Nutrient Recommendations for Field Crops in Michigan
Michigan State University
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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 two years.

Soil test results began to be considered in making fertilizer recommendations in the early 1950s. Phosphorus and potassium 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 pounds P per acre was considered low and above 50 pounds P per acre was considered high. For soils with a pH above 7.5, the separating value was 100 pounds P per acre. For potassium, the separating soil test value was 150 pounds K per acre. 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 pounds P per acre on acid soils, 50 pounds P per acre on soils with pH above 7.5 and 80 pounds K per acre. Even when the soil test was high, some fertilizer was recommended because even in the "high-test" soils it was usual for an economical response to 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 for amounts of P_2O_5 and K_2O per acre in relation to the soil test category. For crops grown on organic soils, the recommendations were given for pounds of P_2O_5 and K_2O per acre on a graded scale according to the actual soil test value. Soon thereafter, nutrient recommendations for all crops grown on mineral and organic soils followed the same format. The tabular recommendations were converted into recommendation equations in 1981.

During the mid-1990s, the 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 followed for the phosphorus and potassium recommendations given in this bulletin for all field crops.

Basis for Recommendations

The growth and development of field crops can be influenced by the levels of essential elements (nutrients) available in the soil. 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 and 91 ppm, respectively.

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 subsequently yield. The amount of a nutrient required to enhance crop growth and yield to the maximum is related to the soil test value.

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 (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.

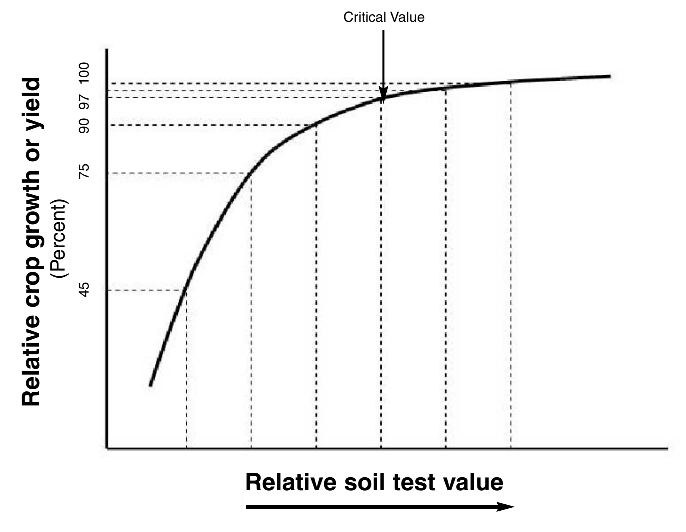

Figure 1. Relative growth or yield response to increasing soil test levels.

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. It may be due to natural soil-forming processes that created differences in soil texture, organic matter or slope, or it may be due to 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 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 more 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. In fields that appear uniform, the maximum area that one composite sample should represent is 40 acres, but fewer is better. This approach will result in samples and test results representative of the designated field areas. When only shallow tillage (< 4 inches) or no tillage is used, collect an additional sample from the surface 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 and E-1616, and NC Multistate Report 348, (Item SB-7647-S), available from the University of Minnesota) 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 prior to or at planting and then gradually decrease during the growing period because of plant uptake. 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 3 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 may change rapidly. For these situations, sample and test at least every 2 years. On organic soils, considerable amounts of potassium may leach from the soil over winter, especially when the spring thaw occurs. Hence, soil test potassium levels will usually be lower for organic soil 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 buffer solution to this slurry and measuring the resulting pH. This value 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 (0.5 N sodium bicarbonate) test provides a better indication of P availability on 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 *N* neutral ammonium acetate. Recommendations for phosphorus, potassium and magnesium are based on these soil test values.

An index of zinc and manganese availability is determined by extraction with 0.1 *N* hydrochloric acid. DTPA is used as an alternative extracting solution, especially for calcareous soils. The hot water extraction procedure is used for boron. Sulfur 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 approximately equal to 2 pounds per acre to a depth of 6⅔ inches.

