Nutrient Recommendations for Field Crops in Michigan
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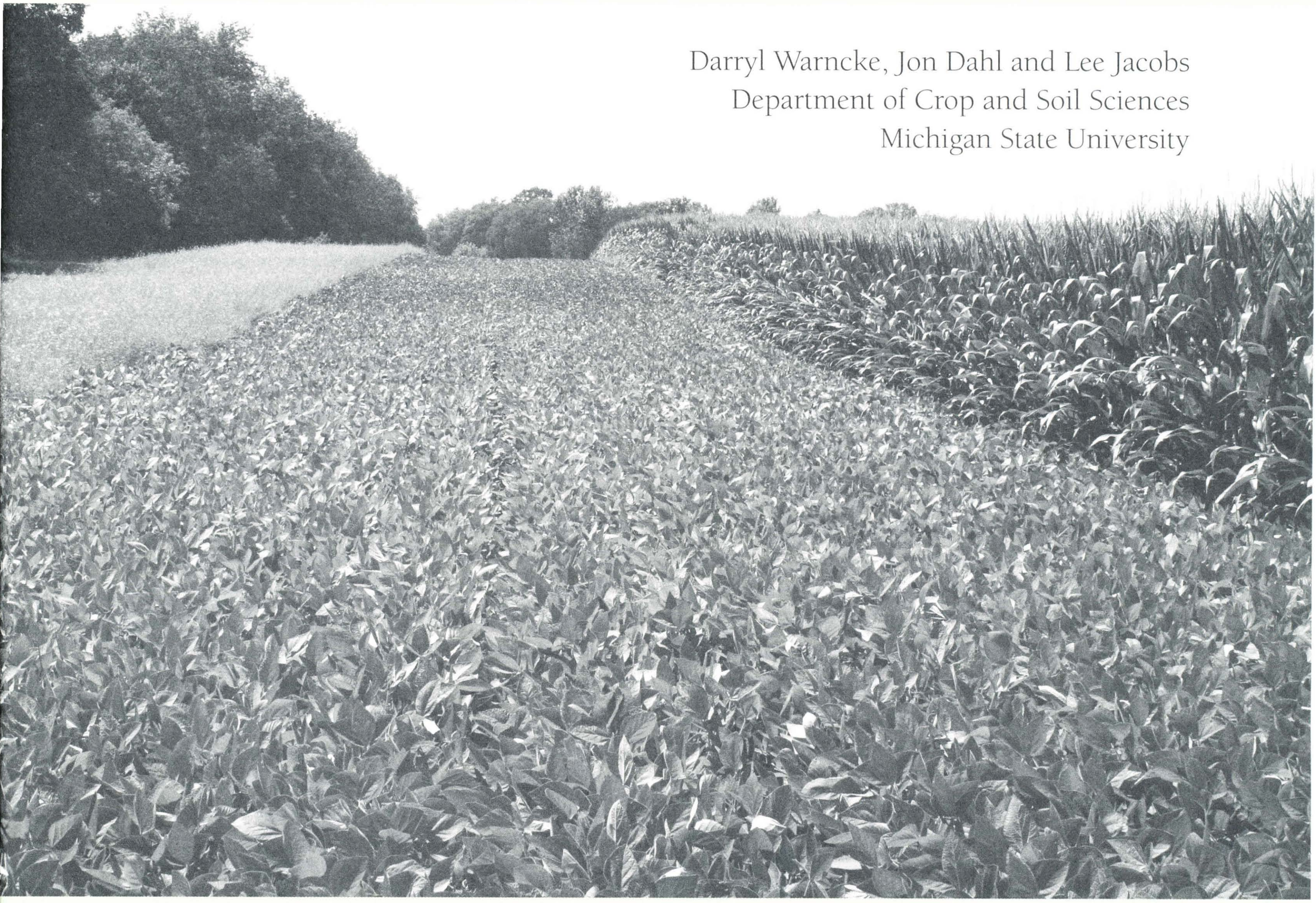

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Nutrient recommendations for field crops grown in Michigan have evolved over the years on the basis of observations and controlled field studies (circular bulletin No. 53, Extension bulletin 159 and Extension bulletin E-550). During the 1920s and 1930s, recommendations given for various amounts of various fertilizer grades were based on the crop grown and the management practices being used. The three management practice categories were: no manure or leguminous green manure in the past two years, clover or alfalfa grown within the past two years and manured within the past two years. In the 1940s, recommendations for the grade of fertilizer to use considered soil texture (sandy or loamy or clayey soil) and whether manure had been applied within the previous two years.

Soil test results began to be considered in making fertilizer recommendations in the early 1950s. Phosphorus (P) and potassium (K) test values were classified as low or high on the basis of the Spurway "reserve" soil test (0.13 N HCl). For phosphorus, a soil test value below 50 lb P/a (per acre) was considered low and above 50 lb P/a was considered high. For soils with a pH above 7.5, the separating value was 100 lb P/a. For potassium, the separating soil test value was 150 lb K/a. When rock phosphate had been applied to the soil, the "active" test (0.018 N acetic acid) was used. The separating soil test values for the "active" test were 25 lb P/a on acid soils, 50 lb P/a on soils with pH above 7.5, and 80 lb K/a. Even when the soil test was high, some fertilizer was recommended because even in the high-testing soils, an economical response usually would occur when a balanced fertilizer was applied.

In the early 1960s, the Bray P1 test for phosphorus and the ammonium acetate test for potassium began to be used. Soil test values were divided into very low, low, medium, high and very high categories. In 1963, recommendations for crops grown on mineral soils were given in pounds of P_2O_5 and K_2O/a in relation to these soil test categories. For crops grown on organic soils, recommendations were given in pounds of P_2O_5 and K_2O/a on a graded scale, according to the actual soil test value. Soon thereafter, all nutrient recommendations for all crops grown on mineral and organic soils followed the same format based on soil test values. These tabular recommendations were converted into recommendation equations in 1981.

During the mid-1990s, soil fertility specialists from Michigan, Ohio and Indiana developed a set of common nutrient recommendations for corn, soybeans, wheat and alfalfa (Extension bulletin E-2567). The conceptual model used for those recommendations is now followed for the phosphorus and potassium recommendations given in this bulletin for all field crops.

Basis for Recommendations

Levels of essential elements (nutrients) available in the soil can influence the growth and development of field crops. Field studies at various locations in Michigan have provided the data for describing growth and yield responses of crops to nutrient additions when available soil levels are less than adequate. Soil testing procedures have been developed to relate extractable nutrient levels to crop growth and yield.

Nitrogen, phosphorus and potassium are the nutrients most likely to be limiting crop growth. The nitrogen status in the soil is quite dynamic, and predicting its availability over time is difficult. The availability of phosphorus and potassium in the soil is fairly stable over time unless major additions are made. Soils in Michigan are naturally quite low in available levels of phosphorus and potassium. Additions of these two elements over time in manures and commercial fertilizers have caused significant increases in the available levels in the soil. In 1962, the median soil test value (Bray-Kurtz P1) for phosphorus in Michigan soils was 12 ppm. This gradually increased over time. Since the early 1980s, the median value has fluctuated around 53 ppm. Similar values for potassium soil test values (1 N neutral ammonium acetate) are 56 ppm in 1962 and around 91 ppm since the 1980s. Buildup occurs when the amount of P or K applied exceeds the amount removed by the crop (crop removal). The phosphorus soil test increases on average 1 ppm for each 20 lb P_2O_5/a added above crop removal, although the range is from 10 to 36 lb/a. Available P levels increase more quickly in sandy soils than in clay soils. Similarly, the potassium soil test will increase about 1 ppm for each 8 to 20 lb K_2O/a added beyond crop removal.

Figure 1 illustrates the general relationship between soil test value and crop growth or yield. With each increment of increase in the soil test value, the increase in yield is less (law of the minimum). The point where yield reaches 95 to 97 percent of maximum is referred to as the critical soil test value. This is also near the point of optimum economic return on investment made in nutrient additions. When phosphorus or potassium is added to the soil, some of it is taken up by the growing crop, some goes to increasing the available level in the soil, and some is converted into slowly available forms. Adding more of a nutrient than is taken up by the crop will result in a buildup of the readily available and slowly available forms. Soil tests have been developed that will extract a portion of the nutrient pool that is available to plants as indicated by plant uptake. Soil test values have been correlated with nutrient uptake, growth and yield. Consequently, the amount of a nutrient required to enhance crop growth and yield to the maximum is related to the soil test value.

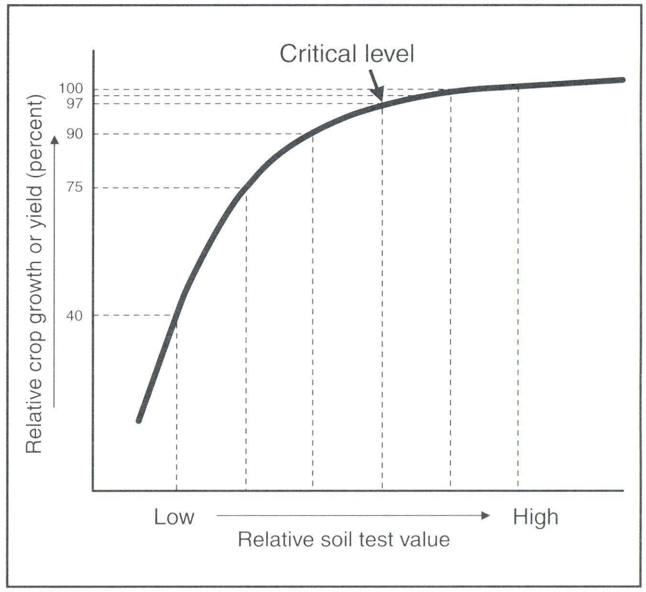

Figure 1. Relative growth or yield response to increasing soil test levels.

Development of Nutrient Management Programs

Development of a cost-effective nutrient management program needs to take into account the nutrient requirements of the crop being grown and the nutrient status of the soil. The elemental analyses of plants have established the general nutrient requirements of crops. Actual nutrient uptake will vary with crop yield and variety. The nutrient requirement of the crop can be met by nutrients available in the soil and by nutrient additions. Soil tests indicate the ability of soils to supply nutrients. When the soil is able to supply all of the nutrients required by the crop (i.e., the soil test value is greater than the critical value in Figure 1), no additional nutrient inputs are needed to achieve maximum yields. Supplying an amount of nutrient equal to crop removal will maintain the nutrient status of the soil. Field studies have established how much of a given nutrient to add at a given soil test value to optimize yield. Soil tests, therefore, provide the base for building a sound nutrient management program.

Soil Sampling

Sampling may be the most important part of soil testing. Representative samples result in meaningful and useful soil test information. Soils in all fields have some degree of variability due to natural soil-forming processes that created differences in soil texture, organic matter or slope, or due to past management practices. Differences in historical cropping systems, crop yields, nutrient applications, manure applications and tillage practices all contribute to variability. Sampling is an averaging process; soil cores should be taken so that the properties of all cores making up a composite sample are as similar as possible. Sample unusual or problem soil areas separately.

The first step in collecting soil samples from a field is to map the field and identify areas with similar physical features and similar historical management practices. Within each designated sampling area, collect about 20 cores to a depth of 8 inches and mix them thoroughly. Banding fertilizer contributes to the variability of chemical soil properties. Where the location of the bands is still apparent, avoid sampling in the band. Where the location of the bands is not discernible, collect soil cores from additional random locations. Collecting one soil sample for at least every 15 to 20 acres will provide good information about the nutrient status of fields. More intense sampling will provide more information about the variability in a field. As the number of acres represented by one composite sample increases, the probability that the sample is truly representative of the sampled area decreases. Therefore, limiting the area represented by one sample to no more than 20 acres will result in samples and test results representative of the designated field areas. When only shallow tillage (less than 4 inches) or no tillage is used, collect an additional sample from the 0 to 3-inch depth to assess the acidity of the surface soil. Surface soil pH is critical to the efficacy of some herbicides. (More information on soil sampling is available in MSU bulletins E-498, E-498S and E-1616, and North Central Multistate Report 348.) Send 1½ to 2 cups of soil to a reliable soil test lab for analysis.

Fall and spring tend to be the best and most practical times to collect soil samples. Available nutrient levels are usually increased before or at planting by nutrient additions and then gradually decrease during the growing period because of plant uptake and conversion to slowly available forms. By fall, the nutrient status is more stable. For long-term nutrient management planning, it is best to take soil samples at the same time of year each time a field is sampled. Sampling while the crop is growing is most appropriate for checking available nitrogen levels; one such test is the presidedress soil nitrate test (PSNT). For most field crop production systems, sampling and testing the soil every three years is adequate. In more intense cropping systems or where the whole aboveground portion of a crop is removed, such as with forages and silage corn, available nutrient levels will change more rapidly. For these situations, sample and test at least every two years. On organic soils, considerable amounts of potassium may leach from the soil over winter, especially when the spring thaw occurs, so soil test potassium levels for organic soils will usually be lower for samples taken in the spring than in the fall.

Soil Test Procedures

The Michigan State University Soil and Plant Nutrient Lab uses soil testing procedures recommended by the North Central Region Committee on Soil Testing and Plant Analyses (see NCR Pub. 221). Soil pH is determined on a 1:1 soil:water slurry, and the lime requirement is determined by adding SMP (Shoemaker, McLean, Pratt) buffer solution to this slurry and measuring the resulting pH. The SMP buffer solution pH is reported as the lime index. An index of available phosphorus (P) is determined according to the Bray-Kurtz P1 (weak acid) test. On soils with free calcium carbonates, the Bray-Kurtz P1 extraction is less effective. The Olsen test (0.5 $\underline{N}$ sodium bicarbonate) provides a better indication of P availability on calcareous soils with pH above 7.2 and a Bray-Kurtz P1 test of less than 10 ppm. An index of available potassium (K), calcium (Ca) and magnesium (Mg) is determined by extraction with 1 $\underline{N}$ neutral ammonium acetate. Recommendations for phosphorus, potassium and magnesium are based on these soil test values.

