 200 pounds per acre sidebanded with the balance applied broadcast or sidedress.

Table 27. Potatoes on Red River Valley soils (without irrigation)

Nitrogen, lbs./acre			Phosphorus		Potassium	
Previous Management*						
N-def.	N-inter.	N-suff.	Soil test phosphorus	Phosphate, P_2O_5 recommended lbs./acre	Soil test potassium	Potash, K_2O recommended lbs./acre
			Above 21	60	Above 300	30
60-90	30-50	20-30	11 to 20	90	151 to 300	60
			0 to 10	120	91 to 150	90
					0 to 90	120

* Key to nitrogen categories:

Nitrogen deficient
- Corn
- Potatoes
- Sugar beets
- Grass sod
- More than 2 years small grain without legume

Nitrogen intermediate
- Soybeans
- Any crop preceded by legume
- Small grains with green manure
- Nitrogen-fertilized, drought-stricken crop
- Grain or corn with above average rates of nitrogen applied
- N deficient crops plus manure

Nitrogen sufficient
- Pure stand alfalfa or clover
- Black or legume summer fallow
- 10 or more tons per acre of manure (credit manure with 6 pounds of N and 10 pounds of potash per ton)

Note: Any combination of the N, P_2O_5, and K_2O rates listed in this table can be applied safely through the planter fertilizer attachment. If some of the N is applied separately, either apply before planting or sidedress before plants are 10 inches high.

Table 28. Potatoes on sandy loam and loamy sand mineral soils and organic soils (500 to 600 bushels goal)

Nitrogen		Phosphorus		Potassium	
Previous management and soil classification	Nitrogen recommended lbs./acre	Soil test phosphorus	Recommended phosphate (P_2O_5) lbs./acre	Soil test + potassium	Recommended potash (K_2O) lbs./acre
Mineral*					
N-def.	150++	101+	60	300+	30
N-inter.	80	21 to 100	120	221 to 300	60
N-suff.	40	0 to 20	180	91 to 220	120
				0 to 90	240
Organic					
Muck or dark colored decomposed peat	20	51+	80	301+	80
Brown or fibrous peat	40	0 to 50	120	150 to 300	120
				0 to 150	240

* Key to nitrogen categories (crops grown before potatoes):

Nitrogen deficient	Nitrogen intermediate	Nitrogen sufficient
Corn	Soybeans	Pure stand alfalfa or clover
Potatoes	Any crop preceded by legume	Black or legume summer fallow
Sugar beets	Small grains with green manure	10 or more tons per acre of manure (credit manure with 6 pounds of N and 10 pounds of potash per ton)
Grass sod	Nitrogen-fertilized, drought-stricken crop	
More than 2 years small grain without legume	Grain or corn with above average rates of nitrogen applied	
	N deficient crops plus manure	

\+ Magnesium deficiency may occur in the Anoka sand plain area. This can be corrected by applying 300 to 600 pounds per acre of dolomitic limestone or substituting sulphate of potash-magnesia (21 percent K_2O) for potash needs. All potash above 60 pounds per acre should be broadcast; the first 60 pounds or less should be row applied.

++ Irrigation is assumed on the sandy textured soils. Without irrigation do not apply more than 80 pounds of N per acre.

Recommendations for all nutrients are somewhat higher on irrigated soils out of the Red River Valley area. In the case of nitrogen and potassium, rates are higher because some of these nutrients are leached away with the irrigation water. Phosphorus rates for corresponding soil tests are also higher on the sandy soils than the heavier Valley soils. This is because these soils are frequently acid and some of the tests indicated phosphorus is unavailable.

SUGAR BEETS

Sugar beets have become an important crop in southern and western Minnesota as well as the Red River Valley area.

Nutrient requirements are relatively high with 150 pounds of N, 60 pounds of P_2O_5, and 170 pounds of K_2O required for an acre yield of 20 tons. Because of the nature of the soils, phosphate is usually the element needed in greatest amount. Most of the phosphate should be broadcast and worked in the soil, but an advantage of rapid early growth is obtained by placing some phosphate near the seed. However, the blocking and thinning operations may displace some of this fertilizer so the individual operator should not place more than 20 to 30 pounds of P_2O_5 in the row.