Conversion Factors

Most soil testing labs report soil test values in terms of ppm P and K. Recommendations are usually given as pounds per acre 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 – 6⅔ inches
ppm x 3.6 = lb/A-ft
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 or alkaline. Values below 7.0 indicate acid soils; 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 aluminum concentration contributes to further acidification of the soil and aluminum toxicity that 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 mineral soil is more acid, pH < 6.0, increase the target pH by 0.2 pH unit. **When crops with different target pHs 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 (Shoemaker, McLean, Pratt) buffer and is reported as the “lime index”. Table 2 shows how much lime is needed to raise the soil pH up to 6.0, 6.5 or 6.8 when mixed with the top 9 inches of soil according to the lime index. Clayey soils tend to be more resistant to pH change (lower lime index) than sandy soils and require more lime at a given soil pH. Recommended lime rates are based on agricultural lime with a neutralizing value (NV) of 90 percent. Adjust lime rate based on 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.

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

Crop	Mineral soils	Organic soils
Alfalfa seeding	6.8	6.0
Alfalfa topdress	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 topdress	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	6.5	—
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 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-Sudangrass hay	6.5	5.3
Sorghum-Sudangass haylage	6.5	5.3
Soybean	6.5	5.8
Spearmint	6.5	5.5
Spelts	6.5	5.3
Sugar beet	6.5	—
Sunflower	6.5	5.3
Timothy hay	6.5	5.3
Trefoil hay	6.0	5.8
Trefoil seed production	6.0	—
Wheat grain	6.5	5.8
Wheat/legume seeding	6.5	5.8

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

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

	Mineral soils			Organic soils	
Lime	Raise soil pH to:			Initial	Raise pH to:
Index	6.0	6.5	6.8	soil pH	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:

To pH 6.0: $XL = 54.2 - 0.78 \times LI$

To pH 6.5: $XL = 65.5 - 0.94 \times LI$

To pH 6.8: $XL = 71.2 - 1.02 \times LI$

Organic soils:

To pH 5.3: $XL = 37.6 - 7.1 \times pH$

Target pH >5.3 $XL = (37.6 - 7.1 \times pH) + ((\text{target pH} - 5.3) \times 0.5)$

where:

XL = Lime recommendation in tons/acre

LI = Lime index

pH = Soil pH

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 lime application, but the lime index indicates little or no lime is needed. If the soil pH is 0.3 to 0.5 pH units 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 units 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 nitrogen utilization and response to applied nitrogen rates. Table 3 indicates an average amount of nitrogen removed in the harvested portion of various field crops. Nitrogen recommendations for field crops 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 50 pounds per acre less than those for mineral soils. For the more responsive crops, such as corn, the cereal grains, canola and sugar beets, the amount of nitrogen 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. Unrealistically high yield goals will result in excess nitrogen 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 nitrogen recommendation.

No nitrogen is recommended for the legumes because they receive nitrogen fixed from the air by symbiotic bacteria. Dry edible beans are the exception. They are not as effective in fixing nitrogen and benefit from some supplemental nitrogen, especially during the early growth stages.

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

Table 3. Nutrient removal in harvest portion of several Michigan field crops.

Crop		Unit	N	P_2O_5	K_2O
			- - - - - - - lb/unit of yield - - - - - -		
Alfalfa	(Hay)	ton	45	13.0	50.0
	(Haylage)	ton	14	3.2	12.0
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
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	22.0	8.2	32.0
	(Silage)	ton	9.4	3.30	8.00
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
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
Sorghum-Sudangrass	(Hay)	ton	40	15	58
Sorghum-Sudangrass	(Haylage)	ton	12	4.6	18
Soybean	(Grain)	bu	3.8	0.80	1.40
Spelts	(Grain)	bu	1.2	0.38	0.25
Sugar beets	(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
Wheat	(Grain)	bu	1.2	0.63	0.37
	(Straw)	ton	13.0	3.3.	23