An index of iron (Fe), manganese (Mn) and zinc (Zn) availability is determined by extraction with 0.1 $\underline{N}$ hydrochloric acid; 1.0 $\underline{N}$ HCl is used for copper (Cu). DTPA is used as an alternative extracting solution for Cu, Fe, Mn and Zn, especially for calcareous soils. The hot water extraction procedure is used for boron (B). Sulfur (S) is determined by extraction with a calcium phosphate solution.

Laboratories with inductively coupled plasma (ICP) spectrophotometers are using the Mehlich III "universal" extracting solution for determining the availability indices of P, K, Ca, Mg and other plant-essential elements.

Soil test results are expressed as parts per million (ppm) of P, K, Ca, Mg, Mn and Zn. For mineral soils, 1 ppm is equal to approximately 2 pounds per acre of soil to a depth of 6 2/3 inches. For organic soils with a bulk density of 0.66, 1 ppm equals 1 lb/a.

Conversion Factors

Most soil testing labs report soil test values in terms of ppm P and K. Recommendations are usually given as lb/a of P_2O_5 and K_2O because fertilizer grades are expressed as percent N - P_2O_5 - K_2O. Following are the factors for converting from one to the other:

ppm x 2.0 = lb/a at a depth of 6 2/3 inches
ppm x 3.6 = lb/a at a depth of 1 foot
P x 2.3 = P_2O_5 or P_2O_5 x 0.43 = P
K x 1.2 = K_2O or K_2O x 0.83 = K

Soil pH Management

Soil pH provides an indication of the acidity or alkalinity of a soil. A pH of 7.0 is neutral, neither acid nor alkaline. Values below 7.0 indicate acid soils, and values above 7.0 indicate alkaline soils. Soil with a pH of 6.0 is mildly acidic, a pH of 5.0 is strongly acidic, and a pH of 8.0 is mildly alkaline.

Nitrogen, phosphorus, potassium, calcium, magnesium, boron and molybdenum are most available in mineral soils when the pH is between 6.0 and 7.0. Zinc, manganese, iron and copper tend to be most available when the soil pH is below 6.5. Therefore, it is desirable to maintain the pH of mineral soils between 6.0 and 6.5. As mineral soils become more acid, especially below 5.5, available aluminum levels increase. Increasing the soluble aluminum concentration contributes to further acidification of the soil and aluminum toxicity, which inhibits root growth. The optimum pH varies by crop. Table 1 lists the target pH values for most field crops grown in Michigan. For organic soils, the target pH ranges from 5.3 to 5.8, depending on the crop. Lower pHs are acceptable in organic soils because aluminum levels are very low. A lime recommendation is given to raise the soil pH to the target pH for the crop being grown. If the subsoil of a mineral soil has a pH below 6.0, increase the target pH by 0.2 pH unit. In organic soils, increase the target pH by 0.2 pH unit when the subsoil pH is less than 4.8. **When crops with different target pH's are being grown in rotation, lime the soil for the crop with the highest target pH.**

Liming Soils

Soils contain soluble and insoluble sources of acidity. The soil pH indicates the soluble or active hydrogen ion concentration in the soil. Changing the pH of acid soils requires neutralizing the insoluble or bound sources of acidity, usually aluminum and iron compounds. The amount of this reserve acidity is determined with the SMP buffer and is reported as the lime index. Table 2 shows how much lime is needed to raise the soil pH to 6.0, 6.5 or 6.8 in mineral soils when mixed with the top 9 inches of soil according to the lime index. Clayey soils tend to be more resistant to pH change (i.e., lower lime

Table 1. Target soil pH values for field crops grown on mineral and organic soils.[1, 2]

Crop	Mineral soils	Organic soils
Alfalfa seeding	6.8	6.0
Alfalfa hay	6.8	6.0
Barley	6.5	5.8
Barley/legume seeding	6.5	5.8
Beans, dry edible	6.5	5.8
Brassica forage	6.5	5.3
Bromegrass hay	6.5	5.3
Buckwheat	6.5	5.3
Canola	6.5	5.3
Clover seeding	6.5	6.0
Clover hay	6.5	6.0
Clover-grass hay	6.5	6.0
Corn grain	6.5	5.3
Corn silage	6.5	5.3
Corn, seed[3]	6.5	5.3[3]
Grass, warm-season (CRP)	6.0	5.3
Grass, cool-season (CRP)	6.0	5.3
Millet	6.5	5.3
Oats	6.5	5.3
Oats/legume seeding	6.5	5.3
Oats for cover	6.5	5.3
Orchardgrass hay	6.5	5.3
Pasture, intensive grazing	6.5	5.3
Pasture, extensive grazing	6.5	5.3
Peppermint	6.5	5.5
Potato	6.0	5.3
Rye grain	6.5	5.3
Rye for cover	6.5	5.3
Sorghum grain	6.5	5.3
Sorghum-Sudangrass hay	6.5	5.3
Sorghum-Sudangrass haylage	6.5	5.3
Soybean	6.5	5.8
Spearmint	6.5	5.5
Spelt	6.5	5.3
Sugar beet[3]	6.5	5.5[3]
Sunflower	6.5	5.3
Timothy hay	6.5	5.3
Trefoil hay	6.0	5.8
Trefoil seed production[1]	6.0	5.8[1]
Wheat grain	6.5	5.8
Wheat/legume seeding	6.5	5.8

[1] Liming the soil above the target pH would not be expected to improve crop yield unless the subsoil pH is less than 6.0 for mineral soils and less than 4.8 for organic soils.

[2] When crops with different target pHs are being grown in rotation, lime the soil for the crop with the highest target pH.

[3] Though a target pH is provided for organic soils, this crop is not recommended to be grown on organic soils.

Table 2. Tons of limestone needed to raise the pH of mineral soils to 6.0, 6.5 or 6.8 on the basis of the lime index, and to raise the pH of organic soils to 5.3 on the basis of the initial soil pH.

Lime index	Mineral soils: Raise soil pH to: 6.0	6.5	6.8	Organic soils: Initial soil pH	Raise pH to: 5.3
	— tons/a —				— tons/a —
70	0.0	0.0	0.0	5.3	0.0
69	0.0	0.6	0.8	5.2	0.7
68	1.2	1.6	1.8	5.1	1.4
67	1.9	2.5	2.9	5.0	2.1
66	2.7	3.5	3.9	4.9	2.8
65	3.5	4.4	4.9	4.8	3.5
64	4.3	5.3	5.9	4.7	4.2
63	5.1	6.3	6.9	4.6	5.0
62	5.8	7.2	8.0	4.5	5.6
61	6.6	8.2	9.0	4.4	6.3
60	7.4	9.1	10.0	4.3	7.1

Recommendations are based on the following equations:

Mineral soils:

Liming to pH 6.0: $XL = 54.2 - (0.78 \times LI)$

Liming to pH 6.5: $XL = 65.5 - (0.94 \times LI)$

Liming to pH 6.8: $XL = 71.2 - (1.02 \times LI)$

Organic soils:

Liming to pH 5.3: $XL = 37.6 - (7.1 \times pH)$

Target pH >5.3 $XL = [37.6 - (7.1 \times pH)] + [(\text{target pH} - 5.3) \times 5.0]$

where:

XL = lime recommendation in tons/acre

LI = lime index

pH = soil pH

index) than sandy soils and require more lime to bring about a given change in soil pH. Recommended lime rates are based on agricultural lime with a neutralizing value (NV) of 90 percent. Adjust lime rate on the basis of the NV of the liming material. Do this by multiplying the recommended amount of lime by 90 and dividing by the NV of the liming material being used — i.e., (lime rate x 90) ÷ NV of liming material.

The lime rate must also be adjusted if the depth of incorporation is different from 9 inches. **For fields being farmed with minimal tillage, apply lime at a rate to neutralize the acidity in the top 3 or 4 inches of soil.** For example, if the lime recommendation is 3 tons per acre-9 inches, then the lime recommendation for 3 inches equals [3 x (3/9)] or 1 ton. The reactivity of liming materials also varies with the particle size and may influence the rate of material to apply. (MSU Extension bulletin E-471 provides more details about liming materials and liming soils.)

On **weakly buffered soils**, usually sandy soils, the SMP buffer may underestimate the lime need. The soil pH may be sufficiently low to warrant a lime application, but the lime index indicates little or no lime is needed. **If the soil pH is 0.3 to 0.5 pH unit below the target pH and the lime index indicates that the lime need is less than 1 ton per acre, then apply 1 ton lime per acre. Similarly, if the soil pH is 0.6 unit or more below the target pH and the lime recommendation is less than 2 tons per acre, apply 2 tons lime per acre.**

Nitrogen Recommendations

Applying the correct amount of nitrogen (N) is important for profitable crop production, water quality and energy conservation. Nitrogen recommendations are based on crop N utilization and response to applied N rates. Table 3 indicates an average amount of N removed in the harvested portion of various field crops. Nitrogen recommendations for field crops, except corn, grown on mineral and organic soils are listed in Table 4. Because of additional mineralization of N in organic soils, the N recommendations for most crops grown on organic soils are 40 to 60 lb/a less than those for mineral soils. For the more responsive crops, such as the cereal grains, canola and sugar beets, the amount of N recommended varies according to the yield expected. It is very important that the expected yield used in this calculation be realistic, based on past yields under favorable growing conditions. Use a five- year running average, omitting unusually low and high yields. Unrealistically high yield goals will result in excess N being applied that might increase the risk to groundwater quality, increase lodging of cereal grains, delay maturity or adversely affect crop quality. Other crops showing less response to applied N receive a static N recommendation.

Table 3. Nutrient removal in harvested portions of several Michigan field crops.

Crop		Unit	N	P_2O_5	K_2O
			— lb/unit of yield —		
Alfalfa	(Hay)[1]	ton	45	13	50
	(Haylage)	ton	14	3.2	12
Barley	(Grain)	bu	0.88	0.38	0.25
	(Straw)	ton	13	3.2	52
Beans (dry edible)	(Grain)	cwt	3.6	1.2	1.6
Brassica forage		ton	11	5.0	22
Bromegrass	(Hay)	ton	33	13	51
Buckwheat	(Grain)	bu	1.7	0.25	0.25
Canola	(Grain)	bu	1.9	0.91	0.46
Clover	(Hay)	ton	40	10	40
Clover-grass	(Hay)	ton	41	13	39
Corn	(Grain)	bu	0.90	0.37	0.27
	(Stover)	ton	22	8.2	32
	(Silage)	ton	9.4	3.3	8
Millet	(Grain)	bu	1.1	0.25	0.25
Oats	(Grain)	bu	0.62	0.25	0.19
	(Straw)	ton	13	2.8	57
Orchardgrass	(Hay)	ton	50	17	62
Peppermint	(Oil)[2]	lb	2.0	1.1	4.0
Potato	(Tubers)	cwt	0.33	0.13	0.63
Rye	(Grain)	bu	1.1	0.41	0.31
	(Straw)	ton	8.6	3.7	21
	(Silage)	ton	3.5	1.5	5.2
Sorghum	(Grain)	bu	1.1	0.39	0.39
Sorgh.- Sudangrass	(Hay)	ton	40	15	58
	(Haylage)	ton	12	4.6	18
Soybean	(Grain)	bu	3.8	0.8	1.4
Spearmint	(Oil)[2]	lb	2.0	1.1	4.0
Spelt	(Grain)	bu	1.2	0.38	0.25
Sugar beet	(Roots)	ton	4.0	1.3	3.3
Sunflower	(Grain)	bu	2.5	1.2	1.6
Timothy	(Hay)	ton	45	17	62
Trefoil	(Hay)	ton	48	12	42
	(Seed)	cwt	3.0	1.25	1.25
Wheat	(Grain)	bu	1.2	0.63	0.37
	(Straw)	ton	13	3.3	23

[1] Biomass yields assume the following moisture contents: corn silage ~ 66%; corn stover at grain harvest ~ 25 to 30%; hay ~ 18%; straw ~ 15%.

[2] Nutrient removal is based on hay harvested, which is estimated from oil produced.

Table 4. Nitrogen recommendations for field crops grown on mineral and organic soils.

Crop	Mineral soil N recommendation — lb N/a —	Organic soil N recommendation — lb N/a —
Alfalfa seeding	0	0
Alfalfa hay	0	0
Barley	**	**
Barley/legume seeding	**	**
Beans, dry edible	40	0
Brassica forage	100	40
Bromegrass hay	160	100
Buckwheat	60	20
Canola	**	**
Clover seeding	0	0
Clover hay	0	0
Clover-grass hay	0	0
Corn grain	*	*
Corn silage	*	*
Corn, seed	180	120***
Grass, warm-season (CRP)	0	0
Grass, cool-season (CRP)	0	0
Millet	60	20
Oats	**	**
Oats/legume seeding	**	**
Oats for cover	40	0
Orchardgrass hay	160	100
Pasture, intensive grazing	160	100
Pasture, extensive grazing	200	140
Peppermint	80	40
Potato	180	120
Rye grain	**	**
Rye for cover	0	0
Rye silage	60	20
Sorghum grain	60	20
Sorghum-Sudangrass hay	150	90
Sorghum-Sudangrass haylage	150	90
Soybean	0	0
Spearmint	80	40
Spelt	**	**
Sugar beet	**	**
Sunflower	80	40
Timothy	100	40
Trefoil hay	0	0
Trefoil seed production	0	0***
Wheat grain	**	**
Wheat/legume seeding	**	**

Equations for calculating nitrogen recommendations

Barley, Canola, Oats, Rye, Spelt, Wheat

Mineral soil: N rec. = A + (B x YP)

Organic soil: N rec. = mineral soil N rec. - 30

Where:

Barley	A = -12	and B = 0.8
Canola	A = 50	and B = 0.8
Oats	A = 0	and B = 0.4
Rye	A = 0	and B = 0.7
Spelt	A = 0	and B = 1.0
Wheat	A = -13	and B = 1.33

Sugar beet

N rec. = 4 x YP

When corn is the previous crop: N rec. = (4 x YP) + 30

* N recommendation based on corn yield, previous crop and N:corn price ratio, see Table 6.