There is evidence that large amounts of fertilizer nitrogen lowers the percent of extractable sugar so recommendations are restricted to 40 pounds of nitrogen or less per acre. The main source of nitrogen should be that released from previous legumes or summer fallow.

Sugar beet fertility experiments have not been conducted on potassium deficient soils in Minnesota, but evidence from other crops indicates a potash need when tests are below 220 pounds of K per acre.

GRASS SEED PRODUCTION[4]

Information on the use of commercial fertilizer for the production of bluegrass, timothy, and bromegrass seeds is quite limited in Minnesota. Research studies are underway at the present time. Practically all of the grass seed is produced in northern Minnesota, but some bromegrass seed has been produced in western and southwestern parts of the state. The production of high quality or certified brome seed is almost impossible unless the field is entirely free of quackgrass. Bromegrass seeds and quackgrass seeds cannot be separated because they are similar in size, shape, and weight. This is not true of bluegrass and timothy seeds.

4 P.M. Burson, Professor, Dept. of Soils.

Supplemental table for Special Report 1.

Table 29. Sugar beets

Nitrogen				Phosphorus		Potassium	
Organic matter soil test	Previous management*			Soil test phosphorus	Phosphate, P_2O_5 recommended lbs./acre	Soil test potassium	Potash, K_2O recommended lbs./acre
	N-def.	N-inter.	N-suff.				
Less than 8.5 percent	40	20	0	21+	20	300+	0
				11-20	80	220-300	40
				6-10	100	91-220	80
More than 8.5 percent	10	10	0	0-5	120	0-90	120

* Key to previous management categories (crops grown the year before sugar beets):

Nitrogen deficient

- Corn
- Potatoes
- Grass sod
- Small grains without legume

Nitrogen intermediate

- Soybeans
- Any crop preceded by legume
- Small grains with green manure
- Corn with more than 70 pounds N
- Small grain with more than 40 pounds N

Nitrogen sufficient

- Pure stand of alfalfa or clover
- Black or legume summer fallow
- 10 tons of manure (credit manure with 6 pounds of N and 10 pounds of K_2O per ton)

+ Of the total fertilizer requirement apply only the phosphate with a planter attachment. Apply all N and K_2O and phosphate above 40 pounds per acre broadcast. Twenty to 40 pounds of P_2O_5 can be row applied.

The nutrient requirements are similar to other crops. Phosphate and phosphate-potash should be applied according to soil test. However, nitrogen must be added to obtain maximum yields. Proper fertilization with nitrogen, phosphate, and potash besides giving increased seed yields develops more and larger seed heads on bluegrass, longer and larger seed heads on bromegrass and timothy, with heavier and more uniform seed quality.

More nitrogen per acre can be added to bromegrass and timothy than to bluegrass because they do not lodge as readily. If bluegrass lodges, there will be a poor seed set and the production will be low. This accounts for the lower recommended rates of nitrogen per acre on bluegrass. If nitrogen is applied to a bromegrass field having quackgrass, the quackgrass will respond as well or better than the bromegrass. Timothy seed and quackgrass seed separation is not a problem. Timothy gives excellent response to nitrogen fertilization.

The following table gives the increase in yields of bromegrass with different rates of nitrogen fertilizer. For each pound of additional nitrogen there was an increase of 10 pounds of brome seed per acre.

Table 30. The effect of nitrogen fertilizer on bromegrass seed production in western Minnesota

N applied per acre	Yield per acre
pounds	pounds
Check	213
20	413
40	625
80	897

Table 31. Fertilizer recommendations for grass seed production, bluegrass, timothy, bromegrass

Crop	Nitrogen*	Phosphate		Potash	
		Soil test	P_2O_5*	Soil test	K_2O*
Bluegrass	60 to 80	31+	0	220 to 600+	---
Timothy	60 to 120	10 to 30	40	150 to 219	30
Bromegrass	60 to 120	0 to 9	60	90 to 149	60
				0 to 90	120

* Nutrients to be applied, pounds per acre.

