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SOILS, SOIL MANAGEMENT AND FERTILIZER MONOGRAPHS

UNIVERSITY OF MINNESOTA
AGRICULTURAL EXTENSION SERVICE
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FOREWORD

Population growth is putting real strain on our soil resource base, not only for efficient and profitable production of nutritious foods that can be sold at a reasonable price, but for the disposal or dilution of large quantities of waste products and to meet alternate land use needs. We must intensify production on fewer farm acres if we are to meet world food needs and at the same time maintain a clean and healthy environment with minimum erosion and proper utilization of fertilizers, agricultural chemicals, and other soil amendments.

Minnesota soils are among the best in the nation, but their productivity is highly variable. Soil scientists must survey and classify soils as well as study their physical, chemical, and biological characteristics for maximum crop production, to enhance environmental quality, and to provide interpretive information for land use decision making.

This monograph brings together comprehensive and technical information on Minnesota soils and on soil-plant-climate relationships, together with soil and crop management principles. Although prepared for intensified soil training schools conducted periodically by the Minnesota Agricultural Extension Service, the several sections are bound together for reference and to provide a well-rounded information source in a single publication. Careful reading will create a better understanding of Minnesota's unique soils heritage and the management alternatives for improving quality and sustaining economic viability.

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FACTORS AFFECTING FERTILIZER RESPONSE

C. J. Overdahl

Growing healthy plants is not easy. Each time a crop is planted, there perhaps is an ultimate genetic yield capacity which cannot be exceeded, but any shortcomings in soil management, the soil itself, weather, and other factors, drop the actual yield far below its potential.

Nutrients can become fixed, rendering them unavailable to plants, but the reverse action also occurs. Soil minerals, as well as organic matter, release nutrients plants can use. The type of soil, soil temperature, and moisture, and in some areas pH, greatly affect the nutrient release rate.

Understanding nutrient release in the soil, the degree to which it can vary, and why it varies, is basic to knowing how to use fertilizers profitably.

The Present Chemical Status

The most obvious factors when considering the need for fertilizer are the soil's chemical ingredients. If this were the only factor, however, figuring fertilizer needs would be easy with a chemical test.

The chemical test is very helpful, but a physical as well as biological evaluation is also necessary. Today, an attempt is made in a general way through the use of the computer to incorporate some of these other factors that help in making soil tests a more complete report. Soils sometimes test low in a nutrient, but crops grow well and don't respond to fertilizer; other soils test high and have crops that respond to fertilizer. This does not indicate poor soil testing, but soil peculiarities that must be understood before arriving at the proper fertilizer rate. The following sections describe how these factors affect the crop's fertilizer response.

Varying Rate of Organic Matter Decomposition

Nitrogen, phosphorus, boron, sulfur, and perhaps other nutrients are released from organic matter every year. Rarely does a soil become so devoid of nutrients that nothing grows. In its natural state, plant growth would fail except for the continual renewal from mineral and organic sources. It is reasonable, then, to expect a much higher and faster availability of nutrients in soils with an abundant supply of organic matter.

Soil moisture, temperature, drainage or aeration and, in many soils the pH, can affect the speed at which nutrients become available even though these factors are indirect, affecting the activity of the soil organisms in rotting residues and soil organic matter.

Soybeans, due to the nature of their unusual nutrient demands, take full advantage of this. Soybeans yield better on highly fertile soils. Since soybeans have their biggest nutrient demand in midsummer, the ideal decomposition rate on soils having abundant organic matter (an indication of a well-managed soil over the years) coincides with this demand to such an extent that few extra nutrients through direct fertilization are needed.

Soil Texture and Nutrient Release from Mineral Sources

Of the sand, silt, and clay particles that makeup all but the organic matter in mineral soils, clay is the most important. Potassium, for example, is involved in a two-way exchange between available and unavailable forms (called equilibrium). When plants draw off potassium, the soil water is replenished from the nonavailable forms. The greater the clay content, the larger the supply of potassium-bearing minerals. In practice, however, this release is too slow to keep a plant properly supplied.

The Effect of Cold Soil Temperature

Before the relationship between soil temperature and fertilizer response was understood, it was commonly thought that the response observed was simply due to overcoming low fertility. It was noticed, however, that in some years there would be a big response and in other years no response at all, while crop yield was as good, and often even better when there was no response, indicating the rainfall was not limiting.

At the Lamberton Experiment Station, Caldwell and Nelson measured a 59 bushel corn yield increase due to a starter fertilizer containing high rates of nitrogen, phosphorus, and potassium. The next year on the same plots, corn yields were considerably higher, but no response to row fertilizer was obtained. Soil temperatures at the 2-inch depth from April 1 through June 10 averaged 9 degrees colder in the year of the big starter response compared with temperatures of the following year.

During the same two years, a nitrogen experiment conducted by MacGregor and Nelson at Lamberton showed corn yields of 26 bushels per acre without nitrogen and 78 bushels from 160 pounds per acre of nitrogen. Cold weather apparently kept yields down, but the nitrogen at least partially offset the bad effects. The next year the no nitrogen plot had corn yields of 133 bushels per acre and increased to 152 with the nitrogen added. Numerous trials such as these have been conducted around the state with similar results. Greenhouse and growth chamber studies with moisture held constant show that fertilizer definitely helps in offsetting cold weather problems. Additions of phosphorus, potassium, nitrogen, zinc, iron, and perhaps other essential elements can be effective in offsetting problems of cold soils.

Soils most apt to be cold are the fine-textured ones with limited drainage. Wetness means cold. If a soil is dry, it warms rapidly and may not have the problems.

What actually happens that makes fertilizer so effective in cold soils has been studied. Fertilizers do not warm the soil, as some people think. Several reasons have been given. They include slow biological activity of the plant when it is cold, restricting nutrient absorption. If fertilizer is placed near the seed or near young roots, the root contact with the high concentration offsets the slower uptake rate, thus more nutrients get into the plant. Next, shallow rooting during cold temperatures because of high moisture restricts much of the absorbing roots to an area where only the row fertilizer can be effective. In warm springs when the soil is dry, roots penetrate more deeply and extend farther laterally, hence use enough broadcast fertilizer or the soil's native nutrients. Last, when soils are warm, soil bacteria can function very actively, decomposing organic material and releasing nutrients. When soils are cold, organic matter is not a reliable source for immediate use by plants.

Dry Soil Conditions and Fertilizer Response

If severe drought is the major limiting factor, fertilizer response is seldom observed. However, in years when moisture is not limiting, fertilizers create more organic matter by increased growth. Over time, these soils are improved physically, have better water infiltration, and conserve moisture better when dry weather occurs.

Fertilizer can also give short term benefits under certain conditions. As subsoil moisture gradually depletes to a seriously low level during the growing season, hastened maturity because of fertilizer is usually beneficial. Row fertilizer is particularly effective in hastening maturity.

It is possible that hastened maturity could reduce yields, too. If severe dry, hot weather prevails at reproduction time and is immediately followed by good rains, a slower growing crop may come along late enough to benefit. Generally it is desirable to promote healthy plants and adjust for prevailing weather conditions in other ways.

Studies at the North Dakota Experiment Station show that differences in soil moisture drawdown for fertilized versus unfertilized wheat were small. They measured a difference of 0.64 inches less water to a 5 foot depth averaged from 12 locations between treated versus nonfertilized plots. Average yield increase was 7.5 bushels, thus about 2/3 of an inch of water was traded for 7.5 bushels of wheat.

Drought and fertilizer effects are different on hay than on grain crops. In forage production, there is no critical reproductive stage. Fertilization of perennials such as sod crops involves a 2 or 3 year program rather than the quick return anticipated on grain crops. If drought retards production one year, the uniformly broadcast fertilizer is likely to be available the next. By contrast, the carry-over from row applications on grain is harder to evaluate.

Soil pH and Nutrient Response

Nutrient response is adversely affected either by too high or by too low a pH. Alkaline soils in Minnesota usually present problems of availability of phosphorus, potassium, zinc, and iron. A partial, but not total, improvement can be made by adding these elements as fertilizer.

Iowa data show that where soils have about 15 percent calcium carbonate equivalent (15 percent lime) potassium is very effective in increasing corn yield, even though a soil may test quite high in K (up to 300 pounds of exchangeable K). Where this problem exists, broadcast applications of 200 pounds per acre of 0-0-60 on these areas are beneficial. On alkaline soils, special attention to phosphorus and zinc must be given, especially in corn production.

Summary

Reliable soils tests should be used in conjunction with knowledge of other factors not measured by the chemical test. Computer programing, within limits, can incorporate these factors in their print-out.

HOW FERTILIZERS AFFECT SOIL ORGANIC MATTER

C. J. Overdahl

Soil science has come a long way from ancient times when the keenest observers merely imitated the best cultural practices they saw work from year to year. Most agricultural knowledge was based on trial and error and passed on from fathers to their sons.

As population increased, there was growing concern about food production. In 1798, Thomas R. Malthus wrote his "Essay on Population" which noted that the population was increasing faster than the food supply and predicted that people would starve like wild animals in overpopulated areas. He was unable to comprehend what future agricultural technological advances, including mechanization, improved varieties, fertilizer, and pesticides, could do to offset or delay it. There are, however, some countries today, too poor for this technology, with millions of people who live in semistarvation.

Modern advances along the way had many mistakes. Two or three hundred years ago, workers tried to discover a principle that made plants grow. Some philosophers explained plant growth as the passing of this principle from a dead plant (or animal) to a new plant: this was called the humus theory of plant nutrition. Later discoveries showed that plants grew from inorganic nutrients and completely invalidated this idea.

The Need for Organic Matter

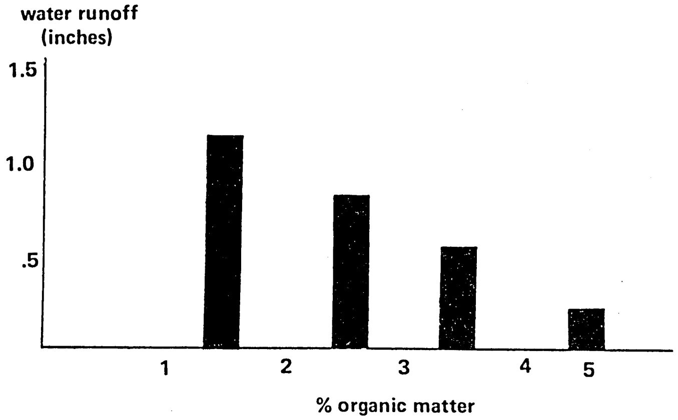
Soil compaction indicates a soil lacks organic matter. By adding organic materials, such as manure or crop residues to these depleted soils, soil structure improves and future crop growth is more vigorous. Organic matter also serves as a storage place for nutrients, but the chief advantage is in the physical improvement that prevents hardness. When soils are loose, not packed, there is more room for air and water for the plant's growth. Also, when more water infiltrates, less runs off, which means less erosion with loss of nutrients and less pollution. It is this improvement from organic matter that caused early observers to think there was some kind of humus principle handed over from dead to living plants.

How Crops Convert Inorganic Material to Organic Matter

Plants create organic matter as they live and grow. They combine carbon dioxide and water in their leaves in the presence of sunlight. The result of this combination, called photosynthesis, is formation of carbohydrates and other organic compounds, which usually return to the soil in modified forms for its improvement. Plants, however, in addition to carbon dioxide and water, need mineral or inorganic elements, which usually come from the soil. If a soil has any deficiency, inorganic fertilizers containing these deficient elements can be added. When this is done, the plant is healthy, grows vigorously and larger than it would have under the handicap of a nutrient shortage.

The Effect of Improved Crop Growth on Water Runoff

Field experiments have been conducted over several years to study the effect of both improved organic matter and improved yields on the amount of water runoff. Wischmeyer reported in Soil Science Society Proceedings, 1966, the runoff data from Bethany and McCredie, Missouri; Clarinda, Castana, Beaconsfield, Iowa; LaCrosse, Wisconsin; and Zanesville, Ohio experiment stations. His studies show the following relationship between runoff and the amount of soil organic matter.



The bar diagram shows water runoff is lower where organic matter is highest: high soil organic matter is related to low runoff.

One of the most practical means of improving organic matter is by returning residues from high yielding crops to the soil. Wischmeyer compared the effect of corn yields and the amount of runoff.