** Uses an equation for calculating N recommendation based on yield potential (YP) and N credit (NC). See Table 5 for nitrogen credits for previous crops. NC for manure = [total N-(NH^{4}-N)]/1,000 gal or ton x mineralization factor x gal or ton/a.

*** Crop is not recommended to be grown on organic soils.

No N is recommended for the legumes because they receive N fixed from the air by symbiotic bacteria. However, these crops will take up N from supplemental sources such as manure or biosolids. Dry edible beans are the exception. They are not as effective in fixing N and benefit from some supplemental N, especially during the early growth stages.

Most legumes leave a significant amount of residual N in the soil. When N-responsive crops are grown in rotation with legume crops, credit should be taken for this amount of residual N. Table 5 presents the average N credits for various legume and rotational crops. Credits may vary depending on the amount of biomass incorporated.

Nitrogen Recommendation for Corn

Nitrogen (N) plays a significant role in the growth, development and yield of corn. Since the mid-1900s, supplemental inputs of N through various N sources, especially legumes and manufactured N fertilizers, have contributed greatly to improvement in corn yields in Michigan. The first increments of N additions result in large increases in grain yield, but with each succeeding increment of N added, the increase in grain yield becomes less until no further increase in yield occurs from additional N (Figures 1, 2). The N recommendation for corn is based on this principle. Many field studies have been conducted over the years to establish the nature of the relationship between corn grain yield and N addition. For many years, MSU's N recommendations for corn were provided in tabular form and based on the yield potential of the soil. More N was recommended for soils with higher yield potentials. Studies indicated that, on average, 1.1 to 1.2 pounds N were required to produce 1 bushel of corn. In the 1970s, the tabular information was used to create a linear N recommendation equation based on yield potential. This equation indicates that the amount of N required is related to the yield potential of the soil. However, the equation may give the mistaken impression that yield can be increased without limit by applying more N. This relation applies only within the bounds of the yield potential of the soil.

Table 5. Nitrogen credit for crops grown the year prior to planting N-responsive crops.

Previous crop	N credit lb N /a
Alfalfa, established[1]	40 + (% stand)
Alfalfa, seeding[2]	40 + 0.5 (% stand)
Clover, established[1]	40 + 0.5 (% stand)
Clover, seeding[2]	20 + 0.5 (% stand)
Trefoil, established[1]	40 + 0.5 (% stand)
Barley + legume	30 + 0.5 (% stand)
Oats + legume	30 + 0.5 (% stand)
Wheat + legume	30 + 0.5 (% stand)
Clover-grass hay	40
Grass hay	40
Dry edible beans	20
Soybeans	30
CRP land[3]	40

[1] Established more than one year.

[2] Six to ~12 months after seeding

[3] Whether grass/legume or just grass.

Corn yield response data collected over the past 10 years show that new corn hybrids are more effective in utilizing N for producing grain. One bushel of corn is being produced, on average, with 0.8 lb N. Summarization of corn yield response to N data in Michigan and other North Central corn-producing states shows that the economic optimum N rate (EONR) is similar across a range of yield potentials. Many states have now adopted the maximum return to N (MRTN) approach to determine the appropriate amount of N to apply for corn. The cost of N increases linearly with rate, whereas the increase in corn grain yield plateaus (Figure 2). Where the difference between the two lines is greatest is the MRTN nitrogen rate. The MRTN nitrogen rate is higher for corn after corn than for corn after soybeans or corn after a small grain because of a rotational/N benefit. When the previous crop is soybeans or a small grain, the N credit is built into the recommendations. Do not take any additional N credit. Nitrogen credits for previous legume crops (see Table 5) or applied manure need to be subtracted from the N recommendations given in Table 6. The MRTN rate will also vary with the productivity or yield potential of the soil. More productive soils tend to mineralize more N. The recommended amount of N

Figure 2. Illustration of maximum return to N (MRTN) concept. This example uses N priced at 40 cents/lb and corn at $4 per bushel. Shaded area is N rate range for ± $1 of the MRTN.

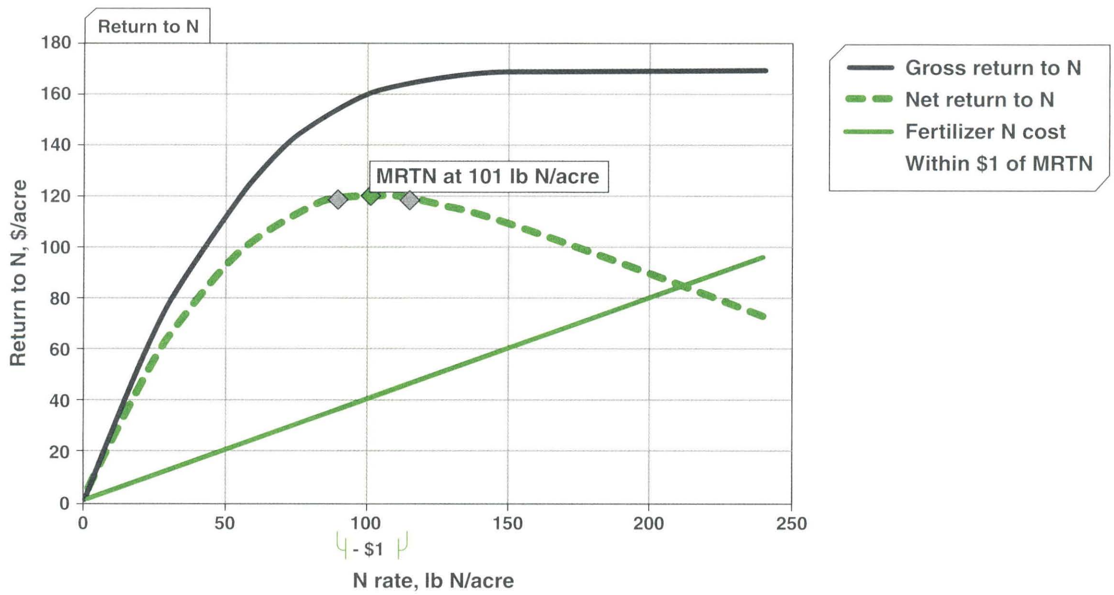

Table 6. Suggested N rates for corn grown in Michigan based on the MRTN approach, 2009.

Soil productivity potential[1]	Previous crop	N cost : corn price ratio 0.05	0.10	0.15	0.20
		Suggested N rate – lb N/acre[2, 3, 4]			
High/very high	Corn	**170** *155-185*	**150** *135-165*	**135** *125-150*	**120** *110-135*
Medium/low	Corn	**140** *130-155*	**130** *120-145*	**120** *110-135*	**105** *95-120*
High/very high	Soybean and small grains	**145** *130-160*	**120** *110-135*	**105** *95-120*	**95** *85-110*
Medium/low	Soybean and small grains	**115** *100-130*	**95** *85-110*	**85** *75-100*	**75** *65-90*
Irrigated sands & loamy sands (CEC ≤ 8.0)	All crops	**210** *195-225*	**190** *175-205*	**175** *160-190*	**165** *150-180*

[1] **Low**: average yield = < 120 bu/a; **medium**: average yield = 121 to 150 bu/a; **high**: average yield = 151 to 180 bu/a; **very high** = more than 181 bu/a *where average yield is the five-year running average (disregard unusual highs and lows).*

[2] Range approximates ± $1 of the maximum return to N (MRTN) rate.

[3] For corn grown on muck soils, reduce the N recommendation by 40 lb/a.

[4] When the previous crop is soybeans or a small grain, the N credit is built into the N recommendations. Do not take any additional N credit. Nitrogen credits for previous legume crops (see Table 5) or applied manure need to be subtracted from the N recommendations.

also varies with the N cost:corn price ratio ($/lb N:$/bu corn). Suggested N rates for corn grown in Michigan based on recent N response data and using the MRTN approach are given in Table 6. More productive soils have soil conditions that are more favorable for mineralization of N, root development and N uptake. Therefore, higher yields can be attained in high productivity soils with only slightly more N fertilizer than in low to medium productivity soils. For corn following corn with an N:corn price ratio of 0.10, the N recommendations are near 130 and 150 lb N/a for low/medium and high/very high productivity soils, respectively. The range of N recommendation for ± $1 of the MRTN is approximately ± 10 to 15 lb N/a. Hence, the range for recommended N will be 120 to 145 and 135 to 165 lb N/a for the previous listed example. As the N cost: corn price ratio increases (i.e., N cost increases relative to the price of corn), the MRTN-recommended N rate decreases.

These recommendations are significantly lower than previous N recommendations. Therefore, farmers may be hesitant to make a complete shift to these recommendations. To test the MRTN recommendations, farmers should put in strips with the MRTN-recommended rate as a comparison to their standard rate and then compare yields and economic return. Research data indicate that the new recommendations will provide the best economic return on investment in N.

For corn silage, having adequate N available to the crop is very important for silage yield and quality. Nitrogen recommendations for corn silage are for an equivalent N cost: corn grain price ratio of 0.10 and vary primarily with yield potential and previous crop. When the previous crop is soybean or a small grain, the N recommendation ranges from 85 to 110 lb/a for yields equal to or less than 19 t/a, and from 110 to 135 lb/a for yields of 20 t/a or greater. When the previous crop is corn, the N recommendations range from 120 to 145 and 135 to 165 lb/a for yields of 19 t/a or less and for 20 tons/a or more, respectively. For irrigated silage corn grown on sandy soils (CEC ≤ 8.0), the N recommendation ranges from 175 to 205 lb/a.

Phosphorus (P) and Potassium (K) Recommendations

Response of crops to additions of P and K is a continuous function. When inadequate amounts are present in the soil, crops respond to P and K additions with increases in biomass and/or grain production according to the general response curve shown in Figures 1 and 3. Recommendations given in this bulletin follow the **buildup, maintenance** and **drawdown** philosophy presented in "Tri-State Fertilizer Recommendations," bulletin E-2567. Figure 3 illustrates this philosophy in combination with a typical response curve. These recommendations provide for **buildup** of available P and K levels when the soil test level is below the critical soil test level (CL) (Figure 3). At the critical soil test level (CL), crop yield will be near 95 to 97 percent of maximum. The **buildup zone** is also the **zone of response or zone of deficiency**, where the amount of P or K ap-

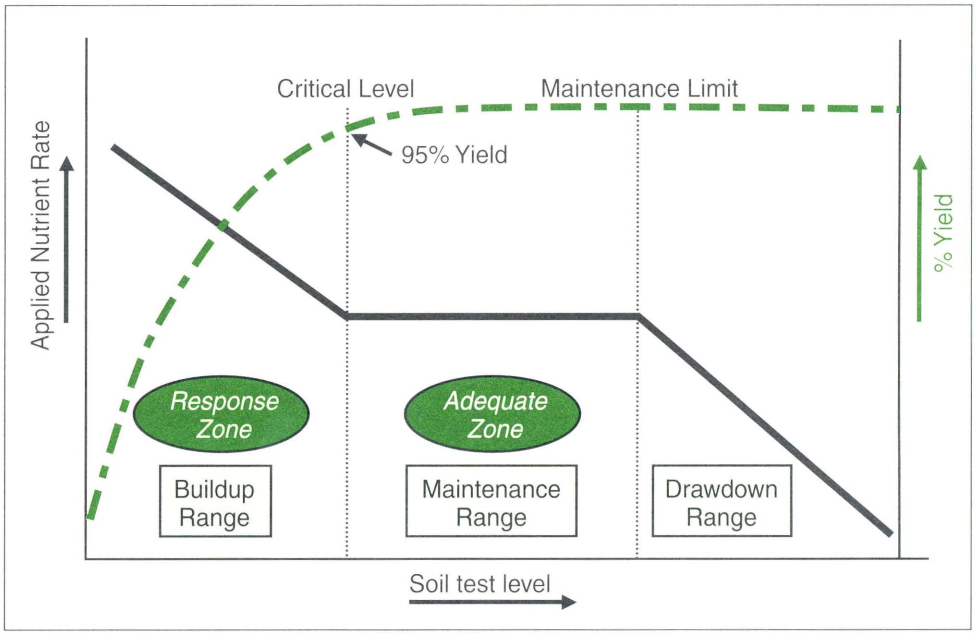

Figure 3. Nutrient recommendation scheme for phosphorus and potassium.

plied to the soil will greatly affect crop growth and yield. When soil test levels are in this zone, the probability of an economic benefit from applied P or K is very good.

Maintenance recommendations (an amount equal to P and K crop removal) are given to keep the available soil P and K levels in the **adequate zone or maintenance range (CL to ML)**. Having soil levels in this range provides insurance against variations due to field and soil sampling variability and usually provides long-term economic benefit. Though some current-season economic benefit from applied P or K fertilizer is possible when soil test values are in the lower end of the maintenance range, the probability is low. When soil test values are near the critical level, economic benefit is more likely to occur from band-applied P and/or K than from broadcast application. Applying amounts of P and K equal to the amounts removed by a crop is expected to maintain the current soil test levels.

Soil test levels in the **drawdown range** (soil test >ML) are more than adequate for top crop production. No additional P or K is needed, and no response to applied P or K should be expected. However, some is recommended to slow the rate of drawdown and allow for field variation. The recommendation goes to zero when the soil test value for P is 10 ppm above the ML and the value for K is 20 ppm above the ML for most field crops.

Crop yield plays an important role in these recommendations. In the buildup zone, the amount of P or K recommended is a combination of the amount required to build up the level in the soil toward the optimum range (CL) plus the amount that will be removed in the harvested portion of the crop. Providing realistic yield goals to the MSU Soil and Plant Nutrient Lab is very important so that you receive nutrient recommendations that are economically and environmentally sound. Table 3 provides a guide for average amounts of nitrogen (N), phosphate (P_2O_5) and potash (K_2O) removed in the harvested portion of major agronomic crops grown in Michigan. The exact amounts may vary with stage of maturity, environmental conditions, and crop type or variety.

Nutrient Use Options

Having available soil P and K levels in the adequate zone (Figure 3) provides the opportunity for excellent yields when growing conditions are favorable. As described previously, applying sufficient P or K to build toward and/or maintain a soil nutrient level in the adequate zone is a preferred management option. Other nutrient management options, however, can result in top yields and better short-term economics of crop production.