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 topdress	0	0
Barley	**	**
Beans, dry edible	40	0
Brassica forage	80	30
Bromegrass hay	60	20
Buckwheat	60	20
Canola	**	**
Clover seeding	0	0
Clover topdress	0	0
Clover-grass hay	0	0
Corn grain	**	**
Corn silage	**	**
Corn, seed	**	
Grass, warm-season (CRP)	0	0
Grass, cool-season (CRP)	0	0
Millet	60	20
Oats	**	**
Oats for cover	40	0
Orchardgrass hay	60	30
Pasture, intensive grazing	80	30
Pasture, extensive grazing	60	20
Rye grain	**	**
Rye for cover	40	0
Sorghum-Sudangrass hay	60	30
Sorghum-Sudangrass haylage	60	30
Soybean	0	0
Sugar beet	**	**
Trefoil hay	0	0
Trefoil seed production	0	
Wheat grain	**	**

** Uses an equation for calculating N recommendation based on yield goal (YG) and N credit (NC). See Table 5 for nitrogen credits for previous crops. NC for manure = quantity applied per acre x N content x 0.5.

Equations for calculating nitrogen recommendations:

Corn	Mineral soil	Organic soil
Corn grain	= (1.36 x YG) – 27 – NC	= (1.36 x YG) – 67 – NC
Corn silage	= (8.33 x YG) – 25 – NC	= (8.33 x YG) – 65 – NC
Corn, seed	= (1.63 x YG) – 27 – NC	

Barley, Canola, Oats, Rye, Wheat

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

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
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

Table 5. Nitrogen credit for N-responsive crops grown in rotation with these crops.

Previous crop	N credit
	- - - lb N /A - - -
Alfalfa, established	40 + (% stand)
Alfalfa, seeding	40 + 0.5 (% stand)
Clover, established	40 + 0.5 (% stand)
Clover, seeding	20 + 0.5 (% stand)
Trefoil, established	40 + 0.5 (% stand)
Barley + legume	30 + 0.5 (% stand)
Oats + legume	30 + 0.5 (% stand)
Wheat + legume	30 + 0.5 (% stand)
Dry edible beans	20
Soybeans	30
Grass hay	40

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 Figure 1. Recommendations given in this bulletin follow the **buildup**, **maintenance** and **drawdown** philosophy presented in "Tri-State Fertilizer Recommendations," bulletin E-2567. These recommendations provide for **buildup** of available P and K levels when the soil test level is below the critical soil test value (Figure 2). At the critical soil test level (CL), crop yield will be near 95 to 97 percent of maximum. **Maintenance** recommendations (amount equal to crop removal) are given to keep the available P and K at the optimum level and provide insurance against variations caused by sampling variability. Beyond the maintenance zone, recommendations are less than crop removal to allow **drawdown** of soil nutrient levels to occur.

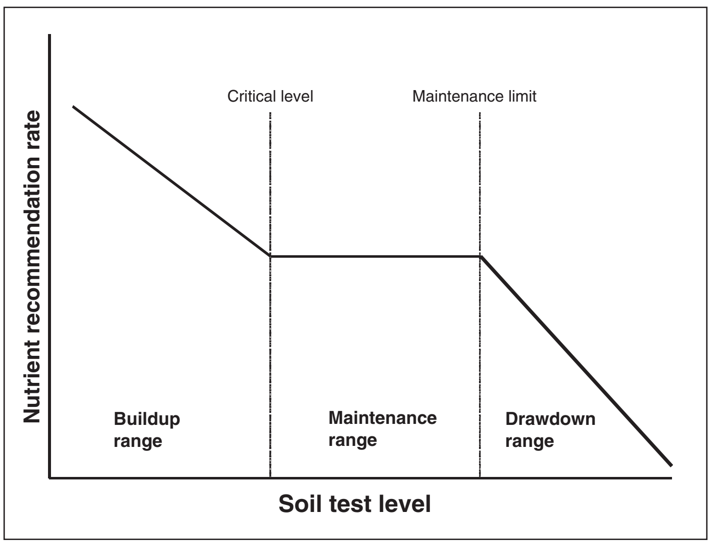

Figure 2. Nutrient recommendation scheme for phosphorus and potassium.