Runoff is less where yields are high, indicating that the residue from the higher yielding crops has its effect after several years. Soil scientists no longer believe the old idea that soils need an occasional rest. Each year soil is idle, a chance is lost to grow more organic matter. Besides, infertile land erodes severely. Therefore, it is safe to say that soils farmed most intensively for high yields are not only today's most profitable, but will be the future's most productive. Soils, like muscles, improve when properly used.

Organic vs. Inorganic Fertilizers

Since there are some nutrients obtained in organic matter, this question arises--why not use organic fertilizers which could serve both purposes? As long as organic fertilizers cost no more than inorganic fertilizers for actual nutrient quantities involved, there are few objections. Barnyard manure presents a disposal problem anyway and spreading it is the only cost of application. It takes at least 10 to 20 tons of manure per acre to supply enough nutrients and manure needs time to decompose to release these nutrients. Commercially available organic fertilizers cost too much if they are applied at such rates. Fuller, et al., in experiments at the Arizona Agricultural Experiment Station, concluded that when organic fertilizers are compared to inorganic fertilizers at equal amounts of actual nutrients, the results are the same. The best inorganic rate in their trials (80+80+0--meaning 80 pounds of nitrogen + 80 pounds of phosphate + 0 pounds of potash) needed about 8,000 pounds (4 tons) per acre of a dry organic fertilizer (1-1-0) to give the same results. Some analyses of commercially available organic fertilizers are slightly higher and would require proportionately less material, but they might need more than a ton per acre.

How a Plant Takes Up Nutrients

How a plant nutrient moves from the soil into a plant cell has been well studied. Water and nutrient absorption are independent of each other, contrary to popular belief; nutrients are not absorbed with water like a blotter absorbs ink. Elements enter the root primarily as ions, a modified form of the element with an electric charge. The cell wall is a barrier for movement of material in or out of a cell. Just how the nutrient moves across this barrier has been difficult to determine. Today it is reasonably well understood. For example, a positively charged ion, such as potassium, can move in a series of steps, probably attached to various enzymes that serve as carriers; a hydrogen ion, also positively charged, moves out simultaneously. The exchange of one positive ion for another maintains the necessary electrical neutrality. Knowledge of ionic transport and the carrier concept has invalidated the-humus theory.

Dr. Emanuel Epstein, plant mineral nutritionist, University of California, Davis, says "the processes of active ion transport, whereby the mineral nutrients are initially secured from the nonliving environment and introduced into the biosphere, are as critical for life as those that bring about photosynthesis." The only difference is "that the leaf is the port of entry for one nutrient (carbon); the root is the interface between plant life and the other mineral sources, the soil."

The failure of some books on plant life to stress mineral absorption has permitted widespread ignorance of this important mechanism. Epstein says that we have witnessed recently an amazing outbreak of a quaint lore about organic gardening and food production that reveals an almost total ignorance among many people of the most basic facts concerning the nutrient elements of plants and their absorption. The neglect of this subject in the current teaching has no doubt contributed to the ready acceptance among some students of thoroughly discredited ideas concerning the nutrition of plants, he concludes.

The lack of information on nutrient uptake has given rise to such myths as organic farming or the production of organically grown foods. For all practical purposes, nutrients enter the plant in one way only, this is in the inorganic form. It makes no difference whether the nutrients come initially from organic or inorganic sources.

The expression organically grown food was formerly a term applied to food from crops that were fertilized through organic materials such as manure, plant residues or animal scraps from butcher shops or packing houses. In more recent times the term appears to have been broadened to refer to the absence of all chemicals such as insecticides and herbicides, as well as food additives.

SOIL ACIDITY AND LIMING

C. J. Overdahl

Nearly everyone knows the chemical formula for water--H_2O. H is the symbol for hydrogen, and is no problem when part of the water molecule, but is the real culprit in causing acid soils when this hydrogen becomes an ion. The hydrogen ion (H^+) is an altered form of hydrogen. Only minute quantities of the water particles (H_2O) actually separate to form such ions. Before a soil is acid, the H ion concentration must outnumber the other part of the separated water molecule, the OH ion. If the OH ion outnumbers the H ion, then the soil is basic or alkaline. Elements carrying positive charges are called cations and negative charged elements are called anions.

Why Soils Become Acid

1. The Effect of High Rainfall

Through the centuries, rainwater moves downward through a soil and the free H ions gradually replace calcium and magnesium ions carried away in drainage waters. The more water moving through the soil profile, the faster the soil becomes acid. That is why soils in areas of high rainfall are more acid than soils in drier regions.

2. The Effect of Coarse Texture

Sandy soils hold fewer calcium and magnesium ions because their low clay and organic matter content offers ions fewer places to hang on. Therefore, sandy soils become acid more rapidly than do fine-textured soils.

3. Crop Removal

Crops, particularly legumes, remove large amounts of calcium and tend to hasten the lime depletion.

4. The Effect of Nitrogen Fertilizers

Any fertilizer containing ammonia such as anhydrous ammonia or ammonium nitrate, or one that forms ammonia, such as urea or organic fertilizers will cause soil pH to be lower. In neutral or acid soil areas, every 100 pounds of nitrogen added would need approximately 200 pounds of lime to maintain the pH at a constant level. In alkaline areas, the effect is small except at very high nitrogen rates.

Measuring Soil Acidity

If we tried to express the small percentage of the water molecules that actually break up into H and OH ions, their concentration in actual numbers would result in very awkward figures for the H ion measurement, such as .0000001 for a neutral soil.

To avoid these cumbersome numbers, we use the so-called pH values. This scale is based on the logarithms of high school mathematics. A few simple examples of hydrogen ion concentrations may be helpful.

.0000001 or $\frac{1}{10,000,000}$ is a neutral soil with pH 7.
.000001 or $\frac{1}{1,000,000}$ equals pH 6.
.00001 or $\frac{1}{100,000}$ equals pH 5.

Note that the hydrogen ion concentration at pH 6 is 10 times larger than at pH 7, and that pH 5 is 100 times larger than pH 7. (Remember when working with fractions that the smaller the number below the line, the larger the fraction.) At pH 4, the hydrogen ion concentration is 1,000 times greater than at pH 7.

You can see that as the pH lowers, the hydrogen ion concentration increases much more rapidly than the simple pH numbers appear to indicate. Actually, as the pH drops 0.3, the acidity of a soil is doubled. Therefore, a soil with pH 5.7 is twice as acid as a soil with pH 6.

How Does Liming Correct Soil Acidity?

Liming simply reverses nature's way of reducing pH.

Minnesota limestones are of the dolomitic type--they are composed of a mixture of calcium and magnesium carbonates ($CaCO_3$ and $MgCO_3$). Applied to the soil, they dissolve slowly in the soil solution where they "come apart"into calcium (Ca^{++}) and magnesium (Mg^{++}) cations and carbonate ($CO_3=$) anions. The calcium and magnesium ions draw off hydrogen ions from the clay and humus particles into the soil solution. Finally, such displaced hydrogen ions may join up with the carbonate anions from limestone to form carbonic acid (H_2CO_3), which ultimately breaks down into carbon dioxide gas (CO_2) and water (H_2O).

Soil Acidity and Its Effect on the Crop

Soil organisms require a pH in a reasonable range above 6.5 to do their most effective work in rotting residues and manufacturing nitrogen in the root nodules. If acid conditions prevent proper nodule development and inadequate amounts of soil nitrogen are available, legume production is reduced and stands eventually become thin. The strain of bacteria not associated with legume nodules, but active in decomposing residues, appears to be slightly more tolerant to acidity than are the nodule bacteria. For this reason, corn alone or other grasses may not need a pH above 6.0.

Under low pH conditions, iron, aluminum, and manganese dissolve in amounts sometimes large enough to be toxic to plants. Also, soil and fertilizer phosphorus may react with the dissolved iron and aluminum to produce phosphorus compounds unavailable to plants.

Soils with pH values considerably above 7 present a different set of problems. Often these soils have an inadequate supply of available iron, zinc, and phosphorus, also excess lime can be the cause of potassium deficiency. High pH conditions are difficult to correct. Sulfur will reduce pH, but costs are prohibitive.

The relationship of pH and bacteria count are approximately as follows:

Soil pH	Bacteria count (millions)
4.4	1.5
5.2	7.8
6.4	12.3
7.0	14.9

Lime Incorporation into the Soil

Research in Wisconsin compared three methods of applying 5 tons per acre of lime to an acid silt loam soil before seeding to alfalfa. Each lime application was worked into the soil by two diskings. At the end of the third hay production year, the pH in 1-inch soil increments was determined to a depth of 6 inches.

1. Lime applied and disked in before plowing corrected soil pH to a 6-inch depth in much the same manner as a split application method (half before plowing and half after). Four years after application, lime applied and disked in only after plowing showed little effect on soil pH at depth below 3 inches.

2. Taken over a 3-year period, lime applied and disked in after plowing resulted in production of one-fourth ton per acre less hay per year than where all the lime was applied before plowing. There was no difference in yield between the split application and applying all the lime before plowing.

We have frequently used indicator solutions to examine pH levels of Minnesota soils in alfalfa fields that have been recently limed. In far too many cases, poor stands and inferior growth are associated with inadequate vertical distribution of lime in the soil profile. In many instances, adequate pH levels have been restricted to the top inch or in a narrow zone at the plow depth. Then it is apparent that the farmer is not accomplishing proper mixing of lime with the soil. Both farmer, lime vendor, and fertilizer dealer will lose when a poor liming job stands in the way of successful alfalfa production.

Time of Application

It takes time for lime particles to dissolve and establish a limed zone favorable to young legumes. The least desirable time to apply lime is after the crop is seeded or after a stand is established. Benefits from such liming will not be realized until further tillage is done and a new legume crop is established.

Applications just prior to spring seeding, even though properly incorporated, are often less satisfactory than if applied 6 to 18 months prior to a legume seeding. Farmers should test their soil and plan ahead so that lime is applied the fall before seeding, or even prior to the preceding crop.

On sandy loams or loamy sands, we have observed a very slow reaction between the lime and the soil unless it is irrigated. At the Elk River Experimental Field in spring 1968, the pH was 5.4. Eight tons of lime per acre were applied at that time.

Half of the alfalfa plots were irrigated intensively, the other half received no added water. There was also a no-lime area that was irrigated. After 3½ years, the results were as follows:

Lime applied April 1968	Soil pH 1968 April	 1969 Sept.	 1970 Sept.	 1971 Oct.
None	5.4	5.2	5.5	5.4
8 tons/A (irrigated)	-	6.2	6.8	6.9
8 tons/A (unirrigated)	-	5.4	6.0	6.5

Particle size	93% passing 8 mesh sieve
	24% " 60 " "
Lime purity	92% calcium carbonate equivalent

After 2½ years, the pH of 6.0 on the unirrigated area was still too acid for favorable alfalfa production. Too often after 2½ years farmers have given up and accept the idea that alfalfa won't grow on their soils. Where sandy soils are often dry, perhaps lime should be applied 2 or 3 years before alfalfa seeding is planned.

Limestone Quality

Limestone quality is determined by purity and particle size.

In Minnesota, as in most states, purity is measured in terms of calcium carbonate equivalent (C.C.E.), the amount of limestone needed to equal one unit of pure calcium carbonate in neutralizing power. ASCS regulations specify 80 percent C.C.E. as the minimum acceptable purity. The hard dolomitic stones of southern Minnesota are uniformly high in purity, averaging nearly 90 percent.

Minnesota's ASCS regulations specify that limestone shall be ground finely enough to enable not less than 80 percent by weight to pass through an 8-mesh sieve. In addition, the purity (C.C.E.) multiplied by particle size (the percent by weight passing through an 8-mesh sieve) must equal at least 0.72. This means that either purity or fineness or both must be sufficiently higher than 80 percent to enable their product to be at least 0.72.

The question of whether sieve sizes finer than 8-mesh might better describe limestone effectiveness has been thoroughly investigated. Barber at Purdue University has summarized the results of 18 widely distributed experiments in which amounts of limestone going through single sieves of differing sizes and/or differing size fractions were compared. In 16 of the 18 experiments, larger yield increases were obtained for the finer lime mesh sizes. In general, limestones of which less than 25 percent would pass through a 60-mesh sieve were less effective than those ground so finely that all passed through 100-mesh sieves. Minnesota limestones show considerable variations in this regard, the average was 35 percent passing through a 60-mesh sieve.