Soil test is in the responsive zone or buildup range. Applying only maintenance amounts of P_2O_5 or K_2O in most situations will provide adequate nutrients for near optimum economical crop production at less cost than following the buildup + maintenance recommendation. This approach will maintain the current soil test level — no buildup or drawdown should occur. As the price of P or K increases relative to the value of the crop produced, the amount of nutrient to produce the most economical return will decrease. (See Figure 4.) Application of phosphate in a band placed 2 inches to the side and 2 inches below the seed at planting improves the efficiency of use in comparison with broadcast application and reduces the amount of phosphate needed in a given year. Applying some potash in the fertilizer band can also help reduce the amount of supplemental K_2O needed in a given year. At some time, however, more than maintenance amounts of P_2O_5 and K_2O will need to be applied to replace those used from the soil.

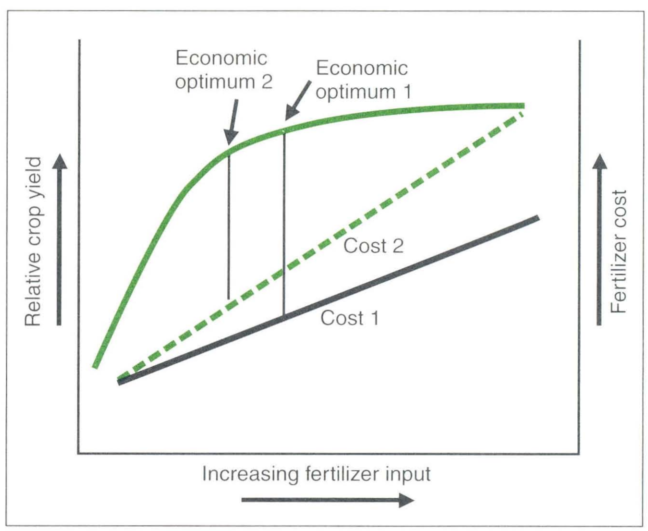

Figure 4. Change in economic fertilizer rate as the cost of fertilizer changes.

Soil test is in the adequate zone or maintenance range. Soil nutrient levels in this range provide flexibility in nutrient management. For the long term, it is good to maintain available nutrients in this range, if financial resources permit. Applying less than maintenance amounts of P_2O_5 or K_2O will result in some decrease in available P or K levels in the soil. For many soils, applying 50 percent of maintenance will result in the soil test value decreasing 2 to 4 ppm P and 5 to 10 ppm K per year, depending on the crop and soil texture. Available nutrient levels will change more quickly in sandy soils than in clayey soils. Depending on the actual soil test level, it may be possible to apply less than a maintenance amount for four to five years without an impact on crop productivity.

Soil test is greater than adequate. There is no yield benefit to applying P and K when the available soil level is greater than adequate. In the drawdown range (10 ppm P and 20 ppm K beyond adequate), some P and K is recommended to slow the rate of drawdown in the soil test value. Also, putting a small amount of P_2O_5 or K_2O in the starter fertilizer band may help stimulate early growth. However, it is perfectly acceptable to apply no P or K and take advantage of the nutrients stored in the soil bank through previous applications of fertilizer, manures or other materials.

As indicated, **P recommendations** take into consideration the soil test level and the crop yield. The buildup portion of the recommendation is intended to build the soil up to the critical value or level (CL), where yield is 95 to 97 percent of maximum. Buildup assumes that, on average, it takes 20 pounds of P_2O_5 to increase the soil test 1 ppm P or 5 lb/a/yr over a four-year period. The P buildup recommendations are given in Table 7. The critical level varies with the crop and its response to P (Table 8). The maintenance plateau for most field crops is 15 ppm on mineral soils. Maintaining the soil test P value in this maintenance zone helps ensure that P will not limit crop yield. When the soil test P value is above the maintenance zone, the soil P level should be drawn down, so the recommendation is less than crop removal. The phosphorus critical levels (CL), maintenance plateau length (PL) and drawdown length (DDL) are given in Table 8 for field crops grown on mineral and organic soils. **The maximum annual phosphorus recommendation for any crop or soil test level is 200 lb P_2O_5/a**.

Equations used to calculate the recommended amount of P_2O_5, in pounds per acre, when the soil test is in each zone.

Mineral soils:

Buildup zone: lb P_2O_5/a = ((CL – ST) x 5) + (YP x CR)
when ST is < CL

Maintenance zone: lb P_2O_5/a = (YP x CR)
when ST is ≥ CL and ≤ ML

Drawdown zone: lb P_2O_5/a = {YP x CR} x {[(CL + PL + DDL) – ST] ÷DDL}
when ST > ML and < (ML + DDL)

Organic soils:

Buildup zone: lb P_2O_5/a = ((CL – ST) x 2) + (YP x CR)
when ST is < CL

Maintenance zone: lb P_2O_5/a = (YP x CR)
when ST is ≥ CL and ≤ ML

Drawdown zone: lb P_2O_5/a = {YP x CR} x {[(CL + PL + DDL) – ST] ÷DDL}
when ST > ML and < (ML + DDL)

where:
- CL = critical soil test value (ppm)
- ML = maintenance limit
- ST = soil test value (ppm)
- YP = yield potential or goal
- CR = nutrient removal in harvested portion of crop (lb/unit of yield)
- PL = maintenance plateau length
- DDL = drawdown length; recommendation is phased to zero

Table 7. Phosphorus buildup recommendations for crops grown on mineral soils.

P soil test	*CL* 15	*20*	*25*	*30*
	Buildup recommendations			
ppm	lb P_2O_5/a			
5	50	75	100	125
10	25	50	75	100
15	0	25	50	75
20	0	0	25	50
25	0	0	0	25
30	0	0	0	0

CL = critical soil test value (ppm)

Table 8. Values for key factors used in calculating the phosphorus recommendations for field crops grown on mineral and organic soils.

Crop	Mineral soil CL[1]	Mineral soil PL[2]	Mineral soil DDL[3]	Organic soil CL[1]	Organic soil PL[2]	Organic soil DDL[3]
	ppm	ppm	ppm	ppm	ppm	ppm
Alfalfa seeding	25	15	10	30	15	10
Alfalfa hay	25	15	10	30	15	10
Barley	15	15	10	40	15	10
Barley/legume seeding	25	15	10	40	15	10
Beans, dry edible	15	25	10	40	15	10
Brassica forage	15	15	10	40	15	10
Bromegrass hay	15	15	10	40	15	10
Buckwheat	15	15	10	40	15	10
Canola	25	20	10	55	15	10
Clover seeding	20	15	10	30	15	10
Clover hay	20	15	10	30	15	10
Clover-grass hay	20	15	10	30	15	10
Corn grain	15	15	10	55	15	10
Corn silage	15	15	10	55	15	10
Corn, seed	20	20	10	55	15	10[4]
Grass, warm-season (CRP)	10	15	10	20	15	10
Grass, cool-season (CRP)	10	15	10	20	15	10
Millet	15	15	10	40	15	10
Oats	15	15	10	30	15	10
Oats/ legume seeding	25	15	10	30	15	10
Oats for cover	25	15	10	30	15	10
Orchardgrass hay	15	15	10	30	15	10
Pasture, intensive grazing	20	15	10	30	15	10
Pasture,extensive grazing	15	15	10	30	15	10
Peppermint	40	30	10	70	15	15
Potato	75	75	50	120	50	20
Rye grain	15	15	10	40	15	10
Rye cover	15	15	10	40	15	10
Rye silage	15	15	10	40	15	10
Sorghum grain	15	15	10	40	15	10
Sorghum-Sudangrass hay	15	15	10	30	15	10
Sorg.-Sudangrass haylage	15	15	10	30	15	10
Soybean	15	15	10	35	15	10
Spearmint	40	30	10	70	15	15
Spelt	15	15	10	40	15	10
Sugar beet	25	15	10	55	15	10[4]
Sunflower	15	15	10	40	15	10
Timothy hay	15	15	10	55	15	10[4]
Trefoil hay	20	20	10	40	15	10
Trefoil seed production	20	20	10	55	15	10[4]
Wheat grain	25	15	10	55	15	10
Wheat/legume seeding	25	15	10	55	15	10

[1]CL = critical P soil test value [2]PL = maintenance plateau length [3]DDL= drawdown length

[4]Though values are provided for organic soils, this crop is not recommended to be grown on organic soils.

Potassium (K) recommendations take into consideration the soil test level and the crop yield. The buildup portion of the recommendation also takes into account the cation exchange capacity (CEC) of the soil. The amount of potassium required to increase the available soil potassium level and reach the critical level (where yield is 95 to 97 percent of maximum) varies with the CEC. The buildup portion of the K recommendation is given in Table 9. The maintenance plateau for most field crops is 30 ppm for mineral soils and 25 ppm for organic soils. In the maintenance zone, the potassium recommendation equals crop removal. When the soil test K value is above the maintenance zone, crops should be allowed to use residual soil K and draw down the soil K level, so the K_2O recommendation is less than crop removal. For most crops grown in mineral soils, the K_2O recommendation goes to zero when the soil test level is 15 ppm beyond the upper maintenance soil test value. The critical levels (CL), maintenance plateau length (PL) and drawdown length (DDL) for field crops are given in Table 10. **The maximum annual K recommendation for any crop or soil test level is 300 lb K_2O/a.**

Table 9. Potassium buildup recommendations for crops grown on mineral soils.

K soil test	CEC, me/100 g: 4	8	12	16
	CL 85	*95*	*105*	*115*
	Buildup recommendations			
ppm	lb K_2O/a			
10	90	119	152	189
20	78	105	136	171
30	66	91	120	153
40	54	77	104	135
50	42	63	88	117
60	30	49	72	99
70	18	35	56	81
80	6	21	40	63
85	0	14	32	54
95	0	0	16	36
105	0	0	0	18
115	0	0	0	0

CL = 75 + (2.5 x CEC)

Equations used to calculate the amount of K_2O, in pounds per acre, when the soil test is in each zone.

Mineral soils:

Buildup: lb K_2O /a = {(CL – ST) x [(1 + (0.05 x CEC)]} + (YP x CR)
when ST is < CL

Maintenance: lb K_2O /a = (YP x CR)
when ST is ≥ CL and ≤ ML

Drawdown: lb K_2O /a = {YP x CR} x {[(CL + PL + DDL) – ST] ÷DDL}
when ST > ML and < (ML + DDL)

Organic soils:

Buildup: lb K_2O /a = [(CL – ST) x 1.5] + (YP x CR)
when ST is < CL

Maintenance: lb K_2O /a = (YP x CR)
when ST is ≥ CL and ≤ ML

Drawdown: lb K_2O /a = {YP x CR} x {[(CL + PL + DDL) – ST] ÷DDL}
when ST > ML and < (ML + DDL)

where:
- CL = critical soil test (ppm); for mineral soils, CL = 75 + (2.5 x CEC)
- CEC = cation exchange capacity (me/100g soil)
- ML = maintenance limit
- ST = soil test value (ppm)
- YP = yield potential or goal
- CR = nutrient removal in harvested portion of crop (lb/ unit of yield)
- PL = maintenance plateau length
- DDL = drawdown length; recommendation is phased to zero

Organic soils. Soil test P and K values for organic soils are handled and calculated on a volume basis. Organic soils have much lower bulk densities than mineral soils, which may have a bulk density of 1 to 1.8 g/cm^3. On average, organic soils will have field bulk densities between 0.65 and 0.70 g/cm^3, but they may vary considerably and may be as low as 0.2 g/cm^3. In general, multiplying the soil test value in ppm by 1.5 will approximate pounds per acre to a depth of 6 2/3 inches. Hence, the critical soil test values are higher for organic soils than for mineral soils.

Calcium (Ca)

Michigan soils generally developed from calcareous parent material and therefore contain sufficient available calcium (Ca) for production of field crops. Soils of the western Upper Peninsula, which developed from acidic

Table 10. Values for key factors used in calculating the potassium recommendations for field crops grown on mineral and organic soils.

	Mineral soil		Organic soil		
	$CL^1 = 75 + (2.5 \times CEC)$				
Crop	**PL[2]**	**DDL[3]**	**CL[1]**	**PL[2]**	**DDL[3]**
	—— ppm ——		—— ppm ——		
Alfalfa seeding	0	50	140	25	95
Alfalfa hay	0	50	140	25	95
Barley	30	20	190	25	15
Barley/legume seeding	30	20	190	25	15
Beans, dry edible	30	20	220	25	15
Brassica forage	30	20	180	25	15
Bromegrass hay	30	20	140	25	15
Buckwheat	30	20	180	25	15
Canola	30	20	220	25	15
Clover seeding	30	20	140	25	95
Clover hay	30	20	140	25	95
Clover-grass hay	30	20	140	25	95
Corn grain	30	20	220	25	25
Corn silage	0	20	220	25	25
Corn, seed	30	20	220	25	25[4]
Grass, warm-season (CRP)	30	20	140	25	15
Grass, cool-season (CRP)	30	20	140	25	15
Millet	30	20	220	25	15
Oats	30	20	160	25	15
Oats/legume seeding	30	20	160	25	15
Oats cover	30	20	160	25	15
Orchardgrass hay	30	20	140	25	15
Pasture, intensive grazing	30	20	140	25	15
Pasture, extensive grazing	30	20	140	25	15
Peppermint	30	20	220	40	60
Potato	30	20	180	60	160
Rye grain	30	20	160	25	15
Rye cover	30	20	160	25	15
Rye silage	30	20	160	25	15
Sorghum grain	30	20	220	25	15
Sorghum-Sudangrass hay	30	20	130	25	100
Sorghum-Sudangrass haylage	30	20	130	25	100
Soybean	30	20	220	25	15
Spearmint	30	20	220	40	60
Spelt	30	20	220	25	15
Sugar beet	30	20	220	40	15[4]
Sunflower	30	20	220	25	15
Timothy hay	30	20	220	25	15[4]
Trefoil hay	30	20	140	25	15
Trefoil seed production	30	20	220	25	15[4]
Wheat grain	30	20	220	25	15
Wheat/legume seeding	30	20	220	25	15

[1]CL = critical K soil test value [2]PL = maintenance plateau length [3]DDL= drawdown length

[4]Though values are provided for organic soils, this crop is not recommended to be grown on organic soils.

parent materials, are the only major exception. Even soils that have become acidic and need lime generally contain sufficient Ca to meet the needs of field crops. Poor plant growth in acid soils is usually due to the excess uptake of aluminum and/or manganese rather than Ca deficiency. The best way to be sure that soils contain adequate Ca is to soil test regularly and apply lime as needed. Supplemental Ca may improve tuber quality of potatoes grown on sandy soils containing less than 300 ppm exchangeable Ca. Maintaining adequate soil moisture is important for adequate Ca uptake.