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 to the optimum range plus the amount that will be removed in the harvested portion of the crop. It is very important to provide realistic yield goals to the MSU Soil and Plant Nutrient Lab 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 potassium (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.

As indicated, **phosphorus recommendations** take into consideration the soil test level and the crop yield. The buildup portion of the recommendation is based on building 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 pounds per acre per year over a 4-year period. The P buildup recommendations are given in Table 6. The critical level varies with the crop and its response to phosphorus (Table 7). 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 7 for field crops grown on mineral and organic soils. The maximum annual phosphorus recommendation is 200 pounds P_2O_5 per acre.

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: $\text{lb } P_2O_5/A = ((CL - ST) \times 5) + (YP \times CR)$

Maintenance: $\text{lb } P_2O_5/A = (YP \times CR)$

Drawdown: $\text{lb } P_2O_5/A = (YP \times CR) - (((YP \times CR) \times (ST - (CL + PL))) \div DDL)$

Organic soils:

Buildup: $\text{lb } P_2O_5/A = ((CL - ST) \times 2) + (YP \times CR)$

Maintenance: $\text{lb } P_2O_5/A = (YP \times CR)$

Drawdown: $\text{lb } P_2O_5/A = (YP \times CR) - (((YP \times CR) \times (ST - (CL + PL)) \div DDL$

where: CL = critical soil test value (ppm)

ST = soil test value (ppm)

YP = yield potential or goal

Table 6. Phosphorus buildup recommendations, mineral soils.

P soil test	Buildup recommendations CL values			
	15	20	25	30
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

CR = nutrient removal in harvest portion of crop (lb/unit of yield)

PL = maintenance plateau length

DDL = drawdown length; recommendation is phased to zero

Potassium 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 (yield is 95 to 97 percent of maximum) varies with the CEC. The buildup portion of the K recommendation is given in Table 8. 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, 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 9. The maximum annual potassium recommendation is 300 pounds K_2O per acre.

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)

Maintenance: lb K_2O/A = (YP x CR)

Drawdown: lb K_2O/A = (YP x CR) – [((YP x CR) x (ST – (CL + PL)) ÷ DDL)]

or = (YP x CR) x [1 – {(ST – (CL + PL)} ÷ DDL]

Organic soils:

Buildup: lb K_2O/A = ((CL – ST) x 1.5) + (YP x CR)

Maintenance: lb K_2O/A = (YP x CR)

Drawdown: lb K_2O/A = (YP x CR) – (((YP x CR) x (ST – (CL + PL)) ÷ DDL

or = (YP x CR) x [1 – {(ST – (CL + PL)}÷ DDL]

where:

CL = critical soil test (ppm) for mineral soils CL = 75 + (2.5 x CEC)

CEC = cation exchange capacity (me/100g soil)

ST = soil test value (ppm)

YP = yield potential or goal

CR = nutrient removal in harvest portion of crop (lb/unit of yield)

PL = maintenance plateau length

DDL = drawdown length; recommendation is phased to zero

Organic soils

Soil test values for organic soils are handled and calculated on a volume basis. Organic soils have bulk densities that are much lower than those of mineral soils. On average, organic soils will have field bulk densities between 0.65 and 0.70, but these may vary considerably and may be as low as 0.3 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 ⅔ inches. Hence, the critical soil test values are higher for organic soils than for mineral soils.