LEGUME SEED PRODUCTION[5]

Legume seeds of alsike, medium red, and sweetclovers can be produced in all parts of Minnesota. Lime, phosphate, and potash are essential soil treatments. Their need should be determined by soil tests. In addition to proper soil treatments, there must be the control of harmful insects and adequate pollination if successful seed production is to be obtained.

5 P. M. Burson, professor, Department of Soils

Legumes are very sensitive to soil fertility variations. A minimum pH of 6.5 is necessary for successful seed production along with adequate amounts of phosphate or of phosphate-potash.

Legumes constitute a part of a good cropping system. They can be used for a hay crop or a seed crop whichever is more desirable. For example, in the southern two-thirds of Minnesota the first crop of medium red clover can be used for hay and the second crop taken for seed. Because of the shorter season in northern Minnesota it is best to let the first crop go for seed.

Eight years of study on the fertilization of all legume seed crops in northern Minnesota have shown that proper soil treatments based on soil tests have increased yields many times over and have improved the size, uniformity, and quality of seed. With adequate fertilization the activity of pollination has increased and this in turn has increased seed yields.

Fertilizer can be applied at the time of seeding the legume crop with a companion crop of small grain, or it can be applied as a topdressing in late fall or in early spring of the seed producing year. If there is a good stand established, topdressing has been just as effective as when the fertilizer was applied at the time of seeding. If the fertility level of the soil is low, proper fertilization applied at the time of seeding will improve the stand. Recommended rates of fertilizer applications are given in table 32 according to the need indicated by the soil test.

Table 32 shows the response of phosphate and phosphate-potash on seed production as applied according to the soil test.

Table 32. The effect of fertilizer on legume seed production

Soil treatment	Sweet-clover *	Alsike clover +	Medium red clover ++
Check	881.0 lb.	181.0 lb.	315.0 lb.
0-60-0	1,126.0	693.4	---
0-60-60	1,270.0	611.0	---
0-100-0	1,236.0	711.0	380.0
0-100-100	1,216.0	618.4	394.0

Soil Test:

* pH 7.1 -- Phosphorus 7 (low), Potassium 150 (medium).

\+ pH 7.6 -- Phosphorus 8 (low), Potassium 200 (medium).

++ pH 7.4 -- Phosphorus 15 (medium), Potassium 200 (medium).

Table 33. Fertilizer recommendations for legume seed production, sweetclover, alsike clover, medium red clover

Nitrogen	Phosphate		Potassium	
	Soil Test	P_2O_5	Soil Test	K_2O
None	30 to 200	---	200 to 600	---
None	20 to 29	30	150 to 219	30
None	10 to 19	60	90 to 149	60
None	0 to 9	100	0 to 90	120

CANNING CROPS

Green peas and sweet corn account for the bulk of all Minnesota acreage planted to canning crops. In 1959, 86,200 acres of sweet corn and 41,000 acres of green peas with a combined value of \$9½ million were harvested.

Most canning crops are harvested in immature condition and may, therefore, remove less total nutrients than field crops. Their frequently higher value, however, makes attention to the fertility needs of nutrient deficient soils especially important.

Canning Peas

Hofman and Halverson cooperated with Birdseye Frozen Foods, Inc. on demonstration work with canning peas in Waseca County in 1959. The soil was a clay loam of pH 6.0 testing medium (19 pounds per acre) in phosphorus and medium (200 pounds per acre) in potassium. Four rates of phosphorus fertilizer were applied prior to planting, and yields measured at harvest time. Results were:

P_2O_5 lbs./acre	Yield cwt./acre	Value acre at \$4.60/cwt.	Seed, harvesting, and fertilizer cost*	Return over seed, harvesting, and in fertilizer costs/acre
0	25.4	\$116.84	\$35.15	\$81.69
30	29.0	133.40	38.15	95.25
60	30.6	140.76	41.15	99.61
90	30.3	139.38	44.15	95.23

* Seed cost--\$34.50 per acre. Harvesting cost--\$1.15 per acre. P_2O_5 valued cost--\$.10 per pound.