Studies in Michigan, Indiana, Ohio and Wisconsin have shown alfalfa and corn to yield equally well over a wide range of calcium to magnesium (Ca:Mg) ratios. Adding Ca to improve the Ca:Mg ratio is not necessary unless the amount of Mg equals or exceeds Ca on an equivalence basis (milliequivalents per 100 grams soil). Adding Ca to modify the Ca:Mg ratio may actually induce a Mg deficiency in sandy soils. The Ca:Mg ratio may be helpful in determining whether to use calcitic (contains Ca) or dolomitic (contains both Ca and Mg) limestone when lime is needed.

Magnesium (Mg)

Magnesium (Mg) deficiency is most likely to occur in acid sandy soils with a subsoil as coarse or coarser than the surface soil. These soils are most common in the southwestern and western areas of Michigan. Use dolomitic limestone (contains Ca and Mg) on low-Mg acid soils to neutralize soil acidity rather than using calcitic lime or marl (they contain primarily Ca), which may induce a Mg deficiency. Potatoes, corn and oats are the field crops most sensitive to marginal Mg levels.

Application of Mg is recommended on the basis of one of the following criteria: when the soil test value is less than 35 ppm on sandy soils or less than 50 ppm on fine-textured soils, when Mg is less than 3 percent (as a percent of exchangeable bases on an equivalence basis) or when exchangeable K exceeds the percent Mg on an equivalence basis (milliequivalents per 100 grams of soil). On acid soils where Mg is needed, apply at least 1,000 pounds of dolomitic limestone per acre. For non-acidic soils low in Mg, broadcast 50 to 100 pounds of actual Mg/a, or include 10 to 20 pounds of Mg/a in band-placed fertilizer. Suitable sources of Mg include magnesium sulfate, potassium-magnesium sulfate and granulated finely ground magnesium oxide-magnesium sulfate (granusols). Broadcasting 200 to 400 pounds of dolomitic limestone on non-acidic soils is also an acceptable practice because it will cause only a modest increase in soil pH. Magnesium deficiencies can be corrected by spraying 1 to 2 lb Mg/a on the crop foliage. When lower rates than this are used, multiple applications may be required.

Magnesium deficiency may be induced by applying high rates of K fertilizer. This can result in a grass tetany disorder in livestock that feed on lush grass. Where forages are being grown, agronomists frequently strive for Mg to be 10 percent of the total exchangeable bases (equivalency basis). If there is concern about grass tetany, avoid applying high rates of K (more than 200 lb/a) in a single application. Use of supplemental Mg in the feed ration may also help avoid grass tetany. Contact your animal feed specialist for guidance.

Sulfur (S)

Plants take up sulfur (S) in amounts similar to P. The primary sources of plant-available S are soil organic matter (maintain with additions of animal manures, plant residues or other organic residuals) and atmospheric deposition. Significant reductions in S from atmospheric deposition have increased the potential for S deficiency. Crops growing in sandy soils low in organic matter are the most likely to show S deficiency. Studies in the past with S-responsive crops grown on potentially S-deficient sites in Michigan have not shown these crops to benefit from supplemental S application. Many soils have an accumulation of S in the subsoil that the crops access once the roots reach that depth, especially where there is an increase in clay content in the subsoil. Crops most likely to benefit from S application are alfalfa and canola. Other crops that may respond to S application include wheat and other small grains, some grasses, soybeans and corn. New studies are needed to reevaluate the need for S by other crops grown in Michigan soils.

Micronutrient Recommendations

Micronutrient recommendations are based on soil test, soil pH and crop responsiveness. The responsiveness of selected field crops is given in Table 11. Equations used to calculate the recommended amounts to apply are given at the beginning of each section.

Boron (B)

Boron (B) recommendations are based on crop response, not on soil tests. A boron soil test (hot-water soluble) can provide a general guide to whether the status is low (<0.7 ppm), marginal or adequate (>1 ppm). Boron occurs in the soil primarily as a water-soluble anion that is subject to leaching, so the available B status may change over time, especially in sandy soils. Boron readily leaches out of sandy soils over the winter and early spring months when precipitation exceeds evapotranspiration. Some leaching may also occur in fine-textured soils but to a lesser degree. For responsive crops such as alfalfa, B deficiency may occur when soil moisture is marginal even though the soil contains adequate B. This frequently occurs during the growth period of the second and/or third cutting . Application of 2 lb B/a per year is recommended for alfalfa grown on sandy soils (CEC <8.0 me/100 grams soil). On fine-textured soils, B application is usually not beneficial except for high-yielding established alfalfa fields, where a topdress B application (0.5 to 1 lb/a) is suggested.

Depending on variety grown, sugar beets may benefit from B application. Sugar beet varieties used to be quite responsive to supplemental B. More recently (over the past 10 or so years), research with newer sugar beet varieties showed supplemental boron was not necessary when beets were grown in the fine-textured soils of the Thumb and Saginaw Valley areas. Within the past two years, some boron deficiency has been observed in sugar beets grown in these same fine-textured soils. Therefore, application of 1 lb B/a may again be beneficial. On loamy sands and sandy loams, 2 lb B/a is suggested. Field beans, soybeans and small grains are sensitive to B application. For these crops, avoid using B in the starter fertilizer. The residual B level from a previous year's application should not be of concern for these sensitive crops unless higher than recommended rates were applied.

Manganese (Mn)

For responsive crops, recommended amounts of manganese (Mn) are based on the (0.1 N HCl) soil test (ST) value and soil pH according to the following equations:

Mineral soils:	Mn rec. = [(6.2 x pH) – (0.35 x ST)] –36
Organic soils:	Mn rec. = [(8.38 x pH) – (0.31 x ST)] –46
where:	Mn recommendation is lb Mn/a (band application only)
	ST is soil test value (ppm Mn)

Manganese availability decreases markedly as soil pH increases. In mineral soils, the critical soil test value is 6 ppm at pH 6.3 and 12 ppm at pH 6.7. In organic soils, the critical soil test value is 4 ppm at pH 5.8 and 16 ppm at pH 6.2. Liming acid soils may induce a Mn deficiency. Manganese deficiency is most likely to occur on organic soils with a pH above 5.8 and on dark-colored mineral soils in lake-bed and glacial outwash areas with a pH above 6.5. Recommended rates of Mn are for band application because Mn is readily bound into unavailable forms when mixed (broadcast and incorporated) with the soil. Flooding and fumigation temporarily increase Mn availability, but it readily decreases once the soil dries and microbial populations are reestablished. Manganese sulfate has proven to be the most suitable carrier for soil application, though granulated finely ground manganous oxide-sulfate mixtures (granusols) and some chelates are also acceptable sources when banded in mineral soils. Manganese chelates are not recommended for application in organic soils. Building up the available Mn status of soils is difficult. Therefore, if a Mn deficiency occurs in a field one year, it will likely reoccur each year, especially when sensitive crops are grown.

Oats, dry edible (field) beans, potatoes, soybeans, sorghum-Sudangrass, sugar beets and wheat are the crops most responsive to Mn. Under high pH conditions, barley may also respond to Mn application. On organic soils, corn may respond. Manganese deficiency in these crops can be alleviated by spraying the crop foliage with 1 to 2 lb Mn/a. When the deficiency is severe and lower rates are used, multiple applications may be necessary. If symptoms persist or appear on the new foliage 10 days after application, make another application. Some Mn carriers have been shown to reduce the efficacy of

Table 11. Micronutrient responsiveness level for selected field crops.

Crop	Boron	Copper	Manganese	Zinc
Alfalfa seeding	M	M	L	L
Alfalfa hay	H	M	L	L
Barley	L	M	M	L
Barley/legume seeding	M	M	M	L
Beans, dry edible	L	L	H	H
Brassica forage	M	M	M	L
Bromegrass hay	L	L	M	L
Buckwheat	L	L	M	L
Canola	L	H	H	L
Clover seeding	M	M	M	L
Clover hay	M	M	M	L
Clover-grass hay	M	M	M	L
Corn grain	L	M	M	H
Corn silage	L	M	M	H
Corn, seed	L	M	M	H
Grass, cool-season (CRP)	L	L	M	L
Grass, warm-season (CRP)	L	L	M	L
Millet	L	M	H	H
Oats	L	H	H	L
Oats/legume seeding	M	H	H	L
Oats for cover	L	M	M	L
Orchardgrass hay	L	L	M	L
Pasture, extensive grazing	L	L	M	L
Pasture, intensive grazing	L	L	M	L
Peppermint	L	L	M	L
Potato	L	L	H	M
Rye grain	L	L	L	L
Rye cover	L	L	L	L
Rye silage	L	L	L	L
Sorghum grain	L	M	H	H
Sorghum-Sudangrass hay	L	M	H	M
Sorghum-Sudangrass haylage	L	M	H	M
Soybean	L	L	H	M
Spearmint	L	L	M	L
Spelt	L	M	M	L
Sugar beet	M	M	H	M
Sunflower	M	M	M	M
Timothy hay	L	L	M	L
Trefoil hay	M	M	M	L
Trefoil seed production	M	M	M	L
Wheat grain	L	H	H	L
Wheat/legume seeding	L	H	H	L

Responsiveness is relative to when the soil contains low available levels of the micronutrient.
H = highly responsive; M = medium; L = low.

glyphosate when the two are tank mixed together or sprayed sequentially within 48 hours. Manganese EDTA (ethylenediaminetetraacetic acid) has shown minimal adverse effect.

Zinc (Zn)

For responsive crops, recommended amounts of zinc (Zn) are based on the (0.1 N HCL) soil test (ST) value and soil pH, according to the following equations:

Mineral and
organic soils: Zn rec. = [(5.0 x pH) – (0.4 x ST)] – 32
where: Zn recommendation is lb Zn/a
ST is soil test value (ppm Zn)

Michigan soils with a pH below 6.5 generally contain adequate Zn to meet the needs of field crops. At pH 6.6, the critical soil test value is 2 ppm; at pH 7.0, it is 7 ppm. Zinc deficiency is most likely to occur on the alkaline mineral soils of the lake-bed regions of eastern Michigan and on near neutral to alkaline organic soils. Deficiencies are also likely to occur on spoil-bank areas and areas where tiles were trenched into calcareous subsoil. High rates of P may enhance the occurrence of a Zn deficiency when the available soil Zn status is marginal. Dry edible beans, corn and sorghum-Sudangrass are the field crops most sensitive to low levels of available Zn. Band application of the recommended Zn rate is preferred, but broadcast application of 10 lb/a or more is effective in meeting the need of the crop and building up the soil level. Annual band applications will gradually build up available Zn levels and eliminate the need for further applications. Zinc sulfate, granulated finely ground zinc oxide-sulfate mixtures and chelates are good sources of Zn for soil application. Chelates are actually more effective than the inorganic salts in improving the Zn availability for a given growing season. The recommended rate for Zn chelates is one-fifth the rate calculated above for the inorganic salts.

Copper (Cu)

Copper (Cu) is recommended for organic soils based on the 1 N HCl soil test.

Cu rec. = 6 – (0.22 x ST)
where: Cu recommendation is lb/a
ST is soil test value (ppm Cu)

The mineral soils of Michigan generally contain adequate amounts of Cu. Soil test values greater than 0.5 ppm (1N HCl extractable) indicate adequate Cu availability. Acid sandy soils that have been heavily cropped are the most likely of the mineral soils to show a Cu deficiency. Organic soils are naturally low in available copper, and many field crops will respond to Cu application when grown on these soils. Once applied to the soil, Cu remains available. Therefore, Cu levels may have been improved by past applications to the soil or by Cu fungicide sprays in fields that have been in production for a long time. The 1N HCl soil test is a good indicator of copper availability in organic soils. No further Cu is needed for most field crops once a total of 20 lb Cu/a have been applied to an organic soil or the soil test exceeds 20 ppm. Alfalfa, sorghum-Sudangrass, oats and wheat are the crops most sensitive to low soil Cu. When grown on high organic matter sandy soils, these crops may benefit from the application of 2 to 4 lb Cu/a. Copper sulfate and copper oxide are both effective sources of copper applied either broadcast or in a band. Copper chelates are also good sources of Cu and may actually be slightly more effective than the inorganic salts.

Managing Nutrient Inputs

Commercial fertilizers supply nutrients in forms that are concentrated, easily handled and applied, readily soluble and available for plant uptake.

Manures, biosolids and composts are also good sources of plant nutrients. The inorganic fertilizer salts of N, P and K are readily available. Some nutrients in organic forms are gradually released over time as they are decomposed by microorganisms. On average, 50 percent of the N in manures will be released during the year of application, and 80 percent of the P and 100 percent of the K are available. The numbers for biosolids will vary with type and treatment, but usually N release will be near 25 to 30 percent, P about 50 percent and K 100 percent the year of application. The composting process tends to stabilize the N components so that only about 10 percent of the N in compost becomes available during the application year. Injection or immediate incorporation of manures or biosolids is necessary not only to reduce odor concerns but also to minimize volatile N loss, primarily as ammonia. The nutrient content of commercial fertilizers is indicated by the grade on the label. Values for manure may vary by type and how it is handled. Table 12 gives the nutrient content range that occurred in animal manures collected from numerous farms. Because of this high degree of variability, organic nutrient carriers — manures, biosolids, composts — need to be analyzed to determine the nutrient content. Once this is known, the amount to apply to meet the nutrient requirements of a crop to be grown or the amount of nutrient credit to take for organic residuals already applied can be calculated.