Table 7. 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 - - - -		
Alfalfa seeding	25	15	10	30	15	10
Alfalfa topdress	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	30	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 topdress	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	—	—	—
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 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	60	40	25	120	50	20
Rye grain	15	15	10	40	15	10
Rye silage	15	15	10	40	15	10
Sorghum	15	15	10	40	15	10
Sorghum-Sudangrass hay	15	15	10	30	15	10
Sorghum-Sudangrass haylage	15	15	10	55	15	10
Soybean	15	15	10	35	15	10
Spearmint	40	30	10	70	15	15
Spelts	15	15	10	40	15	10
Sugar beet	15	15	10	—	—	—
Sunflower	15	15	10	40	15	10
Timothy hay	15	15	10	—	—	—
Trefoil hay	20	20	10	40	15	10
Trefoil seed production	20	20	10	—	—	—
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

Table 8. Potassium buildup recommendations, mineral soils.

K soil test	CEC, me/100 g 4	8	12	16
	CL *85*	*95*	*105*	*115*
	Buildup recommendation			
ppm	- - - - - lb K_2O/A - - - - -			
10	90	119	152	189
20	78	105	136	171
30	66	91	120	153
40	54	77	104	117
50	42	63	88	99
60	30	49	72	81
70	18	35	56	63
80	6	21	40	45
90	0	7	24	27
100	0	0	8	0
110	0	0	0	0
120	0	0	0	0

CL = 75 + (2.5 x CEC)

Calcium

Michigan soils generally developed from calcareous parent material and therefore contain sufficient available calcium for production of field crops. Soils of the western Upper Peninsula, which developed from acidic parent materials, are the only major exception. Even soils that have become acidic and need lime generally contain sufficient calcium 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 calcium deficiency. The best way to be sure that soils contain adequate calcium is to soil test regularly and apply lime as needed. Supplemental calcium may improve tuber quality of potatoes grown on sandy soils containing less than 300 ppm exchangeable calcium. Maintaining adequate soil moisture is important for adequate calcium 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 ratios. Adding calcium to improve the calcium to magnesium ratio is not necessary unless the amount of magnesium equals or exceeds calcium on an equivalence basis (milliequivalents per 100 grams soil). The calcium to magnesium ratio may be helpful in determining whether to use calcitic or dolomitic limestone when lime is needed.

Magnesium

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 calcium and magnesium) on low-magnesium acid soils to neutralize soil acidity rather than using calcitic lime or marl (contain primarily calcium), which may induce a magnesium deficiency. Potatoes, corn and oats are the field crops most sensitive to marginal magnesium levels.

Application of magnesium 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 magnesium is less than 3 percent (as a percent of exchangeable bases on an equivalence basis), or when exchangeable potassium exceeds the percent magnesium on an equivalence basis (milliequivalents per 100 grams of soil). On acid soils where magnesium is needed, apply at least 1,000 pounds of dolomitic limestone per acre. For non-acidic soils low in magnesium, broadcast 50 to 100 pounds of actual magnesium per acre or include 10 to 20 pounds of magnesium per acre in band-placed fertilizer. Suitable sources of magnesium 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 pounds Mg per acre on the crop foliage. Using lower rates than this may require multiple applications.

Magnesium deficiency may be induced by applying high rates of potassium fertilizer. This can result in grass tetany disorder in livestock that feed on lush grass. Where forages are being grown, agronomists frequently strive for magnesium to be 10 percent of the total exchangeable bases (equivalency basis). If there is concern about grass tetany, avoid applying high rates of potassium (more than 200 pounds per acre) in

Table 9. Values for key factors used in calculating the potassium recommendations for field crops grown on mineral and organic soils.