Table 34. Canning peas*, lima beans, and snap beans

Nitrogen			Phosphorus		Potassium	
Previous management+						
N-def.	N-inter.	N-suff.	Soil test phosphorus	Phosphate, P_2O_5 lbs./acre recommended	Soil test potassium	Potash, K_2O lbs./acre recommended
Nitrogen recommended, lbs./acre						
			Over 40	0	200+	0
			26 to 40	30	91 to 200	30
30	15	0	11 to 25	60	0 to 90	60
			0 to 10	90		

* If placement equipment capable of separating fertilizers from the seed is not available, the fertilizers should be broadcast and disked into the seedbed before planting.

\+ Key to nitrogen categories:

Nitrogen deficient	Nitrogen intermediate	Nitrogen sufficient
Continuous corn	Soybeans	Pure stand alfalfa or clover
Potatoes	Any crop preceded by legume	Black or legume summer fallow
Sugar beets	Small grains with green manure	10 or more tons per acre of manure (credit manure with 6 pounds of N and 10 pounds of potash per ton)
Grass sod	Nitrogen-fertilized, drought-stricken crop	
Small grain	Grain or corn with above average rates of nitrogen applied	
	N deficient crops plus manure	

Table 35. Sweet corn

Nitrogen				Phosphorus		Potassium		
	Previous management*							
Soil test organic matter	N-def. Nitrogen++	N-inter. lbs./acre	N-suff. recommended	Soil test phosphorus	Phosphate, P_2O_5 lbs./acre recommended	Soil test potassium	Potash, K_2O lbs./acre recommended	
					Organic and Mineral		Mineral	Organic
High	50	30	10	100 to 200+	0	220 to 600	0	40
Medium				21 to 99	20	91 to 219	40	80
and	60	40	10					
low				11 to 20	40	0 to 90	80	120
8.5+ organic soil	0	0	0	0 to 10	60			

* Key to nitrogen categories (crop previous to sweet corn):

Nitrogen deficient	Nitrogen intermediate	Nitrogen sufficient
Continuous corn	Soybeans	Pure stand alfalfa or clover
Potatoes	Any crop preceded by legume	Black or legume summer fallow
Sugar beets	Small grains with green manure	10 or more tons per acre of manure (credit manure with 6 pounds of N and 10 pounds of potash per ton)
Grass sod	Nitrogen-fertilizer, drought-stricken crop	
Small grain	Grain or corn with above average rates of nitrogen applied	
	N deficient crops plus manure	

\+ If the split boot fertilizer attachment is used, limit the total of N and K_2O to 40 pounds per acre. Any amount of fertilizer can be applied in the row if placed 2 inches below and 2 inches to the side of the seed. However, broadcasting part of the fertilizer has the advantage of being in a better position for carryover effect.

++ The figures are in terms of total nitrogen needed. Amounts of 30 pounds per acre or less are usually applied with the mixed fertilizer. Higher amounts are usually applied as straight nitrogen materials. The amount of nitrogen to be applied as a separate application should be the total less that applied in the starter or broadcast application.

Table 36. Vegetable and truck crops on organic soils

Crop		High P (30-200+) High K (200-600+)			Low-med. P (0-29) High K (200-600+)			High P (30-200+) Low-med. K (0-199)			Low-med. P (0-29) Low-med. K (0-199)		
		lbs. per acre			lbs. per acre			lbs. per acre			lbs. per acre		
		N*	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Asparagus Cabbage Cauliflower Carrots Peas Radishes Table beets	0:1:3 Ratio	0 +	50 +	150	0 +	100 +	150	0 +	50 +	300	0 +	100 +	300
Celery	0:1:1 Ratio	50 +	100 +	200	50 +	200 +	200	50 +	100 +	600	50 +	200 +	600
Onions		50 +	100 +	100	50 +	200 +	100	50 +	100 +	200	50 +	200 +	200
Beans Lettuce Mint Parsnips	0:1:1 Ratio	0 +	50 +	50	0 +	100 +	50	0 +	50 +	100	0 +	100 +	100

* Use nitrogen on newly cultivated peat and highly decomposed muck. On most other organic soils nitrogen is not necessary except for celery and onions.