Using data from several long-term experiments, Barber determined the amounts of limestone of several ranges in fineness needed to give equivalent yield increases in the following findings:

Effect of Limestone Fineness on the Amounts for Equivalent Results

Percent passing a 60-mesh sieve	Equivalent amounts of limestone, tons per acre
41-100	1.00
31-40	1.25
21-30	1.50
10-20	2.00

Minnesota limestone purity is excellent. Fineness of grinding could be improved on. Changes in minimum specifications regarding the percentage passing a 60-mesh sieve is desirable.

The SMP Buffer Test*

Since 1968, a buffer test called "SMP buffer" has been used to better determine lime needs in Minnesota.

1. What the SMP buffer test is and what it does:

The SMP buffer test for lime was developed by 3 soil scientists (Shoemaker, McLean, and Pratt, hence the name) from Ohio State University. This test (currently being used quite widely in the Midwest) allows us to determine total soil acidity and more accurately predict lime needs. With only the soil-water pH, (this is the pH value we are all familiar with as the soil pH) we could only estimate the acidity on the organic matter and clay exchange sites. Two soils with exactly the same soil-water pH might vary quite widely in the amount of lime needed to raise the pH to 6.5 or 6.9, depending on the amount of organic matter and clay content of each of the soils. The soil with the higher organic matter and/or clay content would require more lime due to the higher reserve acidity.

The pH of the SMP buffer solution itself is 7.5. When the SMP is added to a soil, the original pH of the SMP buffer will go down. Since we know how much acid is required to lower the SMP buffer to any given pH level, we can determine the total acidity of the soil. For example, a soil with a soil-water pH of 5.4 might bring the SMP buffer pH index from 7.5 to 6.3. Table 1 shows it would take 5.5 tons of lime to raise the soil-water pH from 5.4 to 6.5.

There is a tendency to mistake the buffer index for soil pH. Even though the buffer index is a pH, it is not the soil pH. We call it buffer index to show that there is a difference. The buffer index is used only to determine lime needs and is in no other way connected with soil water pH.

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* From Soils Fact Sheet No. 10 "Lime Needs in Minnesota," W. E. Fenster, C. J. Overdahl, and J. Grava.

2. SMP buffer is not used above pH 5.9.

   If the soil-water pH (soil pH) is 6.0 or higher, the SMP buffer is not run. The relative error of the SMP buffer is too high in this soil pH range. Table 1 also gives lime recommendations where the SMP buffer does not apply.

3. Soil-water pH and its relationship to the SMP buffer.

   To become better acquainted with the soil-water pH and its relationship to the SMP buffer, table 2 illustrates some typical soil pH values, the SMP buffer index, and the lime recommendations.

Table 1 contains lime recommendations for all Minnesota soils and is a convenient reference when interpreting lime requirements from pH tests.

Recommendations

1. Lime recommendations for corn and soybeans.

   If alfalfa is not in the cropping system, pH levels of 6.0 or above are adequate without liming. If the soil pH is below 6.0, then apply lime at the rates needed to reach a soil pH of 6.5.

2. Limy subsoils call for less lime in western Minnesota.

   In western Minnesota, no lime recommendations will be made for soil-water pH values of 6.1 and higher. Where lime is recommended in this area, the tonnage will be one-half that recommended for eastern Minnesota. In extreme southwestern Minnesota, the Moody-Kranzburg-Vienna soil association has an acid plow layer. Frequently, these soils have adequate lime in the subsoil, and lime is recommended only if soil phosphorus and potassium test levels are medium or high and there is difficulty in establishing stands of alfalfa.

Table 1

LIME RECOMMENDATIONS

	Lime required (tons/acre)(1)			
Where SMP buffer applies (soil-water pH values below 6.0)	To raise soil-water pH to 6.5		To raise soil-water pH to 6.9	
SMP buffer index	Area 1	2	Area 1	2
6.8	3.0	2	5.0	NR(2)
6.7	3.0	2	5.0	NR
6.6	4.0	2	6.0	NR
6.5	4.5	2	6.5	NR
6.4	5.0	2.5	7.0	NR
6.3	5.5	2.5	7.5	NR
6.2	6.0	3.0	8.0	NR
6.1	6.5	3.0	8.5	NR
6.0	7.0	3.5	9.0	NR
5.9	7.5	3.5	9.5	NR
5.8	8.0	4.0	10.0	NR
5.7	8.5	4.0	10.5	NR
5.6	9.0	4.5	11.0	NR
Where SMP buffer does not apply (soil-water pH values of 6.0 and higher)				
Mineral soils				
Soil-water pH				
6.5	0(3)	0	2(3)	NR
6.4	0	0	2	NR
6.3	3	0	5	NR
6.2	3	0	5	NR
6.1	4	0	6	NR
6.0	4	2	6	NR
Organic soils (peats and mucks) (4)				
Soil-water pH				
5.4	2	2	2	2
5.3	2	2	2	2
5.2	2	2	2	2
5.1	2	2	2	2
5.0	2	2	2	2
4.9	3	3	3	3
4.8	3	3	3	3
4.7	4	4	4	4
4.6	4	4	4	4
4.5 and lower	5	5	5	5

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(1) 6-inch plow depth

(2) NR = Not Recommended

(3) These lime rates at water pH 6.0 or above need not be applied where alfalfa is not grown in the cropping system.

(4) Only limed to pH 5.5

Table 2. Example lime recommendations

	Soil Texture	Organic Matter Level	Soil pH (soil-water)	SMP Buffer Index	Lime Recommendations (tons/acre) 6 inch plow depth To attain a pH of:	
					6.5	6.9
Eastern Minn.						
Winona	Sil	L	6.0	ND(2)	4	6
Rice	Sicl	M	5.7	6.0	7	9
Dakota	L	M	5.5	6.0	7	9
Wabasha	Sil	M	5.4	6.2	6	8
Aitkin	Ls	L	5.3	6.2	6	8
Chisago	Sl	L	5.0	6.0	7	9
Western Minn.						
Brown	Cl	H	6.1	ND	NR(3)	NR
Pipestone(5)	Sil	M	5.8	6.5	2	NR
Redwood	Cl	H	5.9	6.4	2.5	NR
Organic Soils						
Anoka	P	VH	5.6	ND	NR	NR
Anoka	P	VH	5.1	ND	2(4)	NR
Isanti	P	VH	4.5	ND	5(4)	NR

(1) These recommendations reached by multiplying 6-inch plow depth recommendation by 1.5.
(2) ND = Not Determined.
(3) NR = Not Recommended.
(4) To reach pH of 5.5.
(5) Lime for loess soils of southwestern Minnesota is recommended only where there is difficulty in establishing stands of alfalfa and phosphorus and potassium levels are medium or high.

Plowing Depth

The basic calcium carbonate recommendation is designed to neutralize the acidity in a 6-inch plow layer of soil. If the plowing depth is other than 6 inches, the recommendation should be adjusted by multiplying the amount recommended by the appropriate multiplying factor in the table:

Plowing depth (inches)	Multiplying factor
4	0.67
5	0.83
6	1.00
7	1.17
8	1.33
9	1.50
10	1.67
11	1.83
12	2.00

Adjusting for Previous Lime Applications

Previous limestone applications may affect the amount of limestone now required. This will depend on uniformity of spreading, how well it was worked into the soil, and the year of application. If good practices have been used previously, the following allowances may be made:

1. Within 6 months after application, deduct the full amount previously applied from the recommended rate. (If 4 tons are recommended and 2 tons were applied 4 months ago, 2 tons should be applied.)

2. One year after application, deduct one-half of the amount previously applied from the recommended rate.

3. Two years after application, deduct one-fourth of the limestone previously applied from the recommended rate.

4. More than 2 years after application, use the recommended rate.

Subsoil Acidity

When liming experiments with alfalfa are conducted on soils that have a pH below 6, a lime response is not always obtained. Even if the pH at the top 6 inches were exactly the same, an experiment at one site could show entirely different results from another. The difference is due to the depth to lime in the subsoil. In Pipestone, Rock, and Redwood counties in southwestern Minnesota, lime responses have seldom been obtained because the pH at 2½ to 3 feet is at or above 6.5. Because of high subsoil pH, lime recommendations in western Minnesota soils are reduced to ½ of what they are in eastern Minnesota. Farmers who have difficulty establishing stands in this area should first be sure phosphorus is adequate before investing in lime. It would be desirable to test the soil at 30 inches in field areas where alfalfa stands are hard to establish or maintain. If the pH is above 6.5, it is doubtful whether a lime shortage is the problem.

Dramatic responses from lime are usually observed where the subsoil to 3 feet is very acid.

Soils with Too High pH

Often soils with very high pH are called alkali. In Minnesota, this term is commonly misused since few soils are actually alkali. Such a soil is basically a sodium soil with pH values between 8.5 and 10.0. An alkaline soil more properly describes some Minnesota conditions. These are soils with pH above 7.0 which may or may not have excessive amounts of harmful salts.

Alkaline soils with pH below 8.3 can usually be profitably farmed, but generally need additions of phosphorus, potassium, and zinc. See "Phosphorus in Soils and Plants," "Potassium in Soils and Its Availability to Plants," and "Background for Micronutrient Needs" discussed elsewhere in this publication.

Efforts to reduce pH on alkaline soils in Minnesota have not been very successful. Fenster and Gunderson, University of Minnesota, made applications up to 1 ton per acre of actual sulfur, but reduction in pH was only temporary. After approximately one year, the pH returned to its original level. There was no effect on crop yield at any time. On a soil with 8.2 pH, not even the temporary effect was observed.

Nitrogen fertilizers, both organic and inorganic, will reduce pH if a soil is neutral or acid, but if the pH is above 7.5, it takes rates too high to be practical before an effect on pH can be noted.

In brief, nutrients likely to be deficient because of high pH are:

phosphorus--because high pH results in large quantities to be in the unavailable di and tri calcium phosphate form.

potassium --because high pH involves excesses of calcium and magnesium that compete too favorably with potassium for entrance into the root.

iron --high pH causes internal balance problems of some crops, particularly flax and soybeans, as well as absorption limitations unless in the form of chelated iron.

copper --prefers pH 6.2 to 6.4.

zinc --uptake is a problem on high pH soils and aggravated by high phosphorus.

Correcting pH problems on alkaline soils is difficult. Most practical attempts should be by variety selection within some plant species, but where problems are severe, susceptible crops should be avoided.

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PREDICTING NITROGEN NEEDS

W. E. Fenster and C. J. Overdahl

Nitrogen is the plant nutrient most universally needed to meet the requirements for high crop yields. Soil differences and variable weather, however, make predicting the need most difficult. Understanding the related factors of soil, plant, fertilizer, and weather can decrease the errors that prevent accurate nitrogen fertilizer recommendations.

Plants with deep-green color and rapid growth usually have an adequate supply of nitrogen. Nitrogen is a constituent of all living cells and is a necessary part of all plant auxins (hormones) and the chlorophyll molecule.

The chief problem with nitrogen fertilization is understanding the need and predicting application rates accurately.

The nitrogen-supplying capacity of Minnesota soils is estimated in several ways. Here, in brief, are the factors to consider when deciding whether and how much nitrogen fertilizer to recommend:

1. Soil Test Information:

   a. Soil organic matter content
   b. Soil texture
   c. Soil Nitrate-Nitrogen test (for western Minnesota only)

2. Effect of Past Crops and Management Practices:

   a. Effect of summer fallow
   b. Effect of legume plowdown
   c. Effect of carryover nitrogen
   d. Nitrogen in manure
   e. Nitrogen-depleting power of preceding crop
   f. Time of plowing
   g. Time of planting

3. Nitrogen Needs of the Crop to be Grown

4. Stored Soil Moisture

5. Form of Nitrogen

Nitrogen Release from Organic Matter and Relationship to Texture

The rate of nitrogen release from organic matter depends largely upon factors that affect micro-organism activity. The rate of decomposition depends upon soil moisture, temperature, aeration, pH, and soil texture. Fine-textured soils often warm up so slowly in the spring that early sown crops such as small grains respond readily to nitrogen fertilization. Poor drainage resulting in an improper balance between soil water and soil air means nitrogen-deficient plants at any time of the year that moisture is overabundant.