Crop	Mineral soil CL[1]= 75+(2.5 x CEC)		Organic soil		
	PL[2]	DDL[3]	CL[1]	PL[2]	DDL[3]
	- - - ppm - - -		- - - - - ppm - - - - -		
Alfalfa seeding	0	50	140	25	95
Alfalfa topdress	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 topdress	30	20	140	25	95
Clover-grass hay	10	50	140	25	95
Corn grain	30	20	220	25	25
Corn silage	0	20	220	25	25
Corn, seed	0	20	—	—	—
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
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 silage	30	20	160	25	15
Sorghum	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
Spelts	30	20	220	25	15
Sugar beet	30	20	—	—	—
Sunflower	30	20	220	25	15
Timothy hay	30	20	—	—	—
Trefoil hay	30	20	140	25	15
Trefoil seed production	30	20	—	—	—
Wheat grain	30	20	220	25	15
Wheat/legume seeding	30	20	220	25	15

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

a single application. Use of supplemental magnesium in the feed ration may also help avoid grass tetany. Contact your animal feed specialist for guidance.

Sulfur

Plants take up sulfur in amounts similar to phosphorus. The primary sources of plant-available sulfur are soil organic matter (animal manures or plant residues) and atmospheric deposition. Significant reductions in atmospheric deposition of S have increased the potential for sulfur deficiency. Crops growing in sandy soils low in organic matter are the most likely to show sulfur deficiency. Studies in the past with sulfur-responsive crops grown on potentially sulfur-deficient sites in Michigan have not been shown to benefit from supplemental sulfur application. Many soils have an accumulation of sulfur in the subsoil that the crops access once the roots reach that depth, especially where there is an increase in clay content. Crops most likely to benefit from sulfur application are alfalfa and canola. New studies are needed to reevaluate the need for sulfur 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 10. Equations used to calculate the recommended amounts to apply are given at the beginning of each section.

Boron

Boron 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 (>1.0 ppm). Boron occurs in the soil primarily as a water-soluble anion that is subject to leaching, so the available boron 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, boron deficiency may occur when soil moisture is marginal even though the soil contains adequate boron. Application of 2 pounds of boron per acre per year is recommended for alfalfa grown on sandy soils (CEC <8.0 me/100 grams soil). On fine-textured soils, boron application is usually not beneficial except for high-yielding established alfalfa fields, where a topdress boron application (0.5 to 1.0 pound per acre) is suggested.

Recent research with newer sugar beet varieties has shown supplemental boron is not necessary when beets are grown in soils of the Thumb and Saginaw Valley areas. On loamy sands and sandy loams, 1 to 2 pounds per acre is suggested. Field beans, soybeans and small grains are sensitive to boron application. For these crops, avoid using boron in the starter fertilizer. The residual boron level from a previous year's application should not be of concern for these sensitive crops unless higher than recommended rates were applied.

Manganese

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

Mineral soils: $\text{Mn rec.} = (6.2 \times \text{pH} - 0.35 \times \text{ST}) - 36$

Organic soils: $\text{Mn rec.} = (8.38 \times \text{pH} - 0.31 \times \text{ST}) - 46$

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 manganese deficiency. Manganese deficiency is most likely to occur on organic soils with a pH above 5.8 and dark-colored mineral soils in lakebed and glacial outwash areas with a pH above 6.5. Recommended rates of manganese are for band application because manganese is readily bound into unavailable forms when mixed (broadcast and incorporated) with the soil. Flooding and fumigation temporarily increase manganese 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 on mineral soils. Manganese chelates are not recommended for application in organic soils. It is difficult to build up the available manganese status of soils. Therefore, if a manganese 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 most responsive to manganese. Under high pH conditions, barley may also respond to manganese application. Manganese deficiency in these crops can be alleviated by spraying the crop foliage with 1 to 2 pounds Mn per acre. Under severe conditions and when 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 manganese carriers have been shown to reduce the efficacy of glyphosate when the two are tank mixed or sprayed sequentially within 48 hours. Manganese EDTA (ethylenediaminetetraacetic acid) has shown minimal adverse effect.