VEGETABLE AND TRUCK CROPS ON ORGANIC SOILS

In the culture of high value truck crops it is important to maintain high fertility levels of phosphorus and potassium. Since the organic soils contain and release substantial quantities of nitrogen, it is usually not necessary to add fertilizer nitrogen. There is also the possibility of excessive nitrogen causing adverse quality effects of some vegetables.

The routine soil testing methods adapted for use primarily on mineral soils have some shortcomings for use on organic soils and specialized crops. However, the soil test information can be of some value in determining the relative nutrient status of P and K.

Table 36 is a guide for determining which areas should have a corrective treatment of phosphate and potash. The grouping of species into categories of P:K ratios is done on the basis of Michigan State University recommendations. Additional information is available in Special Bulletin 425 from Michigan State University.

HOME VEGETABLE GARDENS AND SMALL FRUITS

A practical fertilizer recommendation for home gardens is generally one that involves one grade of fertilizer that can be applied at different rates depending on the phosphorus and potassium fertility. For this reason only two categories of soil tests are considered: 1) P and K are both high or 2) one or both P and K are medium or low. If manure is applied to gardens, no fertilizer is recommended unless P or K are in the low category (below 10 for P and below 90 for K).

Fertilizer for gardens should be applied as a broadcast before planting and worked into the soil. Fertilizer for fruits such as strawberries and raspberries should be applied early in the spring. Research work on the effect of fertilizers on small fruits is very limited.

Recommendations from other states indicate that complete fertilizers are most practical.

HOME LAWNS

The preparation of a fertilizer recommendation for lawns on the basis of soil tests has been difficult because it is not practical for the average home owner to buy grades that fit different soil test situations. Lawn fertilizers are usually complete so there is no chance to adjust P_2O_5 and K_2O rates.

The home owner needs information about methods of fertilizing a lawn, about time of application, and a list of available grades and rates of application.

To meet this need a standard recommendation form has been prepared in the Fact Sheet series that can be sent to the lawn soil test client. This form provides two alternative fertilizer plans, one of which can be recommended on the basis of the soil test.

Plan 1 uses complete grades that would be recommended whenever there are these P and K situations.

1. P is medium, K is high.
2. P is medium, K is low.
3. P is low, K is high.
4. P is low, K is medium.
5. P is low, K is low.

Plan 2 uses only nitrogen fertilizers and would be recommended for these P and K soil test situations:

1. P is high, K is high.
2. P is medium, K is high.

One of the plans would be checked on the recommendation form corresponding to the appropriate soil test situation.

Table 37. Home gardens, small fruits, and ornamental plantings

Plants	P and K tests high +30 for P +220 for K		P or K medium or low, less 30 for P, less 220 for K	
	Amount of * 12-12-12 per acre	Amount of 12-12-12 per 1,000 sq. ft.	Amount of * 12-12-12 per acre	Amount of 12-12-12 per 1,000 sq. ft.
Home garden	250	6	500	12
Strawberries and raspberries	250	6	800	18
Shrubbery	400	9	800	18
Trees	Fertilize only if growth is unsatisfactory or if leaves are light green. Use 12-12-12 or 10-10-10 at rate of 2 pounds per inch of trunk diameter. Apply in 18 inch holes in circle at a distance similar to the crown of the tree. Mix fertilizer with about 3 to 4 times as much soil and pour this in the holes. Space the holes about 24 inches apart.			

* 12-12-12 is used as an example. Grades of ratios 1-2-2 can also be used for high tests. For low tests grades with 1-2-2 and 1-4-4 ratios can also be used.

The fact sheet can also be used for those who want a lawn fertilizer recommendation but do not have a soil test. In this case Plan 1 would usually be used unless considerable plant nutrients had been used in the past.