An acre of soil 6 inches deep contains about 1,000 pounds of total nitrogen for each percent of organic matter. Soils will release perhaps 1 to 5 percent of their total nitrogen in a year, varying from coarse to fine-textured soils and on the same soil from year to year. Sandy textured soils are usually very low in organic matter but are so well aerated that nitrogen release is rapid compared to heavy, fine-textured soils. Approximate relationships have been established under conditions of no legumes and no manure applied the preceding year and are as follows:

Soil texture	Nitrogen released per each 1 percent of organic matter
Loamy sands and sandy loams	40 to 60 lb. N per acre
Loams and silt loams	15 to 30 lb. N per acre
Silty clay loams, clay loams	10 to 20 lb. N per acre

Depending on soil and weather conditions, a loamy sand with 1 percent organic matter, for example, would release 40 to 60 pounds per acre of nitrogen; by contrast, a clay loam with 7 percent organic matter would release 70 to 140 pounds per acre per year. Some of this might be released too late in the season, however, to help the immediate crop. When soybeans are grown on a fine-textured soil the plant may manufacture barely enough nitrogen to supply its own needs, but decomposition of soil organic matter will proceed normally so as to release nitrogen for the following crop. One might conclude from appearances of the succeeding crop that soybeans contributed large amounts of nitrogen through their root nodules, when in reality it was the usual release from soil organic matter which occurred at about the same rate as if fallowed.

On fine-textured soils, the extremes from 70 pounds in some years up to 140 pounds in others makes predicting nitrogen needs difficult. During years of low release, 200 pounds per acre of nitrogen may be necessary for most efficient corn production where moisture is not limiting; at the other extreme, just the amount of nitrogen in starter fertilizer could be sufficient.

Under ideal conditions, high organic matter soils can produce large amounts of nitrates. During the fall of 1970, a virgin plot of land in Martin County was plowed for corn production in 1971 and profile samples of this soil were taken to determine nitrate-nitrogen. An analysis of the top 1 foot of this soil taken right after sampling showed only about 25 pounds of nitrate-nitrogen, however, after 1 month's storage in the greenhouse, this same soil contained over 300 pounds of nitrate-nitrogen per acre, thus indicating the tremendous potential for some soils to produce nitrates when the conditions are favorable. It must be remembered, however, that the soil's ability to produce nitrates is dependent upon the weather conditions and the soil itself. In 1971, no significant corn yield increases from applied nitrogen were realized on this virgin soil.* In a field immediately

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* at 5 percent level of significance

adjacent to the virgin plots, corn had been grown for many years and a chemical analysis of this soil for organic matter content was 4½ percent, about 2 percent less than the virgin soil. Past experiences would indicate that the organic matter content of this soil type stabilizes at about this level. This is a common occurrence in tilled soils, and contrary to the beliefs of some, the organic matter content of soils will not continue to decline indefinitely. Conversely, it is unrealistic to expect soils to maintain the organic matter contents they had in the virgin state. Both the virgin soil and the soil under continuous corn were classified as Webster silty clay loams.

On sandy soils or even fine-textured soils, originally forested, organic matter is generally low. Response to nitrogen fertilization of nonleguminous crops following a nonlegume usually requires regular applications of nitrogen, either as manure or fertilizer, for best yields. The main exception in these soils is when rainfall is inadequate, then 50-75 pounds of nitrogen appears to be a practical rate for corn.

Research shows that where precipitation is predictable and perhaps somewhat limiting, a soil nitrate-nitrogen test may be used to predict nitrogen needs quite accurately for small grains and sugarbeets. This test is now available for producers in western Minnesota.

Effect of Past Crops and Management Practices

Summer Fallow

The result of summer fallow is shown in the preceding paragraphs, since it is related to nitrogen release from organic matter. A tilled soil generally releases nitrogen at a slightly faster rate. The feasibility of fallowing soils to gain more nitrogen for following crops is no longer being promoted. Nitrogen fertilizers can be applied much more cheaply and economically. In some western areas, however, fallowing is still being practiced in order to gain more soil moisture for following crops.

Effect of Legume Plowdown

Legumes fix nitrogen in their roots and provide nitrogen for crops to follow. It has been estimated that an excellent stand of alfalfa hay will contain 50 to 60 pounds of nitrogen per ton. A 3½-ton-per-acre yield of alfalfa contains 175 to 200 pounds of nitrogen in the aboveground portion of the plant. This is about two-thirds of the total in tops and roots. If one-third of the total nitrogen is in the roots and stubble, 85 to 100 pounds of nitrogen would be available for succeeding crops once the residue is decomposed. The figures for sweet clover are similar. Additional nitrogen will be released from other organic sources, plus, of course, the nitrogen contained in the regrowth of alfalfa after its last cutting.

Under desirable weather conditions, nitrogen fertilizer is needed in lesser amounts. The current nitrogen recommendations for corn following good alfalfa or clover are as follows:

Yield goal (bu/A)	Organic matter content	Fertilizer N to apply (lbs/A)
130-160	Low - medium	100
	High	70
100-130	Low - medium	50
	High	20
Less than 100	All levels	15

Adverse weather conditions, however, such as cold temperatures or very wet soils may cause severe nitrogen deficiency on crops that follow even good stands of alfalfa or sweet clover. Apparently under these conditions the decomposition of the organic forms of nitrogen to the form available to the plant is too slow to satisfy the crop needs. Additional nitrogen fertilizer must be added to overcome this.

Carryover Nitrogen

Carryover nitrogen varies with crop sequence, soil texture, preceding nitrogen rates and yields, amount of erosion, and amount of rainfall.

At the West Central Experiment Station, Morris, where moisture is normally limiting, corn 2 years after alfalfa did not respond to nitrogen, but nitrogen on continuous corn in the same experiment resulted in a 25- to 30-bushel average yield increase over 10 years. Deep borings at the Morris Experiment Station showed large nitrate buildups in the subsoil, whereas in Waseca, where there is usually adequate moisture, there appears to be no nitrate buildup below the rooting zone for corn, even when 200 pounds per acre of nitrogen are applied. Therefore, in addition to varying soil temperatures from year to year, which affects the rate of nitrogen release, the rate of downward movement is also affected by rainfall rates. In areas where rainfall is not limiting, there is more nitrogen removed by the crop than in areas where rainfall is limiting.

Carryover from nitrogen fertilizer on coarse-textured soils such as sandy loams and loamy sands is practically nil.

Carryover on a medium- and fine-textured soil may be about 20 percent from a 60-pound treatment, but will vary with yield and rainfall. This percentage will be higher for rates above 60 pounds and less at lower rates. Following a very dry year and near crop failure, carryover will be about double the normal amount.

Nitrogen in Manure

Decomposition of manure must occur before nitrogen and phosphorus are released, but rotting is not necessary for the release of potassium. The average nitrogen content of cattle manure is about 10 pounds per ton. From 30 to 60 percent of this nitrogen is available the first year after incorporation into the soil. Manure from cattle sheds and around feed bunks will release perhaps 60 percent of its nitrogen, while 30 or 40 percent is a close estimate of nitrogen released from manures containing undecomposed bedding. Manure with excessive amounts of bedding can actually cause nitrogen deficiencies on the immediate nonleguminous crop planted.

Nitrogen Depleting Power of Preceding Crop

All nonleguminous crops are nitrogen depleting. These crops are sometimes referred to as soil depleting, but it would be far more accurate to say nitrogen depleting rather than soil depleting. Legumes are nitrogen building, alfalfa and clover being by far the best suppliers of nitrogen.

Time of Plowing

Early plowing starts organic matter decomposition earlier which, in turn, releases increased amounts of nitrogen for the following crop.

Data from the North Dakota Experiment Station indicates what happens to wheat yields as a result of time of plowing the preceding year.

Date plowed	Check plot yield
August 5	43
September 15	42
October 24	35

Early plowing could reduce nitrogen application rates 25 percent. Early plowing can also have an effect on protein content of malting barley. Later plowing may be one means of reducing protein content where too much protein is the problem.

Time of Planting

The later crops are planted in the spring, the less need for nitrogen. Late planting is not the solution to nitrogen problems, however, since late planting in itself usually means lower yields. Late planting of malting barley generally results in too much protein in the barley.

Nitrogen Needs of Crop to be Grown

Grasses, including corn, have a great need for nitrogen, and if a grass crop doesn't follow a legume crop, or fallow, or have heavy applications of manure, nitrogen fertilizer will be needed.

Small grains usually need additional nitrogen. The low price of some crops will reduce the amounts that can be applied in order to obtain a profitable return.

Legumes sometimes need nitrogen, particularly in early growth before nodules are developed. Large responses of legumes to nitrogen would indicate that some management aspect has been omitted. For example: acid soils may prevent the root nodules from performing properly. Failure to inoculate or use of the wrong inoculating bacteria may be a factor. Molybdenum deficiencies will sometimes affect nitrogen manufacture in legumes, but this is rare in Minnesota.

Stored Soil Moisture

In areas of limited rainfall, moisture in the soil at planting time is an important consideration. In general, the less rainfall, the less nitrogen need be applied.

What Form to Use

The nitrogen fertilizer that costs the least per pound of actual nitrogen after it has been properly applied in the field gives the most profitable results. Although anhydrous ammonia is the least expensive form to buy, it often costs more to apply than the solution and dry forms, both of which carry a higher initial cost. In general higher rates make ammonia unquestionably cheaper.

Much research effort has been directed toward comparing the effectiveness of different forms of fertilizer nitrogen. The results have been such that soils specialists generally agree that one form does the job as well as another, when both are properly applied at equal rates of actual nitrogen.

Possible Nitrogen Losses

Fertilizer nitrogen even though properly applied can be lost through runoff on slopes and through leaching on coarse-textured soils. A third source of loss is denitrification, which results in gaseous escape of fertilizer nitrogen to the atmosphere. Denitrification occurs on heavy textured soils that are waterlogged. If the soils have warmed up and excessive rains occur, denitrifying bacteria will convert the nitrate-nitrogen to nitrogen gas, which is then lost back to the atmosphere.

On level-lying, fine-textured soils, losses through runoff and leaching are probably very uncommon in western Minnesota. Because saturated soil conditions and warm soil temperatures are both necessary to get loss from denitrification, losses of this sort probably don't happen very often in western Minnesota. On fine-textured (heavy) soils in south-central Minnesota, losses to the atmosphere during warm weather can be a serious problem. Near the Waseca Experiment Station in 1971, rather severe nitrogen deficient symptoms were noted, even where 200 pounds per acre of nitrogen had been applied. Nitrates in the soil profile and those taken up by the crop did not account for the nitrogen loss, therefore, it was deduced that denitrification had to be responsible for this nitrogen loss.

Topdressed nitrogen fertilizers can also be lost. Under certain conditions, ammonia gas (NH_3) may be lost to the atmosphere. Research in Florida, Kentucky, and Pennsylvania has shown that such ammonia volatilization can occur when urea is topdressed on the soil. The most important factors in this loss process are high temperatures and high soil pH.

Urea breaks down rapidly in the soil to form ammonium carbonate, an alkaline substance. As such, it tends to raise the pH of the soil in the immediate vicinity of the urea particle. If the soil pH is already quite high, it may be further raised in this manner to the point where the ammonium ion breaks down into ammonia gas which, if near the soil surface, may escape to the air.

Although the research is not detailed enough to allow precise predictions of loss under stated conditions, certain guidelines can be followed to reduce the chance of loss.

1. Unless the soil temperature is below 60° F., urea probably should not be applied or left on the soil surface if the pH of the field is 6.5 or above.

2. Losses from urea solutions have been about the same as those from solid urea.

3. Losses do not usually occur until the 2nd to 5th day following surface application. This suggests that there would be little danger in broadcasting urea when it is to be plowed down in a day or two.

Urea has repeatedly shown itself to be as effective as any other nitrogen carrier when plowed down or otherwise incorporated with the soil.

When to Apply Nitrogen

The importance of losses vs. time has been pointed out in the preceding paragraphs. However, other factors may also be considered in selecting an application date. Since small grains make most of their vegetative growth early when soils are likely to be cold, these crops benefit most from nitrogen applied before seedbed preparation or at seeding (30 to 40 pounds per acre of actual nitrogen can be applied in the row with the seed on moist soils to wheat, barley, and oats without stand injury). Flax, on the other hand, is very sensitive to damage by nitrogen salts placed with the seed, making broadcast application before seeding necessary.

Although corn is planted somewhat later than the small grain and has its greatest need for nitrogen after the soil has warmed up, the most common practice today is to apply the nitrogen prior to planting. This would include fall plowdown and spring preplant. On the medium- and fine-textured soils, however, it is also important that a small amount of nitrogen (10-15 pounds per acre) be applied with the starter, since it is characteristic of Minnesota soils to be cold and wet in the spring. On sandy textured soils, which are susceptible to leaching, fall applied nitrogen is not recommended. If the sandy soils are irrigated, the best way to apply the nitrogen is by small increments throughout the growing season through the irrigation system. If the soil is not irrigated, the nitrogen should be applied as close to planting as possible or even a sidedress application after mid-June may be preferable. There are some problems with sidedressing now, however, since many farmers are going to 30-inch row spacings. This, of course, could cause considerable damage through root pruning.