Zinc

For responsive crops, recommended amounts of zinc (Zn) are based on soil test (ST) (0.1 *N* HCl) 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 less than 6.5 generally contain adequate zinc 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 lakebed 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 phosphorus may enhance the occurrence of a zinc deficiency when the available soil zinc status is marginal. Dry edible beans, corn and sorghum-Sudangrass are the field crops most sensitive to low levels of available zinc. Band application of the recommended zinc rate is preferred, but broadcast application of 10 pounds or more per acre is effective in meeting the need of the crop and building up the soil level. Annual band applications will gradually build up available zinc levels and eliminate the need for further applications. Zinc sulfate, granulated finely ground zinc oxide-sulfate mixtures and chelates are good sources of zinc for soil application. Chelates are actually more effective than the inorganic salts in improving the zinc availability for a given growing season. The recommended rate for zinc chelates is one-fifth the rate calculated above for the inorganic salts.

Copper

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

The mineral soils of Michigan generally contain adequate amounts of copper. Soil test values greater than 0.5 ppm (1 *N* HCl extractable) indicate adequate copper availability. Acid sandy soils that have been heavily cropped are the most likely of the mineral soils to show a copper deficiency. Organic soils are naturally low in available copper, and many field crops will respond to copper application when grown on these soils. Once applied to the soil, copper remains available. Therefore, copper levels may have been improved by past applications to the soil or by copper fungicide sprays in fields that have been in production for a long time. The 1 *N* HCl soil test is a good indicator of copper availability in organic soils. No further copper is needed for most field crops once a total of 20 pounds of copper per acre 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 copper. When grown on high organic matter sandy soils, these crops may benefit from the application of 2 to 4 pounds Cu per acre. Copper sulfate and copper oxide are both effective sources of copper applied broadcast or in a band. Copper chelates are also good sources of copper 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 good sources of plant nutrients. The inorganic forms of nitrogen, phosphorus and potassium are readily available. Nutrients in organic forms are gradually released over time as they are broken down by microorganisms. On average, 50 percent of the nitrogen in manures will be released during the year of application, whereas 80 per-

Table 10. Micronutrient responsiveness level for selected field crops.

Crop	Boron	Copper	Manganese	Zinc
Alfalfa seeding	M	M	L	L
Alfalfa topdress	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 (topdress)	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	L	L	M	L
Grass, warm-season	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, for cover	L	L	L	L
Rye, silage	L	L	L	L
Sorghum	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
Spelts	L	M	M	L
Sugar beet	M	M	H	M
Sunflower	M	M	M	M
Timothy hay	L	L	M	L
Trefoil seeding	M	M	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.

cent of the phosphorus and 100 percent of the potassium are available. The numbers for biosolids will vary with type and treatment but on average may be similar to those for manures. The composting process tends to stabilize the nitrogen components so that only about 10 percent of the nitrogen 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 nitrogen loss, primarily ammonia. With commercial fertilizers, the nutrient content is indicated by the grade on the label. Values for manures may vary by type and how it is handled. Table 11 gives the nutrient content range that occurred in animal manures collected from numerous farms. Organic nutrient carriers need to be analyzed to determine the nutrient content. Once this is known, the amount to apply to meet the nutrient requirements of the crop being grown can be calculated or the amount of nutrient credit to take for manure already applied can be calculated.

Table 11. 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 for all nutrient applications. Nitrogen and phosphorus are the nutrients of most concern. Excess nitrogen 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 to leach into groundwater. On finer textured soils, nitrate can be lost to the air through denitrification when the soil is warm (above 50 degrees F) and wet. Environmental concerns related to phosphorus are primarily related to surface water quality. Phosphorus can be transported to surface waters via erosion or surface water runoff. Phosphorus in surface water can lead to eutrophication, which occurs when elevated nutrient concentrations in water create conditions favorable for excess algal and plant growth that may result in fish kills, loss of quality for recreation 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 phosphorus fertilizer results in P binding to the soil and becoming slowly available for plant uptake. For low P testing soils, broadcast applications are less efficient and will normally result in lower yields than band applications. However, broadcast P fertilizer is effective in building up P soil test levels. Starter fertilizer applied 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 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 nitrogen than by the additional P. If starter fertilizer containing P is used on a high P soil, apply it at a rate such that the amount of P applied is less than crop removal. For corn (grain), this would be less than 50 pounds P_2O_5 per acre; for sugar beet, less than 30 pounds P_2O_5 per acre.