The lawn fertilizer guide table used in this fact sheet follows.

Fertilizer grades and rates for lawns

Plan 1. Soils with a deficiency of phosphorus or potassium
(Use one of the grades listed)

Ratio	Grades	Amount per 1,000 sq. ft.	Time of application	Maintenance nitrogen
1:1:1	8-6-6 8-8-6 8-8-8 10-10-10	25 lbs. once a year	Early spring is best but can be used any time during growing season	Usually this will supply N. If color is light green, use an application of fertilizer listed under Plan 2
	12-12-12 14-14-14 15-15-15	16 lbs. once a year		
2:1:1	10-5-5 10-6-4 12-6-6 14-7-7 16-8-8	12 lbs. twice a year	Apply the first application early spring and the second in early July	These fertilizers supply adequate N. After 2 years of this plan, you can use fertilizers listed under Plan 2
3:1:1 and 4:1:1	15-5-5 18-6-6 20-8-8 20-10-5 20-8-8	9 lbs. twice a year		

Plan 2. Soils adequate in phosphorus and potassium, maintenance nitrogen only
(Apply one grade three times per year)

Ratio	Grades	Name	Amount to apply, lbs. per 1,000 sq. ft.		
			March or early April	Early June	September
1:0:0	45-0-0	Urea	$3\frac{1}{2}$	$1\frac{1}{4}$	2
	38-0-0	Urea form	4	2	3
	33-0-0	Ammonium nitrate	5	2	3
	21-0-0	Ammonium sulfate	8	4	4
	16-0-0	Sodium nitrate	10	5	5

The fertilizer grades cited are examples only. Other equally effective grades are commonly available.

APPENDIX

PROCEDURES USED IN UNIVERSITY OF MINNESOTA SOIL TESTING LABORATORY

Before testing, all samples are dried to a uniform moisture, crushed, and sieved. This usually takes from 5 to 7 days. This makes handling easier and assures consistent results. The samples are dried at room temperature and humidity.

Following is a general description of laboratory procedures used:[6]

pH

Soil pH is a number that indicates the relative acidity or alkalinity of the soil. Values below 7 are acid, above 7 are alkaline. The pH is measured with a pH meter on a paste water-soil mixture of a sample.

Extractable Phosphorus

The soil phosphorus measured is that which is extracted by a solution consisting of 0.025 N HCl and 0.03 N NH_4F, commonly referred to as Bray's No. 1 extractant. One gram of soil and 10 milliliters of extractant are shaken for 1 minute.

The amount of phosphorus extracted is determined by measuring the intensity of the blue color developed in the extract when treated successively with hydrochloric acid-ammonium molybdate and amino-napthol-sulfonic acid solutions. A spectro-photometer is used to measure this color which is converted to pounds of phosphorus per acre on the basis of 2 million pounds of soil in the surface 6 inches of an acre. The phosphorus measured does not represent all of the phosphorus that may be available for plant growth, for example, organic phosphorus may become available upon mineralization.

Exchangeable Potassium

Potassium is extracted from the soil samples with 10 milliliters of 1.0 N ammonium acetate mixed with 2 grams of soil. The amount of potassium removed by this reagent in 1 minute is designated as exchangeable potassium and is measured by passing the filtered extraction solution through a flame photometer. This instrument is calibrated with standard solutions so that a direct reading of pounds of potassium per acre can be made.

Organic Matter

The percent organic matter in the samples is determined by oxidation of the organic material with chemical reagents. These reagents are 2.0 N potassium dichromate and concentrated sulfuric acid. The resulting color of a mixture of these reagents and soil is a function of the amount of organic matter. This color is measured in a colorimeter.

Texture

The relative amounts of sand, silt, and clay are estimated by the feel of the soil in a plastic condition. Soil texture is the most important single property of a soil since it affects the capacity to hold water and the capacity to store and supply plant nutrients.

EXAMPLE RECOMMENDATIONS

A complete fertilizer recommendation should include the amount and kind of plant nutrients needed and suggestions on the proper method and time of application. This information should be in a form that's easy for farmers to understand and doesn't discriminate against any particular fertilizer brand.