Table 12. Range in nitrogen, phosphate and potash content of various animal manures showing farm to farm variation.

Type of manure	N	P_2O_5	K_2O	N	P_2O_5	K_2O
	— lb/ton —			— lb/1,000 gal —		
Dairy	5-16	2-16	2-31	3-51	2-21	2-58
Beef	4-20	1-13	3-29	6-37	1-29	5-30
Swine	3-27	1-62	2-18	1-61	1-63	1-49
Poultry	1-111	1-96	2-55	35-75	13-91	13-39

Environmental Considerations

Environmental considerations should be taken into account whenever nutrients are applied. Nitrogen and phosphorus are the nutrients of greatest concern. Excess N applications and certain environmental conditions may cause losses of N from the soil to groundwater and air. In sandy soils, excess water from rainfall or irrigation can cause nitrate-N to leach into groundwater. On finer textured soils, nitrate-N may be leached into subsurface drainage water and can also be lost into the air through denitrification when the soil is warm (above 50 degrees F) and wet. Environmental concerns related to P are primarily related to surface water quality. Phosphorus can be transported to surface waters via soil erosion or surface water runoff. In soils with excessively high soil P test values, P can also be leached into tile drains that discharge directly into surface waters. Phosphorus in surface water can lead to eutrophication, which occurs when elevated nutrient concentrations in water create conditions favorable for excess algal and aquatic plant growth, which may result in fish kills, loss of quality for recreational use and increased costs for industries using that water.

Phosphorus Management

Phosphorus is generally an immobile nutrient in soils, especially at low soil test levels. Addition of P fertilizer results in P binding to the soil and becoming slowly available for plant uptake. For soils testing low in P, broadcast applications are less efficient and will normally result in lower yields than band applications. Broadcast P fertilizer is effective in building up P soil test levels, however. Applying starter fertilizer in a band to the side and below the seed is considered the most efficient placement for P. When soil test P levels are high, broadcast applications of P fertilizer are not likely to improve yields but will build or maintain soil test levels. On soils with high soil test P levels (no fertilizer recommendation), the benefit of applying P in a starter fertilizer is not consistent. On high-P soils, there is only about a 10 percent chance of having a yield response to starter fertilizer. The probability of an economic response depends on the amount of yield increase and the cost of the starter fertilizer. The response to starter fertilizer on high-P soils is more likely caused by N than by the additional P. If starter fertilizer containing P is used on a high-P soil, apply it at a rate well below crop P removal. For corn (grain), this would be about 25 to 30 lb P_2O_5/a; for sugar beet, 20 to 25 lb P_2O_5/a.

Nitrogen Management

Forms of Nitrogen Fertilizer

Nitrate forms of N fertilizer are more subject to loss than other N forms. For example, calcium nitrate and ammonium nitrate are readily available sources of N for plants, but the nitrate-N is immediately subject to leaching when added to soil. Therefore, nitrate forms of N should not be used where leaching potential is high. Ammonium forms of N, such as urea, anhydrous ammonia or urea ammonium nitrate (UAN or 28 percent N solution), are preferred sources of N for most crops because they are less subject to immediate leaching when added to soil. Ammonium N must be converted to nitrate N before it can be leached or denitrified. This conversion to nitrate-N will take time under cool or dry conditions, but it can occur rapidly under warm, moist conditions.

Nitrogen can also be lost by volatilization of gaseous ammonia from urea or N solutions containing urea when they are surface applied and not incorporated. Because the volatilization loss is difficult to assess and represents an economic loss to the farmer, all urea-containing fertilizers should be incorporated.

Timing of Nitrogen Fertilizer and Split Applications

Spring applications of N in the semihumid regions of the United States, including Michigan, have clearly been shown to be superior to fall applications (Table 13). Climatic conditions from fall to spring significantly affect the amount of N lost. Estimates of N losses from fall applications vary from 10 to 20 percent on fine- to medium-textured soils (clay, clay loams and loams) and from 30 to more than 50 percent on coarse-textured soils (sandy loams, loamy sands and sands). Although applying N in the fall on fine-textured soils may have certain economic benefits, the environmental risks of this practice generally outweigh the potential economic benefits. Fall applications of N are not warranted in Michigan and should be discontinued except for small applications on fall-seeded wheat.

Table 13. Yield of corn as affected by nitrogen rate, time of nitrogen application and soil type (11 experiments from 1977 to 1984).

Nitrogen rate[1]	Time of application Fall	Spring
lb/a	bu/a	
	Loamy soils (5 experiments)	
100[2]	118	133
150	127	154
	Irrigated sandy loam soils (6 experiments)	
100	162	172
150	176	181

[1] Applied as anhydrous ammonia knifed in at 30-inch spacings.

[2] Experiments in 1983 and 1984 received 75 lb N/a.

Yield benefits from split or sidedress N applications for corn are frequently observed on coarse-textured soils. Although the benefits of sidedress N on fine-textured soils are less frequently seen, there is no question that sidedress N applications on fine-textured soils can improve N recovery. Sidedress N applications also allow time for the grower to adjust N rates on the basis of soil nitrate tests. For these reasons, corn producers should seriously look at sidedress N applications on all soil types to improve N use efficiency.

Waiting until the corn is well-established before applying large amounts of N has two major advantages: nitrate N losses between preplant and sidedress are eliminated, and yield potential can be more accurately determined at sidedress time. Poor stand, poor weed control and/or dry weather at sidedress time are good reasons for adjusting the yield goal downward and reducing the total amount of N to be applied. The risk of being unable to sidedress N because of wet weather can be greatly reduced if corn is sidedressed when it is 3 to 4 inches tall instead of 1 foot tall. The benefits of sidedressing N when the corn is 1 foot tall or higher, rather than 3 to 4 inches tall, are minimal. As high-clearance tractors become more popular, the risk of being unable to sidedress corn because of wet weather is also minimized.

Applying nitrogen fertilizer through an irrigation system offers several advantages for irrigators: N can be applied when the crop's demand is greatest, the technique requires little additional energy for application, and the practice is well-suited to sandy soils where irrigation is needed and leaching can be a serious problem. Up to two-thirds of the total N requirements of corn may be supplied by this method. Some irrigators choose to apply one-third of their N at planting, one-third at sidedress time and one-third through the irrigation system. Depending too much on the irrigation system to supply N can have its drawbacks. Rain during the early growing season may prevent crop producers from using their irrigation systems. If no previous N was applied, this could result in an N shortage early in the season. To eliminate this problem, some crop producers have modified their center-pivot systems so they can apply only a very small amount of water in one application. This allows them to apply N through irrigation regardless of rainfall patterns. More important is not to overirrigate during the early part of the growing period, June and July, because nitrate-N concentrations, which are most subject to leaching loss, are highest during this time.

Nitrification Inhibitors

Crop producers in many states have successfully used nitrification inhibitors to delay the conversion of ammonium-N to nitrate-N. Preventing rapid conversion of ammonium to nitrate can reduce the amount of nitrate-N that is available for denitrification or leaching early in the growing season.

Crop producers should consider using nitrification inhibitors when it is not feasible to use delayed N applications such as sidedressing or applying through an irrigation system. Nitrification inhibitors can be beneficial if N applications are made in early spring and leaching or denitrifying conditions exist. Nitrification inhibitors are designed to improve N use efficiency and minimize N loss. The amount of N used is very crucial to meeting this goal. **Nitrification inhibitors are best applied with slightly less than the recommended N amount**. If the rate of N fertilizer applied is adequate or excessive, no economic benefits can be expected. Nitrification inhibitors can improve N recovery when used appropriately, but they should not be used as a substitute for following other recommended management practices.

Urease Inhibitors

When urea is applied on the soil surface, N can be lost as volatile ammonia as urea is converted into inorganic N forms by the enzyme urease. This is of most concern when dry urea (46 percent N) or urea-ammonium nitrate (UAN) solution (which contains 50 percent urea) is applied to no-till fields either preplant or as a topdress. Urease inhibitors slow the conversion process and provide more time for rain or irrigation to move the urea into the soil, where the released ammonia is adsorbed to the soil. Volatile N loss from urea is of most concern at higher soil and air temperatures, especially above 60 degrees F. Therefore, the potential for loss would be greater for topdress than for preplant-applied urea. When urea is incorporated into the soil, volatile N loss is not a concern. Placing urea or UAN into the soil with a disc opener or knife or by tillage will eliminate the concern about volatile N loss.

Soil Nitrate Testing

Nitrate is the form of N that is most available to plants. Soil type, rainfall and temperature greatly affect the seasonal availability of N to plants. Under wet conditions, N losses can occur by leaching from the rooting zone and/or by denitrification from the soil. Denitrification is a microbial process that occurs rapidly when soils become water-saturated and temperatures are warm (above 50 degrees F). Denitrification is the conversion of nitrate to some form of nitrous oxide. Nitrate leaching can occur at any soil temperature. Denitrification losses are greatest on fine-textured soils with poor internal drainage; leaching losses are greatest on coarse-textured sandy soils with good internal drainage. The seasonal availability of nitrate-N should be assessed each year and matched to crop needs.

Soil nitrate testing is an excellent and inexpensive way of evaluating the available N status of your soil. Michigan State University research and demonstration studies have shown that corn producers can reduce their N fertilizer application rate without the risk of reducing yields if they use the soil nitrate test. Nitrate testing can also help to prevent overapplication of N fertilizers. The soil nitrate test measures only nitrate-N — it does not measure ammonium-N or organic N.

Although soil samples may be taken anytime to establish the available N status, the best time to take samples is in late May and early June after the soil has warmed up and before sidedressing. The soil usually contains the greatest amount of nitrate-N during this time. The presidedress nitrate test (PSNT) measures both residual nitrate N from the previous year and N that has mineralized (become available) from organic matter, crop residues and manures during the spring. Soil samples taken in early spring (April or May) will contain primarily residual nitrate. Although testing in early spring may still be helpful in assessing how much additional N is needed, samples taken just before sidedress time provide the greatest advantage in determining the appropriate rate of sidedress N.

Manured fields and fields where the previous crop was a legume will likely contain the most nitrate-N. Early sampling of these fields will not result in the maximum

N credit because ammonium-N and easily decomposed organic N will not yet have been converted to nitrate-N and will not be measured by the test. Therefore, only the PSNT is recommended for these fields.

Other fields that show high nitrate-N levels are fields with medium- and fine-textured soils (loam, clay loam and clay) that have been heavily fertilized in previous years. Sandy soils, even though heavily fertilized the previous year, may not show much N carryover because nitrate N can easily be lost by leaching.

PSNT soil samples are best taken shortly before side-dressing (when the corn is anywhere from 3 to 12 inches tall). At least 15, 1-foot-deep soil cores should taken across no more than 20 acres and mixed together to make a sample. Samples should be dried immediately before sending or kept cold until delivered to a laboratory. Nitrogen credits are assigned on the basis of the outcome of the nitrate test. The PSNT results will be more accurate if less than 40 lb N/a is applied at or before planting.

Stalk Nitrate Testing

The nitrate concentration in the lower part of the cornstalk after black layer formation in the grain can provide an indication of the efficiency of the N management program. Concentrations between 450 and 2,000 ppm generally indicate good nitrogen use efficiency with optimum yields and limited residual soil N. Values below 450 ppm may indicate very efficient N use and optimum yields or a corn crop that ran short on N with some reduction in yield. Values above 2,000 ppm indicate more N was available than was necessary. Maintaining a database of stalk nitrate values from field to field and from year to year will enable appropriate adjustment of N rates.

Crop Rotations, Forages and Cover Crops

Crop rotations can be very beneficial in a successful crop production system. For example, a corn-soybean rotation is preferable to a continuous corn rotation because continuous corn requires more N fertilizer to obtain the optimum yield. Some of the yield improvement may be due to the rotational effect — i.e., better disease, insect and weed control, and improved soil tilth — and some to N fixation by soybeans. Rotation with other non-legume crops has also been shown to produce better yields of corn with less N fertilizer, especially corn following wheat and other small grains. Including wheat in the rotation has been found to increase corn yields by at least 10 percent. In Michigan studies, when wheat was followed by a cover crop, such as frost-seeded red clover, corn yields were always increased by at least 15 percent over those of continuous corn.

Cover crops such as oats, barley or rye, seeded after crop harvest, can be very beneficial in taking up residual soil N and in preventing wind and water erosion. They protect the soil surface from erosion and thereby reduce the risk of nutrient losses by runoff as soluble nutrients or erosion as sediment. Cover crops may also be used as green manure crops to take up nitrate-N and prevent it from being leached to groundwater. Oilseed radish is quite effective at this but must be seeded in August or early September. This practice is well-suited to many soils in Michigan and could be used more effectively than it is now. One of the keys to utilizing cover crops successfully is to get them established in early fall so that they have a chance to take up excess nitrate-N before winter dormancy and excessive precipitation occur.

Calibration of Equipment

Evidence of uneven fertilizer distribution due to improperly adjusted fertilizer spreaders can be seen almost every year, particularly on winter wheat. Uneven distribution of fertilizer results in overfertilization in some areas of the field and underfertilization in others. The result is less than optimum whole-field yields and potential loss of excess nutrients to surface water and groundwater.

All fertilizer applicators need to be accurately calibrated. If crop producers are unsure whether the equipment they are using is properly calibrated, they should recalibrate the equipment to avoid crop yield loss and potential risk to the environment. Improving the calibration of fertilizer applicators will result in more uniform distribution of the fertilizer at the proper rate.

Suggested Nutrient Management Practices for Individual Crops

Soil test to determine lime and nutrient requirements!

Corn Grain and Corn Silage

Nitrogen recommendations are based on field data and are designed to provide the maximum return on the investment in N. These recommendations are given in Table 6. The total amount of N to apply depends on the soil productivity (potential yield based on a five-year running average, disregarding unusual lows and highs), previous crop and the N cost:corn price ratio ($/lb N:$/bu corn). The N recommendations for silage corn are those used for the N:corn price ratio of 0.10 with the break between low/medium yields and high/very high yields being 19 ton/a.