Money can also be a factor. If the farmer had a good year, he may want next summer's nitrogen requirement applied in the fall so he can deduct the expenditure from that season's income for tax purposes. Or, he may have to borrow for his fertilizer needs, so he'll probably want to save interest money by deferring application until spring. Then, too, fall discounts may wipe out such an advantage. Fall application of nitrogen also helps to spread the work loads for both the farmer and fertilizer dealer.

NITRATE POLLUTION OF SURFACE AND GROUND WATERS AND ITS RELATIONSHIP TO FERTILIZER NITROGEN

W. E. Fenster

Within the past four or five years, the public has become increasingly aware and concerned about pollution and environmental quality. An awareness that nitrates may be entering the surface and ground waters is of public concern since there is a possibility of health hazards to humans and animals. Also of major concern is the fact that nitrates and other nitrogen compounds entering our lakes and streams may promote excessive weed growth and algae blooms, thus causing surface waters to deteriorate at an accelerated rate.

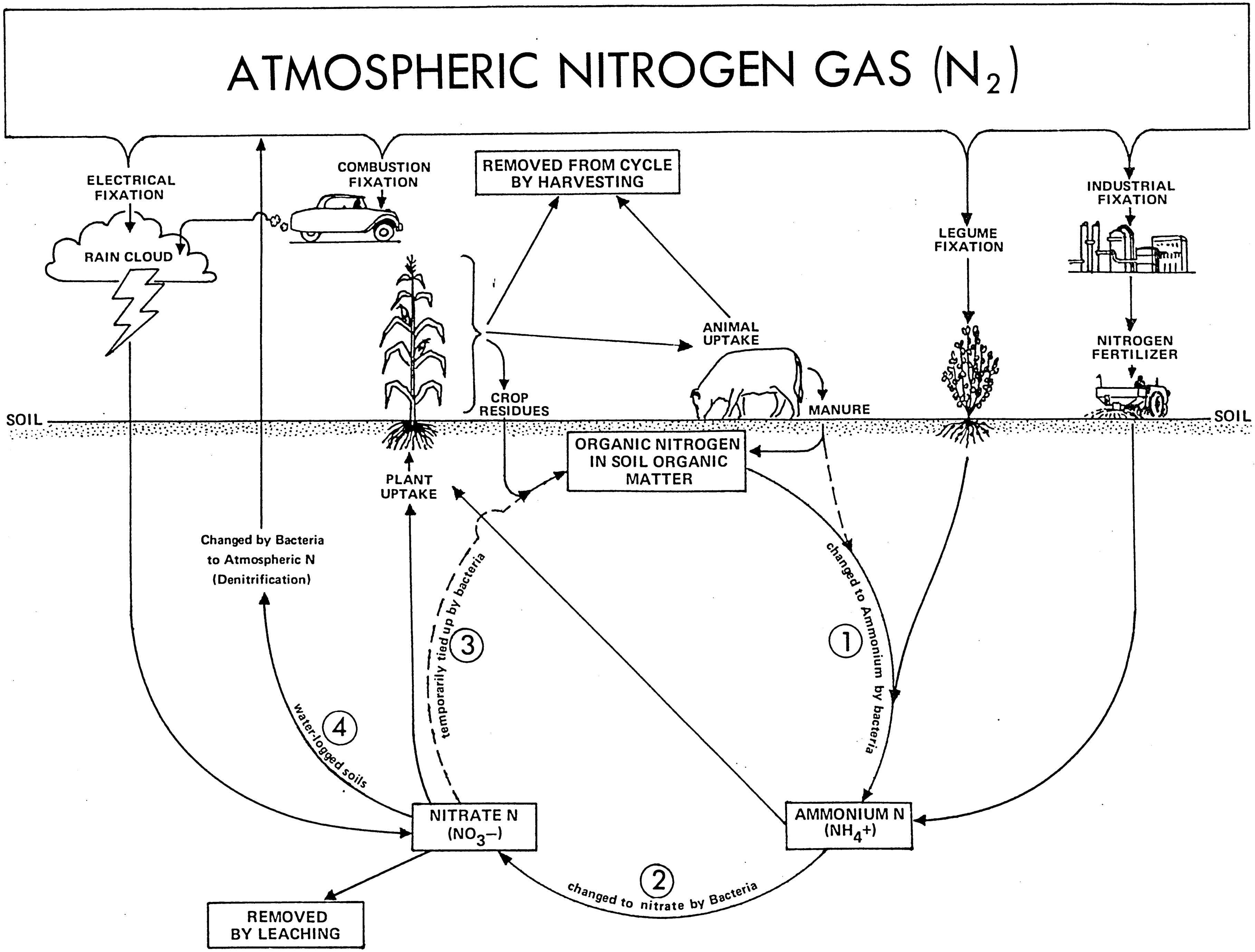
Many people are "quick to point the finger" at agriculture and place the chief blame for nitrogen water pollution on the backs of the fertilizer industry. It must be remembered, however, that many other contributors are also responsible and until this is fully realized, and steps are taken to control these, the nitrogen pollution of our surface and ground waters will continue. Some of these nitrogen contributors include: municipal, industrial, and domestic waste treatment facilities, soil organic matter, manures, leguminous crops, crop residues, urban development areas, and precipitation. In some instances, geologic deposits containing nitrates may also be contributing to ground water nitrates.

In this section, we will only try to determine the effects of nitrogen fertilizers and their wise use on possible contamination of our surface and ground waters. Before doing this, however, it is important to understand nitrogen itself and how it acts and reacts in the soil. This can best be accomplished by studying the nitrogen cycle (figure 1) which follows. Generally, at least 95 percent of the total nitrogen in soils is in the organic form which is unavailable to plants. From the nitrogen cycle (figure 1), note that regardless of the nitrogen form when it enters the soil, eventually most of it will end up in the nitrate form. Once the nitrogen is in the nitrate form, it is available to crops, and also susceptible to leaching and denitrification. It must also be remembered that all forms of nitrogen are a potential pollution hazard when erosion is a problem. Good conservation practices are, therefore, extremely important when considering pollution control mechanisms.

Nitrate Movement in the Soil Profile and Its Relationship to Fertilizer Nitrogen

Since nitrates are highly soluble in water, it is logical to assume that wherever the water moves in the soil any nitrates in that water will also move. Water entering the soil will eventually be evaporated, transpired, move along on top of impermeable layers or percolate down to the water table. The amount of nitrate leaching will, therefore, be directly related to evapotranspiration, soil physical conditions, precipitation distribution and intensity, and the amount of nitrates present. Also, the incorporation of crop residues would tend to retard nitrate production and movement due to microbial tieup of the nitrogen.

In Wisconsin, the annual application of 300 pounds per acre of nitrogen as ammonium nitrate to a silt loam soil planted to corn resulted in the accumulation of


ATMOSPHERIC NITROGEN GAS (N_2)
ELECTRICAL FIXATION
RAIN CLOUD
COMBUSTION FIXATION
REMOVED FROM CYCLE BY HARVESTING
INDUSTRIAL FIXATION
LEGUME FIXATION
ANIMAL UPTAKE
NITROGEN FERTILIZER
CROP RESIDUES
MANURE
SOIL
SOIL
ORGANIC NITROGEN IN SOIL ORGANIC MATTER
PLANT UPTAKE
Changed by Bacteria to Atmospheric N (Denitrification)
temporarily tied up by bacteria
③
changed to Ammonium by bacteria
①
water-logged soils
④
NITRATE N (NO_3-)
AMMONIUM N (NH_4+)
changed to nitrate by Bacteria
②
REMOVED BY LEACHING

excessive amounts of nitrates in the subsoil. When 100 pounds per acre of nitrogen was applied, little or no accumulation of nitrate resulted. The rate of downward movement of the nitrates, where excessive rates were applied, was about 16 inches annually. The Wisconsin scientists concluded that pollution of the ground water from fertilizer-applied nitrogen can be effectively controlled by limiting the nitrogen fertilizer application to needs of the crop. The Illinois Pollution Control Board concluded that within a given set of supporting cultural practices, the greater the amount of nitrogen applied the greater the potential for loss to ground and surface water. Farmers, however, who produce the highest yields and apply the highest rate of nitrogen may produce a unit of crop with less potentially leachable nitrate than farmers who produce average yields. It was further shown that recent increases in nitrogen consumption in Illinois, and for the entire cornbelt, are due to higher application rates on previously underfertilized fields. The proportion of fields that received more than 150 pounds per acre has actually decreased in recent years.

In Minnesota, a nitrogen rate study on continuous corn began in 1970 in Waseca County and on a virgin soil planted to corn in 1971 in Martin County. The object of these studies was to determine the rates of nitrogen which would give the farmer the highest yield with a minimum of nitrates moving beyond the rooting zone for corn on fine-textured soils. Rates of nitrogen applied varied from 0 to 400 pounds per acre and the soils were sampled to a depth of 6 feet in Martin County and 5 feet in Waseca County. The 1971 corn yields in Waseca County varied from 43 bushels per acre with zero nitrogen to 151 bushels per acre with 400 pounds per acre of nitrogen. In Martin County on the virgin sod, the corn yields varied from 179 bushels per acre with zero nitrogen to 194 bushels per acre with 200 pounds per acre of nitrogen. The highest economical yield was with 50 pounds per acre of nitrogen where an average yield of 190 bushels per acre was harvested. It is expected that, with time, after the readily decomposible organic matter is used up, higher rates of nitrogen will be needed for highest corn yields on this virgin soil.

In Waseca County, after 2 years of applying the nitrogen, there is no accumulation of nitrates anywhere in the soil profile until 400 pounds per acre of nitrogen were applied. When an excess of nitrogen was applied (400 pounds per acre) it appeared throughout the 5 foot profile (table 1). In Martin County, the nitrate readings on the virgin sod were very low in fall 1970 right after the field was plowed. However, even after removing 179 bushels per acre of corn in 1971, on the zero nitrogen plots the nitrates were almost three times as high, thus demonstrating the tremendous nitrate producing capacity of this soil. The fertilizer nitrogen applied remained in the top 2 feet of soil after the first year (table 2).

Table 1. NO_3-N in soil profile--continuous corn--Waseca County

Soil depth (ft.)	ppm NO_3-N (sampled in fall of 1971) Treatment--lbs. N/A applied--1971 0	50	100	150	200	400
0-1	4	4	6	6	5	17
1-2	2	2	3	4	3	12
2-3	3	3	3	3	3	27
3-4	2	2	2	3	3	17
4-5	3	2	3	4	4	10

Soil classified as a Webster silt clay loam

Table 2. NO_3-N in soil profile--virgin soil--Martin County

Soil depth (ft.)	Virgin soil fall 1970	ppm NO_3-N (sampled in fall of 1971) Treatment--lbs. N/A applied--1971 0	50	100	150	200	400
0-1	6	17	19	24	15	31	40
1-2	4	10	23	32	29	47	32
2-3	5	7	9	8	14	14	11
3-4	3	3	5	4	5	4	5
4-5	3	3	3	4	5	6	3
5-6	3	4	3	4	4	6	4

Soil classified as a Webster silty clay loam

In western Minnesota, where the rainfall is usually the most limiting factor in corn production, the nitrates will tend to accumulate near the surface. This results primarily from evaporation during droughty periods. If excessive rains occur following these droughty periods, the accumulated nitrates may be leached beyond the rooting zones of the crops and there appear to be higher accumulations of deep nitrates where moisture is limiting. Because of the limiting moisture factor in western Minnesota, the nitrogen recommendations are considerably lower. This is due to lower yield potentials.

Some investigators have tried to measure nitrates in tile line discharges and correlate them with fertilizer applications. Some good general data have been collected, however, for these data to be very meaningful, several criteria should be met. These would include having: (1) a drainage system which permits the quantitative measurement of water discharge from an area whose dimensions are accurately known, (2) a continuous water sampling system that allows taking samples proportional to flow volume, and (3) taking measurements under unfertilized conditions on comparable soils so valid comparisons can be made. Probably the most difficult aspect is locating an area where all of these criteria can be met in a single experiment.