There are two methods of expressing a fertilizer recommendation, that of total plant food per acre such as 0+60+60 and a rate of certain grade such as 300 pounds of 0-20-20. There are advantages to expressing each recommendation in both forms. The total plant food method shows that the important information is that certain amounts of nitrogen, phosphate, and potash are needed for the crop. The rate and grade form then shows one method of applying this plant food. Most farmers understand the rate and grade form more easily than the plant food per acre form.

Effort should be made to make the plant food per acre concept more widely understood because this allows the operator flexibility in buying fertilizers. Also, a significant amount of fertilizer is bulk mixed and spread and the total plant food per acre method is appropriate for this.

Well designed recommendation forms or individual letters should be sent with each laboratory test report. With a large number of samples in a county a standard form letter approach is most satisfactory, but as much individual attention as possible should be given to each cooperator. Fertilizer recommendation forms are available on request to the Extension Soils Specialists' office.

It is the policy of the Soil Testing Laboratory and Extension Service to provide an extra copy of the soil test report and fertilizer recommendation to fertilizer dealers or others if this is requested on the information sheet. This is sent from the county extension office.

Following are examples of how recommendations should be made for different crop and soil situations.

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6 Adapted from "Soil Analysis Methods as Used in the University of Minnesota Soil Testing Laboratory." John Grava. Form 15-G, Institute of Agriculture, University of Minnesota, June 1957.

Crop and soil situation -

Organic matter	4.6M	Past crops	Corn preceded by beans
pH	6.8	Manure	No
Extractable P	12	Crop to be fertilized	Corn
Exchangeable K	170	Yield goal	100 bu.
Texture	Clay loam		

Equipment available -	Disk planter attachment	X
	Split boot attachment	
	Broadcast	X

Recommendation -

Total plant nutrient need:

100	pounds of nitrogen per acre
40	pounds of phosphate per acre
40	pounds of potash per acre

This can be applied as:

Example of grade	Amount pounds per acre	Method of application	Time of application
5-20-20	200	Planter attachment	At time of planting
	None	Broadcast	Fall or spring
90 pounds of nitrogen		Supplemental N sidedress or broadcast	Fall, spring, or June

Comments -

Generally it is best to recommend the supplemental nitrogen as pounds of N per acre. Do not recommend specific grades such as 33-0-0, 41-0-0, or 82-0-0. When supplemental N is to be used, limit the starter N to 10 to 12 pounds.

If no planter attachment was available, increase the phosphate 20 pounds per acre or 40 pounds in this case.

Crop and soil situation -

Organic matter	2.5L	Past crops	Alfalfa
pH	5.9	Manure	No
Extractable P	40	Crop to be fertilized	Corn
Exchangeable K	105	Yield goal	85 bushels
Texture	Sandy loam		

Equipment available -

Disk planter attachment	
Split boot attachment	X
Broadcast	X

Recommendation -

Total plant nutrient need:

15	pounds of nitrogen per acre
20	pounds of phosphate per acre
80	pounds of potash per acre

This can be applied as:

Example of grade	Pounds per acre	Method of application	Time of application
8-16-16	125	Planter attachment	At planting time
0-0-60	100	Broadcast	Fall or spring
None		Supplemental N broadcast or sidedress	

Comments -

(1) It is impractical to recommend a broadcast rate of less than 100 pounds of fertilizer per acre. For this reason the amount of K_2O recommended is increased from the 60 pounds given on table 9 to 80 pounds per acre. If table 8 were used, the 40 pounds of K_2O would be increased to 80 pounds.

(2) If a disk attachment were available, all of the fertilizer would be recommended as a starter. Two hundred pounds per acre of 5-10-30 could be used.