Phosphorus and K recommendation guidelines are given in Tables 14, 15, 16 and 17.

In Michigan, soils are usually quite cool when much of the corn is planted. Placement of fertilizer 2 inches to the side and 2 inches below the seed at planting can enhance early growth. At this placement, the starter fertilizer can supply up to 40 pounds of N, 100 pounds of phosphate (P_2O_5) and 100 pounds of potash (K_2O) per acre. Applying an amount of P_2O_5 equal to crop removal will help maintain the available P level in the soil when the soil test value is above the critical value of 15 ppm. Inclusion of P in starter fertilizer when the soil P level is high may enhance early growth but seldom increases grain yield. Potassium in the starter fertilizer is most beneficial when planting no-till or planting into soil with a heavy layer of surface residue. Broadcast and incorporate preplant amounts of P and K required to build up the soil levels. (See Tables 7 and 9.)

Nitrogen may be managed with a combination of application times: preplant, planting time and/or sidedress. Apply preplant N as close to planting time as possible to reduce the risk of N loss. Fall application of N is not recommended because of the potential for leaching loss, even with a nitrification inhibitor. Sidedress N application made on the basis of the PSNT when the corn is 3 to 12 inches tall provides the most efficient use of N inputs. Irrigating corn increases the yield potential and the fertilizer requirements. A significant portion of the N may also be applied through the irrigation system. One approach is to apply two-thirds of the N in some combination of preplant, planting-time and/or sidedress applications and the remainder through the irrigation system.

Soybeans

Phosphorus and K recommendations are given in Tables 18 and 19.

Soybean is a legume that can meet its N needs by symbiotic fixation of atmospheric nitrogen. In general, soybeans will not benefit from supplemental N application. Soybeans are widely grown in Michigan. Most fields have adequate indigenous populations of the appropriate Bradyrhizobia bacteria strains that cause effective nodulation of soybean roots and N fixation.

Table 14. Phosphorus recommendations for selected yields of corn (mineral soils).

	Yield (bu/a)	
Soil test	140	180
ppm	— lb P_2O_5/a —	
5	102	117
10	77	92
15-30	52	67
35	26	33
40	0	0

Numbers highlighted are maintenance amounts.

Table 15. Phosphorus recommendations for selected yields of corn silage (mineral soils).

	Yield (t/a)	
Soil test	140	180
ppm	— lb P_2O_5/a —	
5	116	149
10	91	124
15-30	66	99
35	33	50
40	0	0

Numbers highlighted are maintenance amounts.

Table 16. Potassium recommendations for selected yields of corn (mineral soils).

Soil test	140 bu/a				180 bu/a			
CEC	4	8	12	16	4	8	12	16
ppm	— lb K_2O/a —				— lb K_2O/a —			
40	92	115	142	173	103	126	153	184
80	44	59	78	101	55	70	89	112
85	38	52	70	92	49	63	81	103
95	38	38	54	74	49	49	65	85
105	38	38	38	56	49	49	49	67
115	38	38	38	38	49	49	49	49
125	19	38	38	38	25	49	49	49
135	0	19	38	38	0	25	49	49

Numbers highlighted are maintenance amounts.

Table 17. Potassium recommendations for selected yields of corn silage (mineral soils).

Soil test	20 t/a				30 t/a			
CEC	4	8	12	16	4	8	12	16
ppm	— lb K_2O/a —				— lb K_2O/a —			
40	214	237	264	295	294	300	300	300
80	166	181	200	223	246	261	280	300
85	160	174	192	214	240	254	272	294
95	160	160	176	196	240	240	256	276
105	160	160	160	178	240	240	240	258
115	160	160	160	160	240	240	240	240
125	80	160	160	160	120	240	240	240
135	0	80	160	160	0	120	240	240

Numbers highlighted are maintenance amounts.
Maximum annual recommendation is 300 lb K_2O/a.

Where soybeans have not been grown recently, inoculation of the soybean seed with soybean-specific Bradyrhizobia strains is essential for effective nitrogen fixation.

Soybeans are more sensitive to fertilizer placement and rate than corn. Starter fertilizer placed 2 inches to the side and 2 inches below the seed can contain up to 100 pounds of phosphate (P_2O_5) and 60 pounds of potash (K_2O) per acre. Placement of fertilizer with the seed may cause serious injury and reduced plant stands. When soybeans are drilled (7- to 10-inch spacing), broadcast and incorporate all the P_2O_5 and K_2O before planting. The P_2O_5 and K_2O required for soybeans may also be broadcast prior to the previous corn crop. For no-till soybeans, use a band-placed starter fertilizer or broadcast the required fertilizer before planting. On lake-bed soils and dark-colored soils where the soil pH is above 6.5, Mn application will usually improve soybean growth and yields. Include 2 lb Mn/a (or the recommended amount based on a soil test) in the starter fertilizer, or apply one or two applications of 1 to 2 lb Mn/a to the foliage. Broadcast applications made to the soil are not effective.

Table 18. Phosphorus recommendations for selected yields of soybean (mineral soils).

Soil test	Yield (bu/a) 40	60
ppm	— lb P_2O_5/a —	
5	82	98
10	57	73
15-30	32	48
35	16	24
40	0	0

Dry Edible (Field) Beans

Phosphorus and K recommendations are given in Tables 20 and 21.

Dry beans, like soybeans, are legumes and can fix N. Nitrogen fixation in dry bean can be unreliable, however, because of environmental conditions and variability among varieties. Therefore, applying 40 to 60 lb N/a is recommended to achieve maximum yield. Apply 60 lb N/a for beans grown in narrow rows (less than 23 inches) and for colored beans grown under irrigation. For beans grown with less intense management systems, apply 40 lb N/a. Applying ex-

Table 19. Potassium recommendations for selected yields of soybean.

Soil test	CEC	40 bu/a				60 bu/a			
		4	8	12	16	4	8	12	16
ppm		— lb K_2O/a —				— lb K_2O/a —			
40		110	133	160	191	138	161	188	219
80		62	77	96	119	90	105	124	147
85		56	70	88	110	84	98	116	138
95		56	56	72	92	84	84	100	120
105		56	56	56	74	84	84	84	102
115		56	56	56	56	84	84	84	84
125		28	56	56	56	42	84	84	84
135		0	28	56	56	0	42	84	84

Numbers highlighted are maintenance amounts.

Table 21. Potassium recommendations for selected yields of dry beans (mineral soils).

Soil test	CEC	20 cwt/a				30 cwt/a			
		4	8	12	16	4	8	12	16
ppm		— lb K_2O/a —				— lb K_2O/a —			
40		86	109	136	167	102	125	152	183
80		38	53	72	95	54	69	88	111
85		32	46	64	86	48	62	80	102
95		32	32	48	68	48	48	64	84
105		32	32	32	50	48	48	48	66
115		32	32	32	32	48	48	48	48
125		16	32	32	32	24	48	48	48
135		0	16	32	32	0	24	48	48

Numbers highlighted are maintenance amounts.

cess N can delay bean maturity and may increase potential for white mold if the crop canopy is dense.

Dry beans are sensitive to low levels of available Zn. Providing adequate amounts of Zn fertilizer, if needed, is important because even mild Zn deficiency can delay maturity. Use a soil test to determine available Zn levels, and calculate the amount to apply from the equation on page 27. In the absence of a soil test, apply 1 lb Zn/a if the previous crop was sugar beets or if the soil pH is above 6.5.

Table 20. Phosphorus recommendations for selected yields of dry edible beans (mineral soils).

Soil test	Yield (cwt/a) 20	30
ppm	— lb P_2O_5/a —	
5	74	86
10	49	61
15-40	24	36
45	12	18
50	0	0

Dry beans do not tolerate fertilizer applied with the seed. Up to 40 lb N/a, all of the P_2O_5 and 60 lb of K_2O/a may be included in a starter fertilizer placed in a band 2 inches to the side and 2 inches below the seed. Before planting, broadcast and incorporate any additional fertilizer that is needed. Additional N may also be sidedressed two weeks after planting.

Bean yield may be affected by nutrient management and cropping systems. Dry beans grown after sugar beets often experience Zn deficiency, which results in delayed maturity and reduced yield. Dry beans rely on a symbiotic relationship with mycorrhizal fungi to assist the plant in taking up nutrients. Sugar beets do not host these fungi. Reduced numbers of mycorrhizae after sugar beets result in Zn deficiency because the bean plant can not take up enough Zn on its own.

Dry beans are also more sensitive to soil compaction than some other crops, particularly soybean. So take care to avoid soil compaction after primary tillage.

Small Grains: Barley, Canola, Spelt, Oats, Rye, Wheat

Nitrogen recommendations for small grains can be calculated using the equations on page 9.

Phosphorus and K recommendations for wheat and barley are given in Tables 22, 23, 24 and 25. Phosphorus and potassium recommendations for oats are about 10 lb P_2O_5/a and 5 lb K_2O/a more than those for barley at the same yield level. Recommendations for the other cereal grains can be calculated from the equations on pages 14 and 16 and the information in Tables 8 and 10.

Many grain drills deliver fertilizer in direct contact or close proximity with the seed. Large amounts of fertilizer may adversely affect germination and seedling establishment, especially if the soil is dry. To minimize the potential for injury, apply no more than 100 lb/a of nutrients ($N + P_2O_5 + K_2O$) in contact with the seed in sandy soils and no more than 140 lb/a in fine-textured soils. Where greater amounts of fertilizers are needed,

Table 22. Phosphorus recommendations for selected yields of wheat (mineral soils).

Soil test	Yield (bu/a) 60	90
ppm	— lb P_2O_5/a —	
5	138	157
10	113	132
15	88	107
20	63	82
25-40	38	57
45	19	28
50	0	0

Numbers highlighted are maintenance amounts.

Table 23. Phosphorus recommendations for selected yields of barley (mineral soils).

Soil test	Yield (bu/a) 50	80
ppm	— lb P_2O_5/a —	
5	69	80
10	44	55
15-30	19	30
35	10	15
40	0	0

Numbers highlighted are maintenance amounts. For oats, add 10 lb/a.

Table 24. Potassium recommendations for selected yields of wheat (mineral soils).

Soil	60 bu/a				90 bu/a			
test CEC	4	8	12	16	4	8	12	16
ppm	— lb K_2O/a —				— lb K_2O/a —			
40	76	99	126	157	87	110	137	168
80	28	43	62	85	39	54	73	96
85	22	36	54	76	33	47	65	87
95	22	22	38	58	33	33	49	69
105	22	22	22	40	33	33	33	51
115	22	22	22	22	33	33	33	33
125	11	22	22	22	17	33	33	33
135	0	11	22	22	0	17	33	33

Numbers highlighted are maintenance amounts.

Table 25. Potassium recommendations for selected yields of barley (mineral soils).

Soil	50 bu/a				80 bu/a			
test CEC	4	8	12	16	4	8	12	16
ppm	— lb K_2O/a —				— lb K_2O/a —			
40	67	90	117	148	74	97	124	155
80	19	34	53	76	26	41	60	83
85	13	27	45	67	20	34	52	74
95	13	13	29	49	20	20	36	56
105	13	13	13	31	20	20	20	38
115	13	13	13	13	20	20	20	20
125	7	13	13	13	10	20	20	20
135	0	7	13	13	0	10	20	20

Numbers highlighted are maintenance amounts.
For oats, add 5 lb/a.

broadcast and incorporate the additional fertilizer before planting. The alternative is to broadcast and incorporate all the required fertilizer nutrients before planting.

For winter wheat or barley, apply no more than 25 lb N/a in the fall. This may be included in either the preplant broadcast or planting-time fertilizer. In the spring, before green-up, topdress additional N on the basis of the yield potential of the field. For high-yielding wheat varieties and sites, this is usually 80 to 100 lb/a. Another option is to split the N between pregreen-up and Feeke's stage 5 or 6. Wheat does best following soybeans, dry edible beans or silage corn.

For rye grown for grain, apply 40 lb/a before spring green-up. No N is recommended for rye grown as a cover crop. For spring-seeded grains (barley, oats, millet and buckwheat), broadcast and incorporate the required amounts of N, P_2O_5 and K_2O before seeding.

When small grains are grown on slightly acidic sandy soils, application of Mg may be beneficial. If the soil Mg level is marginal or low (below 35 ppm), including 10 lb Mg/a in the broadcast fertilizer or foliar application of 1 to 2 lb Mg /a may be beneficial.

Wheat, oats and barley may benefit from Mn application when grown on lake-bed soils and dark-colored soils where the soil pH is above 6.5. Manganese is best applied in the planting-time fertilizer or as a spray on the actively growing foliage. Manganese that is broadcast and incorporated is readily bound into unavailable forms. Test these soils for Mn and apply recommended amounts.

Sugar Beets

Nitrogen recommendations for sugar beets can be calculated from the following equations:

N rec. = 4 x YP

When corn is the previous crop: N rec. = (4 x YP) + 30

where: YP is yield potential

Phosphorus and potassium recommendations for sugar beets are given in Tables 26 and 27.

Nitrogen management in sugar beet production is critical to maximize sugar yield. Nitrogen is needed to produce high yields of beets, but too much N reduces the sugar quality of the harvested beet. Sugar yield is maximized by balancing high yield and quality. In general, 80 to 100 lb N/a will maximize yield and sugar quality. The majority of research that went into developing this recommendation was for beets following beans. When beets are grown after corn, increase the N application rate by 30 lb N/a because corn is not a legume as dry bean and soybean are. Recent research results support this recommendation.

Table 26. Phosphorus recommendations for selected yields of sugar beets (minerals soils.

Soil test	Yield (t/a)	
	20	28
ppm	— lb P_2O_5/a —	
5	126	136
10	101	111
15	76	86
20	51	61
25-40	26	36
45	13	18
50	0	0

Numbers highlighted are maintenance amounts.

Table 27. Potassium recommendations for selected yields of sugar beets (mineral soils).