On sandy soils, the probability of losing nitrates to the ground waters by leaching is much higher than on the previously discussed fine-textured soils. Wisconsin found that the loss of nitrates was closely related to the amount of fertilizer nitrogen and irrigation water applied. To minimize nitrate losses on irrigated sands, the nitrogen should be applied in small increments throughout the growing season. This can be accomplished by "spoon feeding" the nitrogen through the irrigation system.

Research from the University of Minnesota indicates that if nitrogen fertilizer rates are applied according to realistic yield goal predictions and if good conservation practices are followed, there will be minimal nitrogen pollution problems resulting from fertilizers.

PHOSPHORUS IN SOILS AND PLANTS

C. A. Simkins and C. J. Overdahl

Pure phosphorus will ignite spontaneously when exposed to air. It is used on match tips and demonstrates its combustible nature every time a match is lit.

It is evident, then, that phosphorus in its pure form cannot be conveniently used in agriculture, nor does pure phosphorus exist naturally in the soil. What phosphorus reacts with or how it is combined in various forms are topics for an intensive study in soils.

Phosphorus in Soils

The mineral phosphate compound most commonly found in the soil is some form of calcium phosphate. These compounds occur in three degrees of availability to plants, (1) monocalcium phosphate, which is the water soluble form and is immediately available; (2) the dicalcium form, which is not water soluble but is citrate soluble (in fertilizers, the legal definition describes this form as available), it is more slowly available to plants; and (3) tricalcium phosphate, which is neither water soluble nor citrate soluble.

1. Phosphorus in high-lime or alkaline soils.

Total phosphorus in high-lime soils can be very high, but occurs predominantly in the tricalcium or other nonsoluble forms. Any strong acid reagent used to test for soil phosphorus will indicate a high level of phosphorus, but this is misleading since most of what is measured is unavailable. Phosphorus additions are extremely important where alkaline conditions prevail.

2. Phosphorus in acid soils.

Acid conditions dissolve iron and aluminum which readily react with soil phosphorus to form compounds unavailable to plants. Soil tests too frequently measure these phosphorus forms which gives misleading results. Acids change the tricalcium phosphates to a more available form; hence, less of this form exists in acid soils. Acid sands in Minnesota usually test high in phosphorus because of less tricalcium phosphates. It is advisable, however, to apply some phosphorus to these soils, since it is known that the test records some of the unavailable iron and aluminum phosphates.

3. Phosphorus in soil organic matter.

Organic phosphorus can become available to plants in much the same way as nitrogen; that is, through organic matter decomposition. Soil moisture and temperature govern the rate at which this form is released. Soils with high organic matter content will release large amounts of phosphorus during the warmest part of the summer. When conditions are favorable, the high organic matter soils may release enough phosphorus so that broadcast applications give only a small benefit. Soybeans don't appear to have an early need for phosphorus; hence a good level of organic matter could supply the plant's needs during midsummer. This may explain why soybeans do so well on fertile soils.

The amounts released vary considerably with the season and complicate the predicting of phosphorus needs.

Phosphorus in Plants

Phosphorus is absorbed by the plants in an ionic form. This means it has an electrical charge and through a series of exchanges with other ions or compounds, it moves into the plant. These exchanges are rapid when the plant has all its biological reactions going rapidly, and is slowed if weather conditions such as cold temperatures slow the life processes of the plant.

Cold soils, then, can retard phosphorus uptake. Researchers at Cornell University demonstrated in growth control chambers that phosphorus uptake was greatly reduced at cold temperatures and to a much greater extent than was plant growth itself. They also showed that if phosphorus concentrations in the soil were increased, particularly near the seed, considerably more phosphorus was absorbed. This helps explain why soils with limited drainage respond so well to starter fertilizer, while well-drained soils, particularly in drier parts of the state, have less dramatic effects from starter. Also, during dry springs, even in soils with limited drainage, big starter responses may not show because when dry, they warm up faster.

Yields of corn plants as dry matter in grams per pot 5 weeks after emergence are shown according to soil temperature and phosphorus treatment:

Rate of P*	59° F.	68° F.	77° F.
	dry matter yield grams per pot		
35 lb.	1.6	4.0	5.7
70 lb.	2.4	5.0	6.3

* No zero phosphorus. Data by Knoll, Brady and Lathwell, Cornell University.

Uptake of phosphorus in milligrams per pot from the same experiment as above, when totally mixed with the soil and when banded (as with starter) was as follows:

Rate of P (mixed)	59° F.	68° F.	77° F.
	phosphorus uptake milligrams per pot		
35 lb.	1.5	10.0	18.1
70 lb.	2.6	11.8	19.1
(banded)			
35 lb.	3.5	10.4	18.0
70 lb.	6.7	13.5	19.0

Cold soil temperature may play a greater role in low phosphorus content of corn than does low soil fertility itself, particularly in areas of adequate rainfall and fine textured soils. Since dry soils warm up faster, cold temperature may be less of a problem in western Minnesota, except on the poorly drained soils. Small grain areas are similarly affected, but these crops grow and function better in cool weather; hence the temperature effect is slightly less than for corn.

Phosphorus and Soil Testing

In testing soils for phosphorus, we try to estimate by rapid chemical means whether or not and to what extent a crop growing on that soil will show yield response to the application of phosphorus fertilizers.

Having soil test information neither guarantees response to phosphorus on low-testing soils nor eliminates the chance for response on high-testing soils. To expect any chemical determination to accomplish such an objective would be unrealistic for the following reasons:

1. Soil tests for phosphorus operate on the mineral portion of the soil only. Although crops often depend most heavily on the mineral phosphorus source, up to 50 percent of the total phosphorus content may occur in the organic matter. Depending on soil-water-air-temperature relationships, the organic phosphorus source may contribute substantially to the phosphorus nutrition of crops without being measured or allowed for in the soil testing procedure.

2. Sampling only the surface 6-inch layer does not allow for the contribution made by the subsoil. This contribution may be substantial on soils that increase in phosphorus availability with increasing depth, such as on Fayette soils in southeastern Minnesota.

3. With certain crops, the period of time over which final yield can be influenced by phosphorus fertilization may be quite short.

4. Cold soils or other conditions unrelated to soil phosphorus may operate to restrict phosphorus uptake.

The value of testing soils for phosphorus lies not in guaranteeing response or nonresponse to fertilizer phosphorus application in particular cases; rather, it is to improve the overall odds or the probability of making an economically favorable fertilizer decision on the basis of incomplete information about the phosphorus supplying capability of a soil.

Choice of soil test procedure: For a chemical test to be useful in making response predictions, the amount of a nutrient it will extract from the soil must correlate well with the real availability of that nutrient to growing plants. This must be done with greenhouse and field experiments.

Soil Test Correlation: Choosing low, medium, and high soil test ranges can be done only after the test procedure in use has been adequately calibrated. Calibration is carried out in both field and greenhouse. It requires comparing yields from untreated with treated pots or areas, using soils on which the test value for the questionable nutrient is known, and that the other essential mineral nutrients are present in adequate supply on both untreated and treated pots or areas.

Calibrating soil test procedures often requires that we use data from large numbers of soils obtained in different years and under varying growing conditions. Since absolute crop yields may vary markedly from field to field and season to season, an idea of percent yield is introduced to provide a common basis for comparison. The following example illustrates the idea of percent yield as it is used in soil test calibration work.

An experiment with millet as the test crop was conducted in the greenhouse. The soil was a Skyberg silt loam from Dodge County with a low phosphorus soil test (10 pounds extractable phosphorus by Bray's No. 1 procedure).

Plant nutrients were applied in varying combinations and four replications as follows:

160 + 0 + 200
0 + 80 + 200
160 + 80 + 0
160 + 80 + 200

Yields were harvested and the percent yields calculated in the following manner:

$$\text{Percent yield Without P} = \frac{\text{Yield of 160+0+200 plots}}{\text{Yield of 160+80+200 plots}} \times 100 = \frac{5.6 \text{ grams}}{20.0 \text{ grams}} \times 100 = 28\%$$

The example shows that when phosphorus was omitted from the treatment, yields were only 28 percent of those obtained with adequate phosphorus. One can conclude that Skyberg silt loams from other locations with 10 pounds per acre extractable phosphorus according to our extraction procedure are (1) very phosphorus deficient, and (2) usually respond well to phosphorus fertilization.

Such plant and soil test relationships must be established before a soil test means anything. It is not difficult to relate such results to various crop species since research is already available on these relationships.

The Significance of Phosphorus Water Solubility in Fertilizers

In row application for corn: Webb and Pesek at Iowa State University compared fertilizers varying in phosphorus water solubility in hill placement with corn in 25 experiments from 1951 to 1956. The soils ranged from moderately acid to neutral and above.

Results of the Iowa work predict that 90 percent of the yield increase obtainable with completely water soluble phosphorus could be obtained with materials having 50 percent of their available phosphorus in water soluble forms. It is likely that few, if any, manufacturers selling fertilizers for starter use in Minnesota produce mixed goods in which water solubility of the phosphorus component falls below the 60 percent recommended minimum.

In broadcast and/or plowdown application for corn and small grains: Maximizing soil-fertilizer contact through broadcasting "iron-out" differences in availability to plants of different water soluble phosphate fertilizers.

On acid to neutral soils with corn and small grains, available phosphorus of low water solubility has been as effective as the highly water soluble materials. On alkaline soils with corn, materials of low phosphorus water solubility have not been taken up as efficiently in some experiments, but these uptake differences have not been consistently followed by yield differences at harvest time. On high-lime soils, small grains treated with broadcast fertilizer applications often showed greater yield responses to the more highly water soluble phosphorus forms.

THE MOVEMENT OF SOIL PHOSPHORUS TO SURFACE WATERS

C. A. Simkins and C. J. Overdahl

The stimulation of growth of algae and other aquatic plants by nutrients present in waters has been a subject for considerable discussion and argument.

If we assume that all other growth factors are adequate, phosphorus can be a principal nutrient controlling the growth of algae and other aquatic plants.

Numerous investigators have shown that relatively low concentrations of phosphorus and other elements can support a sizable plant population in a water environment. On the other hand, efforts to develop a simple and reliable technique for evaluating nutrient supplies and their influence on aquatic growth have not been successful to date. The picture is a complicated one. Adequate sampling is a problem. Also when dealing with unrooted aquatic plants, one cannot be certain that the plant has not moved from its original site of growth. Additionally, there is always a complicated exchange between nutrients in the sediment and the overlying water as well as many other factors. Rather than to be concerned as to whether phosphorus, carbon dioxide, nitrogen, or some other nutrient is responsible, or the key to eutrophication of our surface waters, let us look rather at the extent of phosphorus contributed to the surface waters by (1) soil phosphorus and (2) fertilizer phosphorus.

Phosphorus in Soil Formation

Considerable phosphorus is lost from soils during soil formation. Various investigations have shown that phosphorus in waters is directly related to the phosphorus content of the soils and rocks from which the soils are formed. The losses of phosphorus to surface waters as a result of geologic formation can range from 0.22 ppm to .07 ppm. These losses are a normal part of the continuous cycle of nutrients being made available through soil formation. In New Zealand, it has been calculated that the rate of loss of phosphorus from soils derived from sand dunes is as high as .02 lbs per acre annually.

Phosphorus in Runoff Waters

Work by Timmons, et al of A.R.S. in Minnesota has shown that cropping practices can influence phosphorus content of runoff waters. The following table (1) indicates the quantity of inorganic phosphorus contained in runoff water under different cropping systems.

Crop	P added lbs/acre	lbs/acre year
Fallow	0	.04
Corn (continuous)	29	.05
Corn (rotation)	29	.05
Oats (rotation)	N.A.*	.01
Hay (rotation)	0	.23

* NA - not available

Under the above conditions, haylands which were unfertilized lost considerably more phosphorus to the surface water than corn which had been fertilized.

Recent studies in Minnesota and Indiana have shown that little losses of phosphorus fertilizer occur if the fertilizer materials are plowed down or incorporated into the soil.

Phosphorus in Soil Erosion

A large portion of the water soluble phosphorus applied to our Minnesota soils is rapidly converted to forms which are not readily available to plants. Perhaps as much as 80 percent of the phosphorus added to the soil in a given year may not be absorbed by plants in their growth. This allows for an accumulation of phosphorus in the upper portion of the soil which is of considerable importance when soil is lost through erosion.

There appears to be little question that vast amounts of phosphates are added to surface waters through erosion. Estimates in the United States indicate that from 1 to 5 pounds per acre per year is lost. This is roughly a total of 180,000 tons of phosphorus annually.