Crop and soil situation -

Organic matter	5.3 M	Past crops	Oats and sweetclover
pH	7.1	Manure	5 tons
Extractable P	8	Crop to be fertilized	Corn
Exchangeable K	230	Yield goal	125 bushels
Texture	Clay loam		

Equipment available -

Disk planter attachment	X
Split boot attachment	
Broadcast	X

Recommendation -

Total plant nutrient need:

70	pounds of nitrogen per acre
80	pounds of phosphate per acre
12	pounds of potash per acre

This can be applied as:

Example of grade	Pounds per acre	Method of application	Time of application
6-24-12	100	Planter attachment	At time of planting
0-45-0	120	Broadcast	Fall or spring
65 lbs. of N		Supplemental N broadcast or sidedress	Fall, spring, or June

Comments -

In this case some potash is recommended in the starter even though manure may add about 50 pounds of potash. Reasons for this are discussed in section on manure. Manure is credited for 30 pounds of N, so the total recommended as fertilizer is 100-30 or 70 pounds.

Crop and soil situation -

Organic matter	2.3 L	Past crops	Corn
pH	6.4	Manure	None
Extractable P	16	Crop to be fertilized	Oats and alfalfa
Exchangeable K	140	Yield goal	--
Texture	Silt loam		

Equipment available -

Disk planter attachment	
Split boot attachment	
Broadcast	X
Grain drill attachment	

Recommendation -

Total plant nutrient need:

30	pounds of nitrogen per acre
60	pounds of phosphate per acre
90	pounds of potash per acre

This can be applied as:

Example of grade	Amount pounds per acre	Method of application	Time of application
8-16-24	374	Broadcast	Fall or spring or after cutting

Comments -

Here a 1:2:3 ratio is called for if the guide is followed and one fertilizer is used. If a fertilizer such as 8-16-24 is not available, a grade such as 10-20-20 could be used at 350 pounds per acre. This would apply 35 pounds of N, 75 pounds of P_2O_5, and K_2O which would be acceptable. If the K tests were closer to the low level, the full 90 pounds of potash should be applied.

Crop and soil situation -

Organic matter	5.2 M	Past crops	Wheat
pH	7.4	Manure	None
Extractable P	8	Crop to be fertilized	Barley
Exchangeable K	500	Yield goal	50 bushels
Texture	Silty clay loam		

Equipment available -

Disk planter attachment	
Split boot attachment	
Broadcast	
Drill fertilizer attachment	X

Recommendation -

Total plant nutrient need:

40 pounds of nitrogen per acre

32 pounds of phosphate per acre

0 pounds of potash per acre

This can be applied as:

Example of grade	Amount pounds per acre	Method of application	Time of application
24-20-0	165	Drill attachment	Seeding

Comments -

Recommendation assumes a medium to fine textured soil adequately supplied with moisture at seeding time. On fine textured soils in dry condition apply phosphorus requirement down the spout using a mixed fertilizer having a 1:4 ratio of N to P and apply balance of nitrogen broadcast preplant. On sandy soils do not exceed 30 pounds per acre of N and/or K_2O in down-the-spout application under any soil moisture condition.

The separate nitrogen application method would also be used when it is known that grades such as 24-20-0 are not available.

The example recommendation of grade and amount should agree with the total plant food figures given. In this case the 32-pound phosphate figure is used rather than 30 pounds because of the grade used.

Crop and soil situation -

Organic matter	4.8 M	Past crops	Sweetclover fallow
pH	6.8	Manure	None
Extractable P	17	Crop to be fertilized	Sugar beets
Exchangeable K	370	Yield goal	14 tons
Texture	Clay loam		

Equipment available -

Disk planter attachment	X
Split boot attachment	
Broadcast	X

Recommendation -

Total plant nutrient need:

10 pounds of nitrogen per acre

80 pounds of phosphate per acre

0 pounds of potash per acre

This can be applied as:

Example of grade	Pounds per acre	Method of application	Time of application
10-20-0	100	Planter attachment	Planting time
0-46-0	175	Broadcast	Fall or spring

Comments -

The situation here is quite straightforward. One alternative would be to broadcast all the fertilizer in which case the nitrogen could be eliminated because the 10 pounds would not have a significant effect unless placed near the row.

SPECIAL

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