Soil		20 t/a				28 t/a			
test	CEC	4	8	12	16	4	8	12	16
ppm		— lb K_2O/a —				— lb K_2O/a —			
40		120	143	170	201	146	169	196	227
80		72	87	106	129	98	113	132	155
85		66	80	98	120	92	106	124	146
95		66	66	82	102	92	92	108	128
105		66	66	66	84	92	92	92	110
115		66	66	66	66	92	92	92	92
125		33	66	66	66	46	92	92	92
135		0	33	66	66	0	46	92	92

Numbers highlighted are maintenance amounts.

Sugar beets need a majority of their N early in the season to obtain canopy closure; relatively small amounts are required for canopy maintenance. Having adequate N early in the season is important for the crop to get off to a good start. Starter fertilizers (2- by 2-inch band placement) should provide 30 to 40 lb N/a. Alternatively, the N can be applied before planting. Some experiences suggest that, to reduce the risk of fertilizer burn adversely affecting germination, growers should apply no more than 50 lb N/a preplant.

Beets generally will not respond to P fertilizer when soil test values are greater than 30 ppm. On high-P soils, P is not needed in a starter fertilizer. If one wishes to use a starter fertilizer containing P_2O_5, the amount of P_2O_5 applied should be less than crop removal (approximately 30 lb P_2O_5 /a). Beets are sensitive to low levels of available Mn, particularly when the soil pH is higher than 6.5. Use a soil test to determine available Mn levels and the amount of Mn to apply. Manganese applications are most effective in starter fertilizers. Foliar applications of Mn (1 lb/a) can be used to remediate deficiencies that appear after crop establishment. Sugar beets grown on sandy loams will benefit from application of 2 lb B/a in the starter or broadcast fertilizer. On finer textured soils, applying 1 lb B/a may be a good preventive practice — some deficiencies have been observed recently on these soils.

Sugar beets grow best when the soil pH is between 6.0 and 7.0. Preliminary research in another beet-growing region of the United States suggests that soil pH above 6.5 decreases the incidence of root diseases.

Forage Crops

Legumes

Phosphorus and potassium recommendations for alfalfa and clover are given in Tables 28, 29, 30, 31 and 32.

For alfalfa, be sure to adjust the soil pH to near 7.0 by applying the appropriate rate of limestone. For other legumes, adjust pH to 6.5. This is best done by applying and incorporating the lime about six to 12 months before seeding. When no-till seeding legumes on erosive sites, broadcast the lime without incorporation. Broadcast and incorporate the required P_2O_5 and K_2O during seedbed preparation or apply it through the seeder, basing rates on soil tests. When fertilizer is applied with the seeding unit, allow the seed to fall on the top of the soil above the fertilizer band and to be firmed in no more than ½ inch deep with press wheels or cultipacker. Fertilizer placed 1 to 1½ inches below the seed may supply all the recommended P_2O_5 and up to 150 lb K_2O/a. For fertilizer placed directly with the seed, limit the amounts to 100 lb P_2O_5/a and 50 lb K_2O/a. Planting-time N is not necessary for legume seedings, but be sure to inoculate the seed with the appropriate strains of

Table 28. Phosphorus recommendations for selected yields of alfalfa (mineral soils).

Soil test	Yield (t/a) 4	6	8
ppm	— lb P_2O_5/a —		
5	152	178	200
10	127	153	179
15	102	128	154
20	77	103	129
25-40	52	78	104
45	26	39	52
50	0	0	0

Numbers highlighted are maintenance amounts.

Table 29. Phosphorus recommendations for selected yields of clover hay (mineral soils).

Soil test	Yield (t/a) 3	6
ppm	— lb P_2O_5/a —	
5	105	135
10	80	110
15	55	85
20-35	30	60
40	15	30
45	0	0

Numbers highlighted are maintenance amounts.

Table 30. Phosphorus recommendations for selected yields of clover-grass hay (mineral soils).

Soil test	Yield (t/a) 3	6
ppm	— lb P_2O_5/a —	
5	114	153
10	89	128
15	64	103
20-35	39	78
40	20	39
45	0	0

Numbers highlighted are maintenance amounts.

Table 31. Potassium recommendations for selected yields of alfalfa hay (mineral soils).

Soil	4 t/a				8 t/a			
test CEC	4	8	12	16	4	8	12	16
ppm	— lb K_2O/a —				— lb K_2O/a —			
40	254	277	300	300	300	300	300	300
80	206	221	240	263	300	300	300	300
85	200	214	232	254	300	300	300	300
95	160	200	216	236	300	300	300	300
105	120	160	200	218	240	300	300	300
115	80	120	160	200	160	240	300	300
125	40	80	120	160	80	160	240	300
135	0	40	80	120	0	80	160	240

Numbers highlighted are maintenance amounts.
Maximum annual recommendation is 300 lb K_2O/a.

Table 32. Potassium recommendations for selected yields of clover and clover-grass hay (mineral soils).

Soil	3 t/a				6 t/a			
test CEC	4	8	12	16	4	8	12	16
ppm	— lb K_2O/a —				— lb K_2O/a —			
40	174	197	224	255	294	300	300	300
80	126	141	160	183	246	261	280	300
85	120	134	152	174	240	254	272	294
95	120	120	136	156	240	240	256	276
105	120	120	120	138	240	240	240	258
115	120	120	120	120	240	240	240	240
125	60	120	120	120	120	240	240	240
135	0	60	120	120	0	120	240	240

Numbers highlighted are maintenance amounts.

Rhizobia before planting. Including 20 lb N/a in the broadcast or planting-time fertilizer may improve seedling establishment in cool soils but generally provides little benefit.

Legumes are more difficult to establish when using a small grain as a nurse crop rather than by clear seeding, although frost seeding red clover can be done successfully. The small grain nurse crop is best harvested early as silage to reduce competition with the new legume seeding. The P and K fertilizer applied for the small grain is usually sufficient to carry the legume through the first season. If a cutting is taken off, apply amounts of P_2O_5 and K_2O equal to crop removal. Legumes remove large amounts of K_2O (45 to 60 lb/ ton) from the soil. Weathering of the soil minerals releases potash in the soil over the winter. To minimize luxury consumption of K by alfalfa, it is best to wait and make the first application of K_2O after the first cutting. To replace potassium removed by the crop, topdress K_2O after the first and third or fourth cutting. Needed P can be applied along with the K_2O when it is spread. On loamy sands and sands, where significant leaching may occur, do not apply K_2O in the late fall. It is suggested to limit single applications to no more than 200 lb K_2O/a and yearly applications to 300 lb K_2O/a.

Boron is needed annually on sandy soils (CEC < 8.0) at a rate of 2 lb/a per year. Fine-textured soils can usually supply adequate B, so B applications have seldom proven beneficial. Where B is needed, apply it in the topdress fertilizer. Boron deficiency sometimes occurs during the growth period of the second or third cutting. When this occurs, spray the foliage with 0.25 lb B/a.

Grass Hay or Pasture

The N recommendation for a grass hay and for an intensively grazed (rotational grazing) grass pasture is 160 to 200 lb N/a. Nitrogen should be applied in split applications of 40 to 50 lb N/a at green-up, June 1, August 1 and September 1. Phosphorus and potassium recommendations are presented in Tables 33 and 34 for bromegrass. Phosphorus recommendations for other grasses are similar to those of bromegrass, but K recommendations are different because the various grasses take up different amounts of K. (See Table 3.)

Table 33. Phosphorus recommendations for selected yields of bromegrass hay (mineral soils).

Soil test	Yield (t/a) 4	6
ppm	— lb P_2O_5/a —	
5	102	128
10	77	103
15-30	52	78
35	26	39
40	0	0

Numbers highlighted are maintenance amounts.

Table 34. Potassium recommendations for selected yields of bromegrass hay (mineral soils).

Soil test	4 t/a CEC 4	8	12	16	6 t/a CEC 4	8	12	16
ppm	— lb K_2O/a —				— lb K_2O/a —			
40	258	281	300	300	300	300	300	300
80	210	225	244	267	300	300	300	300
85	204	218	236	258	300	300	300	300
95	204	204	220	240	300	300	300	300
105	204	204	204	222	300	300	300	300
115	204	204	204	204	300	300	300	300
125	102	204	204	204	153	300	300	300
135	0	102	204	204	0	153	300	300

Numbers highlighted are maintenance amounts.
Maximum annual recommendation is 300 lb K_2O/a.

When grass is seeded for hay or pasture, the fertilizer may be broadcast and incorporated before seeding or applied at the time of seeding. Base the amounts to apply on a soil test. When fertilizer is applied with the seed, limit the total amount of nutrients ($N + P_2O_5 + K_2O$) to 100 lb/a on sandy soils and 140 lb/a on fine-textured soils. Broadcast and incorporate any additional amounts of phosphate and potash. Include 30 to 40 lb/a in the preplant or planting-time fertilizer.

For grass hay, annually topdress 200 lb N/a in split applications (50 lb N/a at green-up and after each of the first three cuttings) plus maintenance amounts of phosphate and potash. For grass-legume hay with more than six legume plants per square foot, no additional N is needed. As the percent legume decreases, the need for N increases. With a legume stand of less than 40 percent (fewer than three plants per square foot), apply 100 lb N/a.

For timothy hay, apply 100 lb N/a just before green-up. Timothy has a shallow root system, so unless soil moisture is adequate, there is little regrowth. When soil moisture is adequate for reasonable regrowth and a second cutting, apply an additional 50 lb N/a after taking the first cutting.

Grass Pasture

Annually topdress with N plus maintenance amounts of P_2O_5 and K_2O. Apply, in split applications (at green-up, June 1, August 1 and September 1), 160 lb N/a for intensively grazed pastures (rotational grazing) and 200 lb N/a for extensively grazed pastures. Extensively grazed pastures require more N because the continuous grazing results in less regrowth of the grasses, and the additional N is needed to help stimulate regrowth. Intensive (rotational) grazing systems allow an adequate rest period for better regrowth and productivity of the pasture grasses and better utilization of N between grazing events. When pastures contain more than 40 percent legume, additional N is not recommended.

Brassicas for Forage

Several of the brassica species (kale, rape, swedes, turnips) can be used as a fall forage crop to be grazed. They are frequently planted after the harvest of small grains. Apply a total of 100 lb N/a. Broadcast and incorporate the recommended amounts of P_2O_5 and K_2O before planting.

Grass Waterways and Critical Areas

Grass waterways, highly erodible soils and other critical areas need good fertility to maintain a dense, uniform cover through the year. Follow the guidelines for grass hay. Because there will be no crop removal, the amount of fertilizer to apply will be that for building the soil test values up to the critical level. Broadcast and incorporate 40 lb N/a and the required amounts of P_2O_5 and K_2O before seeding, or, if the crop is already established, broadcast the fertilizer. To maintain vigor, annually top-dress with up to 25 lb N/a.

Conservation Reserve

The Conservation Reserve Program (CRP) provides cost sharing for the establishment of long-term, resource-conserving ground covers to improve water quality, control soil erosion and enhance wildlife habitat. Native cool- or warm-season grasses alone or in combination with a legume are frequently seeded for CRP plantings. For establishment and maintenance of long-term vegetative covers, adjust the soil pH to above 6.0 before seeding. Required soil P and K levels are lower than those for forage hay production because there is no removal of biomass. Apply the amounts of P_2O_5 and K_2O needed to build the soil level to the critical level (10 ppm P, 95 ppm K). No N is recommended for establishment of warm- or cool-season grasses with or without a legume. Studies have shown that N application increases weed competition. No maintenance fertilization is needed once ground cover is established because nutrients taken up by the plants will be recycled as the biomass dies and decomposes.

Potato

Recommended N can be calculated as follows:

N rec = 150 + [(YP – 300) x 0.3]
where YP is yield potential in cwt/a

For Russet Burbank, Snowden and other late-maturing varieties, increase the N recommendation by 40 lb N/a. Phosphorus and K recommendations are given in Tables 35 and 36.

Apply up to 60 lb N/a, all of the P_2O_5 and up to 100 lb K_2O/a in starter bands 2 inches to the side and level with or slightly below the seed pieces. Placing bands on both sides of the seed pieces is more effective than

Table 35. Phosphorus recommendations for selected yields of potato (mineral soils).

	Yield (cwt/a)		
Soil test	350	400	450
ppm	— lb P_2O_5/a —		
20	200	200	200*
40	200	200	200
60	120	127	133
75-150	45	52	58
175	23	26	29
200	0	0	0

*Recommendation is capped at 200 lb P_2O_5/a.
Numbers highlighted are maintenance amounts.

Table 36. Potassium recommendations for selected yields of potato (mineral soils).

Soil	350 cwt/a				450 cwt/a			
test CEC	4	8	12	16	4	8	12	16
ppm	— lb K_2O/a —				— lb K_2O/a —			
40	274	297	300	300	300	300	300	300
80	226	241	260	283	289	300	300	300
85	220	234	252	274	283	297	300	300
95	220	220	236	256	283	283	299	300
105	220	220	220	238	283	283	283	300
115	220	220	220	220	283	283	283	283
125	110	220	220	220	142	283	283	283
135	0	110	220	220	0	142	283	283
145	0	0	110	220	0	0	142	283
155	0	0	0	110	0	0	0	142
165	0	0	0	0	0	0	0	0

Numbers highlighted are maintenance amounts.
Maximum annual recommendation is 300 lb K_2O/a.

banding on just one side. Before planting, broadcast and incorporate needed K_2O in excess of the amount applied in the fertilizer bands. Fall application of K on sandy and organic soils is not recommended because of the potential for leaching loss. Incorporating a legume cover crop or animal manure can significantly reduce the amount of supplemental N needed. Nitrogen broadcast before planting has an increased risk of loss by leaching. Nitrogen applied after planting is used more efficiently than N applied preplant. For best N management, supply needed N through a combination of applications at planting time, hilling and topdressing, or through irrigation. (For more information on nutrient management of potatoes, see MSU Extension bulletin E-2779.) After harvest, establish a cover crop to take up any residual N and to protect against wind erosion.

Manganese may be needed when the soil pH is above 6.5 on mineral soils and above 5.8 on organic soils. Use a soil test to determine the amount of Mn needed. Include the required amount of Mn in the starter fertilizer and/or spray the foliage with 1 to 2 lb Mn/a at least twice during active growth. On organic soils, foliage application is essential.