Phosphorus from Fertilizer

The use of fertilizer phosphorus has not contributed significantly to raising the phosphorus level of our surface waters. There is considerable evidence to indicate that fertilizer phosphorus is contributing to a betterment of our water quality. Phosphorus use can increase plant growth and help develop more erosion resistant vegetation.

Summary

Natural losses of phosphorus from soils and rocks are often sufficient to support algal and other plant growth in surface waters.

It is also evident that soil erosion can contribute considerable amounts of potentially available phosphorus to streams and lakes.

Present research information indicates that only a small portion of fertilizer phosphorus is leached from soils into drainage waters.

Fertilizer phosphorus can be carried into rivers or lakes if soil particles on which it has been absorbed are allowed to be eroded from the land. This is the most serious problem concerning phosphorus reaching our lakes and streams.

POTASSIUM IN SOILS AND ITS AVAILABILITY TO PLANTS

C. J. Overdahl

All soils except acid sands or peat and mucks have high contents of potassium. The part available to plants, however, may be only 1 percent or less in any year. The total in a fine-textured soil may be 40,000 pounds per acre, with 400 pounds per acre of available potassium, while some unfertilized sandy soils may have only 20 to 30 pounds of available potassium per acre.

Factors Affecting Potassium Availability

The following factors can indicate why there is variability in potassium absorption by plants:

1. Long term rainfall effects
2. Soil texture
3. Soil temperature and moisture
4. Soil pH
5. Crop species
6. Rate of previous applications

1. Longtime rainfall effect on potassium supply.

Throughout the U. S., total potassium in soils increases from east to west. Likewise, in Minnesota, soils in the western counties have considerably more potassium than in the eastern counties. Quantity of rainfall over the past thousands of years is a factor related to total potassium supplies in our soils.

In dry areas, slow weathering due to limited freezing and thawing action has allowed the preservation of large amounts of potassium bearing minerals. These minerals are very important suppliers of potassium that supports growth of crops. There are soils in western Minnesota that have such large quantities of these minerals that it is doubtful that the supply will become exhausted in the foreseeable future. There are, of course, exceptions. Very high pH, poor drainage, sandiness, and other factors discussed in paragraphs to follow could create conditions where added potassium shows a response, even in the high potassium areas.

Across southern Minnesota, there is a pattern of potassium use that follows the rainfall areas. Commonly used fertilizer ratios in southeastern Minnesota are high in potassium such as 1:3:9 or 1:4:4, in south central Minnesota the 1:4:2 ratio is popular, while in western Minnesota 1:4:0 or 1:4:1 ratios are common.

2. Soil texture and potassium needs.

Since the natural potassium supply in soils is primarily from clay size minerals, the fine-textured soils with high clay content are high in potassium. Intensive cropping on clay loam or silty clay loam soils at the Waseca and Lamberton Experiment Stations may occasionally show responses to potassium, but seldom are the responses very dramatic. Yield increases, due to potassium, of 200 or 300 percent on coarser-textured soils on experiments in north central Minnesota are not surprising. Fortunately, soil tests indicate these differences, but knowing the texture is helpful in figuring potassium needs.

On low potassium sandy soils either irrigated or where drought is not a persistent problem, alfalfa, for example, is often fertilized with 400 to 600 pounds per acre of 0-0-60 at seeding time and after the first production year, potassium is topdressed annually with no less than 200 pounds per acre of 0-0-60. Alfalfa on fine-textured soils in Minnesota often won't need half these amounts.

3. Cold soil temperature and potassium requirements.

During April, May, and perhaps June, soils are wet and consequently cold, but cold soils aren't cold every year. The variation of response to potassium between wet years and moderately dry years often puzzles farmers. A fertilizer experiment on corn in Dodge County, conducted by Caldwell and colleagues from the Soil Science Department, showed the extremes from a cold, wet spring one year to a dry, warm spring the next. On the wet spring, the potassium-treated plot produced a 260 percent yield increase over the check plot, while the following year, the increase was only 16 percent. The corn on the untreated plots after the warm spring yielded more than 3 times as much as it did on these untreated plots in the year of the wet spring. Subsequent work in the growth control chamber where moisture and temperature were independently varied, soil temperature was isolated as the chief cause for yield differences. Soil compaction can also cause soil coldness and inhibit potassium uptake similar to when soils are wet.

Band applications for row crops are more efficient in overcoming cold conditions than when broadcast. North Dakota researchers observed small but significant responses to potassium on small grains on certain years, even though the soil test K was high. Responses were from rates as low as 15 pounds of K_2O per acre in the row, but infrequency of occurrence and small yield increases make the need somewhat debatable for small grains. Burson at Minnesota, found that 40 pounds of K_2O in the row plus 80 pounds broadcast for corn was more effective in increasing yield at Rosemount, Minnesota than 120 pounds all broadcast. He averaged 12 bushels more corn when row potassium was used. The increased efficiency due to row application is probably associated with early season cold soil conditions, and when spring conditions are warm, only small benefits of row over broadcast applications are observed.

4. Potassium absorption under high pH conditions.

The best place to see potassium problems related to high soil pH is on a so-called "alkaline rim." Frequently adverse growth conditions are observed when one compares crop growth conditions in the rim to the adjacent surrounding area. The rims around a low spot have an overabundance of calcium and magnesium. These elements on a high pH rim are so concentrated that they compete with potassium for uptake by the plant. Generally elements enter the plant in proportion to their occurrence in the soil. Therefore, if unusually large amounts of calcium and magnesium are present, these nutrients simply outnumber potassium for entry through the roots, even though the soil may have an adequate K supply for a normal situation.

All soils with a pH above 7 are not necessarily afflicted with this problem. At Morris and Crookston, in western and northwestern Minnesota, respectively, soils with a pH range of 7.2 to 7.4 showed no response to potassium on corn, alfalfa, soybeans or flax. These soils had a medium-high potassium test.

The problem frequently occurs on soils where the calcium carbonate equivalent is above 15 percent. Some of these rims may have as high as 30 percent to a depth of 3 to 4 feet. Salt problems are usually prevalent in these soils, which confuses the situation. Generally soil tests for salts are needed to determine whether there is an overabundance of soluble salts. Calcium carbonate equivalent is not routinely measured, therefore, the most practical means of ascertaining the over supply of calcium or magnesium is by pH. If there is an obvious problem indicated by poor crop growth, salts are low, the K soil test is below 300, and the pH is 7.5 or above, potassium should be added at about 120 pounds per acre of K_2O. This has been effective in bringing a corn crop to normal health, but observation on other species is limited.

Excess potassium on acid sandy soils has created the reverse situation, particularly magnesium deficiency, on potatoes and corn. Potassium is so important on these soils that it is better to include magnesium along with the high rates of potassium, rather than reduce potassium fertilization.

5. Variation in potassium need by crops.

A good demonstration of how plant species vary is to observe differences between alfalfa and small grain growth side by side on a low potassium soil. If no other nutrients are limiting, the small grain will produce moderately well, while the alfalfa produces poorly. Fertilizer recommendations reflect these differences. For example, on a sandy loam soil with a very low soil test and low subsoil potassium, 360 pounds per acre of K_2O is recommended for alfalfa at seeding time. Recommendations for small grains with the same soil conditions would be only 60 pounds per acre of K_2O broadcast and even as low as 40 pounds if applied in the row.

One reason for differences between species appears to be due to its type of root system. A fibrous rooted plant has a greater absorbing surface and absorbs K more easily than a tap rooted plant. There are perhaps other inherent differences of potassium needs by species as well.

The following table shows what some crops remove at specific yield levels both in the plant residue and the part removed as grain:

Crop	Acre yield	lbs. of K_2O
Corn	150 bu.	40
	4 tons stover	130
Oats	100 bu.	20
	2½ tons straw	100
Wheat	60 bu.	20
	2 tons straw	80
Soybeans	40 bu.	55
	1 ton	40
Potatoes	400 CWT	200
	vines	100
Alfalfa	6 tons	270

It is obvious from this table that the portion of potassium in the grain is quite small. Crops removed for grain, with the residue returned to the soil, do not deplete the soil potassium nearly as rapidly as when the entire crop is harvested, such as with corn silage or hay.

6. High applications of potassium on previous crop.

It used to be simple to show areas of the state where low potassium was a problem. Maps that were drawn for this purpose probably are still useful as an indication of subsoil levels, but farmers have been fertilizing at such different intensities that the surface test today primarily reflects what type soil manager the farmer is.

Sandy soils which are usually low in potassium but have been heavily fertilized over a long period of time will test very high, even to a depth of 2 feet. This amount will be reflected in crop yields for several years. Just one heavy application, however, will last through no more than about two crops.

Potassium Absorption by the Plant

Potassium is taken up as an ion, it has a plus charge of 1. By the time potassium has been released from manure, from organic residues or is just separated from the potassium chloride molecule in fertilizer, it has lost its identity as to origin. This potassium ion probably has been taken up thousands of times before by preceding plants, but it is in no way different from when it was absorbed the first time. There are two basic ways the potassium ion is absorbed.

Active absorption.

This type of absorption depends on the biological activity of the plant. The energy released in respiration during this activity is probably the source of energy needed to move the ion into the root. Respiration in plants involves a need for oxygen the same as human respiration. Compacted, or water logged soils, would obviously have less oxygen and thus slower respiration. Also, a cold soil would reduce the biological activity of the plant, thus having slower respiration and a reduced rate of absorption. There is evidence that high concentrations of the nutrient can partially offset the reduced uptake due to slower activity, thus where fertilizer is placed close to the plant such as in row applications or by high broadcast rates, the adverse conditions can be partially corrected.

Passive absorption.

This type of absorption is not related to the plant's activity, but to a concentration or chemical gradient. The nutrient moves from an area of high concentration to an area of low concentration, which in this case is to the inside of the plant.

Soil Tests

The large amount of total potassium found in soils exists in various forms. The purpose of a soil test is to measure the part that is available to plants. This part is either in the soil water or the potassium in clay and organic matter that can be replaced rapidly by other elements with a positive electrical charge. These elements could be calcium, magnesium, ammonium, hydrogen or others.

The portion of soil potassium that is replaced by other plus charged elements is referred to as "exchangeable" potassium. This is the quantity of potassium in pounds per acre reported in soil tests. Most laboratories in Minnesota use ammonium to displace the potassium by leaching a known amount of soil with a standard amount of ammonium acetate. The quantity of potassium leached from a soil is measured by a flame photometer.

The pounds per acre of exchangeable potassium measured is usually matched to fertilizer recommendations by a computer. The computer relates the value to the crop to be grown, soil texture and other information provided with the soil sample.

Of added interest when studying exchangeable potassium is the fact that a portion can be converted to nonexchangeable potassium. There actually is an equilibrium between these two forms. If no potassium fertilizer is added, crop removal will deplete the exchangeable form (observed by a lower soil test) and slowly this form will be replenished from the nonexchangeable source. It is for this reason that some plant growth can be maintained even on rundown land that has never been fertilized. The difficulty is that the replenishing is very slow, usually too slow to produce profitable crops in areas of the state that need added potassium. Where larger quantities of potassium have been added beyond what the crop can use, there will be a slow conversion toward the nonexchangeable form. This is one reason why soil tests do not increase in direct proportion to the amount added, even under fallow conditions. The following table shows the effect of varying rates of potassium on the soil test where the land is under intensive corn production. The soils at these two locations are similar. The small increase is due to losses to the crop and possibly the conversion to nonexchangeable potassium.

K_2O lbs/acre annually 1970-1971	Martin Co. 1970	Martin Co. 1971	Waseca Co. 1970	Waseca Co. 1971
	lbs. of exchangeable K/acre			
0	202	230	260	210
50	212	258	275	213
100	222	278	260	220
200	270	328	262	223
400	243	320	312	310

Other Points

Since potassium doesn't become part of organic compounds, stalks and straw don't have to decompose before their potassium becomes available. Usually, potassium in manure is available entirely during the year it is spread, compared to only 30-60 percent of the phosphorus and nitrogen.

Potassium is readily removed from residues by rains. Peat soils can release and lose their potassium rapidly; potassium is possibly the most important nutrient added to organic soils.

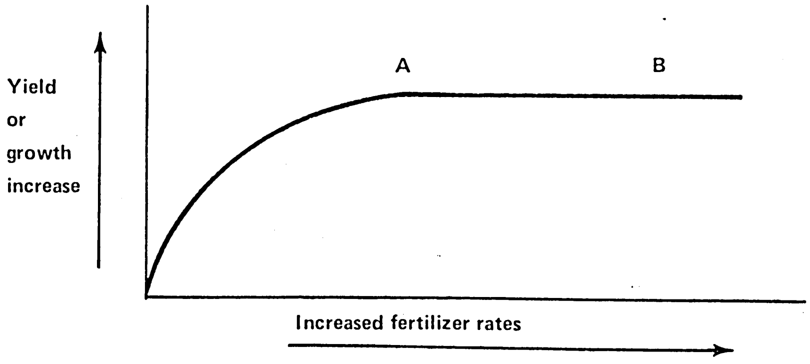
BACKGROUND FOR MICRONUTRIENT NEEDS

C. J. Overdahl

Micronutrients are often called the missing link in crop production. Too often, inadequate liming, N-P-K fertilization, or absence of weed control, is still the limiting factor.

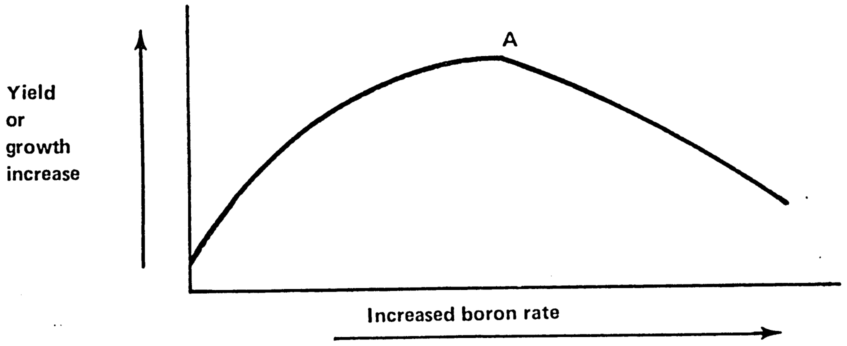
Even though recommendations for micronutrients must be very specific, there are some basic conditions where we would expect these nutrients to become limiting: low organic matter levels, coarse-textured (sandy) soils, organic soils, or soils with high pH. Most often, with the exception of molybdenum and boron, deficiencies are related to high pH soils.

Many of you are familiar with the growth curve describing plant or grain yield increases with increased fertilizer applications. The increase generally occurs something like this:



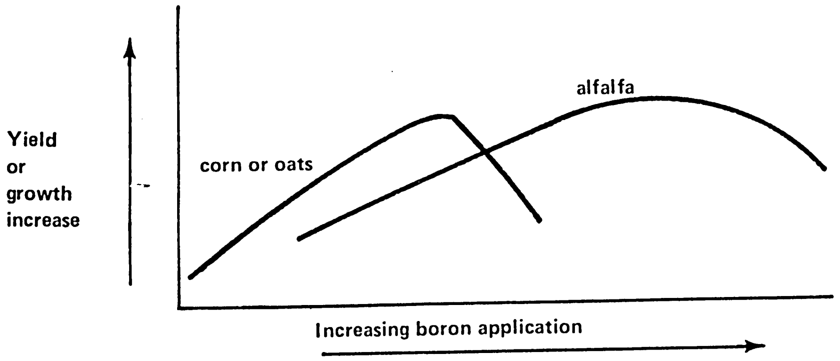
An equivalent of 2,000 pounds per acre of 16-16-16 was applied on continuous corn at the Southern Experiment Station, Waseca, for 6 consecutive years with no adverse effects on yield. With the major (macro) nutrients, therefore, we have a broad base, except nitrogen on small grains, after which yields no longer increase with increased fertilizer rates (from A to B above diagram) before yields decline. This is not true with the micronutrients.

A curve for boron, for example, would appear something like the diagram on the following page.



There is a peak in yield increases after which plant growth or yield is strikingly reduced upon additional applications.

This peak of the curve occurs at different rates of the nutrient for different crops. (It will also peak at different rates for the same crop depending on the initial level of soil nutrients.) The following figure compares boron needs of corn or oats versus alfalfa.



If a concentration in a nutrient solution were optimum for alfalfa, it would be too much for corn or oats. This serves to emphasize the care needed in knowing the deficiency and plant differences to avoid toxicity.

Seven micronutrients are known to be essential for the full growth cycle from seed to mature plant producing seed. These nutrients are boron, iron, zinc, molybdenum, manganese, copper, and chlorine.

Boron

The soil: Sandy textured soils with low organic matter most frequently show boron deficiency, although silt loams show deficiencies after prolonged drought. Available boron is released to plants largely from decay of soil organic matter. During extended dry periods the surface area becomes dry; thus, decay and release of boron is at a standstill.

Crops affected: Crops vary considerably in their boron needs. Alfalfa, sweet clover, sugar beets, cabbage, celery, apples, cauliflower, and rutabagas usually show boron deficiency symptoms first. Corn, soybeans, small grains, potatoes, and strawberries show less need under the same soil conditions.

Deficiency symptoms: Absence of boron affects the growing tip, the flowering and fruiting process, cell division, and pollen germination. In alfalfa, a relatively severe deficiency will cause a dead growing point. When boron is supplied on such plants, either through fertilization or renewal of organic matter decomposition, side branches begin to grow more rapidly and may extend above the dead mainstem. It is quite easy to identify boron deficiency by the stunted upper portion of the plant, giving a bushy, umbrella-like appearance. The upper leaves turn yellow or sometimes reddish. The lower or older leaves stay green. Severely affected plants do not produce blossoms.

With milder deficiencies, there is a loss of yield without apparent symptoms. Alfalfa that is partially affected by boron deficiency may have many short-growing plants among tall, healthy ones. You will observe no apparent deficiencies unless you lean the larger plants to the side and look beneath them. Such deficiencies may reduce yields 15 to 20 percent without noticeable ill effect.

Symptoms on other legumes will be similar to alfalfa. Affected corn plants are short with poorly filled ears or barren stalks. Root crops may have heart rot of roots.

Recommendations: Apply approximately 2 to 3 pounds of elemental boron per acre for alfalfa and vegetables. Corn should receive about 0.5 pounds per acre and not more than 1 pound. Boron can be applied as borax, borate, or other boron compounds mixed in the N-P-K fertilizer. Boron-containing fertilizers such as 0-12-36B or 0-20-20B can be obtained by special request from fertilizer manufacturers. The suffix "B" indicates the presence of boron. If these grades contain 1 percent boron, then 200 pounds per acre would supply 2 pounds of elemental boron. Do not apply such materials with the grain drill for new alfalfa seedings if a small grain companion crop is grown, since this concentration could be toxic to the small grain. Even where these materials are added broadcast, apply them 1 or 2 weeks before seeding to avoid injury to the companion crop.

Iron

Soil characteristics: Characteristics associated with iron deficiency are usually high-lime, low-lying mineral soils. The deficiency is most common in south-central or western Minnesota. Low iron-supplying power of soils is usually a consequence of its insolubility or inhibited uptake rather than its actual absence. Iron deficiency in soybeans could be related to excess manganese.

Plants affected: Soybeans, flax, and many ornamental shrubs and trees are affected. Corn can also be affected, but less seriously.

Symptoms: Even though iron is not a constituent of the chlorophyll molecule, it is indispensable for chlorophyll production. Since chlorophyll is responsible for the green color in plants, iron deficiencies inhibiting its production cause a yellowing of leaves. On plants such as soybeans the yellowing is between leaf veins; the veins themselves remain green. Since iron is not easily translocated from leaf to leaf within the plant, old leaves tend to be green while young upper leaves show the deficiencies. Iron generally functions as a constituent of enzymes.

Recommendations: Correction of iron deficiency is easily done with iron chelate, but the cost of this material makes its use prohibitive. Iron sulfate applied on leaves at about 0.1 pound per acre will correct the deficiency under some soil conditions. If soils tend to warm up in June and July, the iron deficiency may not develop on the new leaves and an early leaf application may correct the deficiency of the early emergence leaves; when later developing leaves are not deficient, leaf spraying can be effective. If the deficiency persists during the summer, little can be done to overcome the situation. Some varieties are more susceptible to iron deficiency than others. Seed treatment has been inadequately tested, but on limited field trials, such treatments have been inefficient.

Zinc

A survey collecting corn leaf samples in 1962 and 1963 shows low zinc content on some fields in the western half of Minnesota from the Iowa line to the Fargo-Moorhead area and as far east as Owatonna. Most soils in the state, however, contain sufficient zinc for normal plant growth. Soils likely to produce zinc-deficient crops are high in lime, poorly drained, or severely eroded. Usually only small areas of a field are deficient and deficiencies are difficult to predict without a growing crop so that symptoms can be observed.

Crops most severely affected are corn, soybeans, and flax. Mildly affected crops are potatoes, sugar beets, alfalfa, sorghum, tomatoes, and onions. Frequently, high phosphorus applications, particularly when row applied, tend to induce zinc deficiencies on soils relatively low in zinc.

Symptoms: Corn with zinc deficiency shows striking leaf symptoms. Young corn plants have yellow stripes parallel with the leaf and appear concentrated on either side of the midrib and the leaf borders. The midrib, a small area near the midrib, and the leaf edges remain green. The older portion of the plant, the lower leaves, show the symptoms first. Plants have a stunted growth and the seriously discolored leaf area eventually dies. Mild deficiencies appear only on lower leaves and begin to show when the corn is about knee high. Cornfields affected with zinc deficiency have an uneven appearance. Veins on soybean leaves remain green, but areas between the veins show yellowing and death of tissue.

Recommendations: Determine zinc by soil or plant tissue tests. Eight to 20 pounds per acre of elemental, inorganic zinc applied broadcast on the soil will correct the deficiency. Zinc sulfate contains about one-third zinc; therefore, 20 to 60 pounds of zinc sulfate should be applied. Zinc chelates cost more per pound, but considerably less material is necessary to correct the deficiency. Row applications accompanied with mixed fertilizer including nitrogen are also quite effective. Trace amounts in fertilizer on deficient areas will not do the job. Zinc fertilizer mixtures are perhaps the best way to apply the material if the fertilizers contain enough zinc to supply the required amounts.

Molybdenum

Molybdenum deficiency is most likely to occur in acid soils.

Molybdenum treatments are most likely to be beneficial to legumes such as soybeans, alfalfa, clovers, and peas.

Function and symptoms: Molybdenum enables the root nodule bacteria to fix nitrogen from the atmosphere. Also, nitrates must be converted (reduced) to the amino form. Molybdenum plays an important role in the plant enzyme system, making these conversions possible in protein synthesis. Symptoms of molybdenum shortages are those of nitrogen deficiency.

Recommendations: Alfalfa yields at Rosemount were significantly increased on an unlimed acid soil. Liming generally will correct molybdenum deficiency. Greenhouse experiments with molybdenum applications on several soil types of Minnesota have failed to increase alfalfa yields. Molybdenum can be used on an experimental basis, using ½ pound of elemental molybdenum per acre as ammonium molybdate or sodium molybdate as a spray or seed treatment.

Manganese

Deficiencies generally occur on soils slightly acid to alkaline in reaction and are also common on some organic soils with pH's above 5.8. On mineral soils in Minnesota there appears to be a problem of imbalance on soils relatively low in available iron; excess manganese may induce iron deficiency where there is high soil moisture.

Few established cases of manganese deficiency have been reported in Minnesota. Symptoms of a deficiency on broad-leaved plants such as soybeans are similar to iron deficiency; that is, green veins with discoloration between the veins. Grasses such as small grains may have a general discoloration called "gray speck."

Soil micro-organisms that decompose crop residue oxidize available soil manganese to unavailable forms. A U. S. Department of Agriculture report of Iowa studies shows that manganese-oxidizing bacteria were more numerous on mulched soils than on bare soils. Corn plants contained more manganese on unmulched soils. The report did not establish, however, whether the lowest levels found were low enough to cause a manganese deficiency. Manganese sulfate on a trial basis is recommended at rate ranges from 25 to 100 pounds per acre. Higher rates can be used on soils with pH above 7.5.

Copper

Deficiencies are most likely on organic soils with pH below 5.5. Lettuce, onions, spinach, carrots, alfalfa, and small grains are crops where possible deficiencies may occur.

Symptoms of copper deficiency are wilting and eventual death of leaf tips. In grain, it looks like frost damage. Leaves are yellowish in color. There is poor pigmentation of carrot roots, small grains, and onion bulbs.