Nitrogen Management

Forms of Nitrogen Fertilizer

Nitrate forms of N fertilizer are more subject to loss than other 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 there is a high leaching potential. 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 not 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 occurs 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 semi-humid regions of the United States, including Michigan, have clearly been shown to be superior to fall applications (Table 12). 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 economic benefits. Fall applications of N are not warranted in Michigan and should be discontinued except for small applications on fall-seeded wheat.

Table 12. Yield of corn as affected by nitrogen rate, time of nitrogen application and soil type (11 experiments from 1977 to 1984).

Nitrogen	Time of application	
Rate[1]	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/A of nitrogen.

Yield benefits from split or sidedress N applications for corn have frequently been 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 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 efficiency and fine-tune N application rates.

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 due to wet weather is 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 is a 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. It is important not to overirrigate during the early part of the growing period in June and July because nitrate 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 season.

Crop producers should consider using nitrification inhibitors when it is not feasible to use delayed N applications, such as by 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 nitrogen 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, nitrogen can be lost as volatile ammonia as urea is converted by urease into inorganic N forms. 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, providing more time for the urea to be moved into the soil by rain or irrigation where the released ammonia is adsorbed by 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 disk-opener or knife or by tillage will eliminate the concern for volatile N loss.

Soil Nitrate Testing

Nitrate is the form of nitrogen 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 risk of reducing yields if they use the soil nitrate test. Nitrate testing can also help to prevent over-application 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 June after the soil has warmed up and prior to sidedressing, when it usually contains the greatest amount of nitrate N. 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 prior to 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 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 be easily lost by leaching.

PSNT soil samples are best taken shortly before side-dressing (when the corn is 6 to 12 inches tall). At least 15, 1-foot soil cores across no more than 20 acres should be mixed together to make a sample. Samples should be dried immediately before sending or kept cold until delivered to a laboratory. N credits are assigned on the basis of the outcome of the nitrate test. Multiply parts per million (ppm) nitrate-N in the soil by 6 to obtain the N credits in pounds per acre to a depth of 2 feet. The conversion factor of 6 assumes that the amount of N in the second foot of soil is two-thirds of that found in the top foot. This is based on observations of hundreds of PSNT soil samples taken from cornfields in Michigan.

A few caveats for using the PSNT must be stated. First, the PSNT results will be more accurate if less than 40 pounds N per acre is applied at or prior to planting. Second, if the PSNT is less than 5 ppm, no N credit should be taken. Third, if the PSNT is greater than 25 ppm, no additional N is needed for corn production.

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 nitrogen program. Concentrations between 450 and 2,000 ppm generally indicate good nitrogen use efficiency with optimum yields and limited residual soil nitrogen. 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 nitrogen was available than was necessary. Maintaining a database of stalk nitrate values from field to field and from year to year is a good way to fine-tune N management.

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.

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 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 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 calculated according to the following equations. Phosphorus and potassium guidelines are given in tables 13, 14, 15 and 16.

Mineral soil

Corn grain = – 27 + (1.36 x YG) – NC

Corn silage = – 25 + (8.33 x YG) – NC

Corn, seed = – 27 + (1.63 x YG) – NC

Organic soil

Corn grain = – 67 + (1.36 x YG) – NC

Corn silage = – 65 + (8.33 x YG) – NC

where YG = yield goal and NC = nitrogen credit

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 nitrogen, 100 pounds of phosphate (P_2O_5) and 100 pounds of potash (K_2O) per acre. Applying an amount of phosphate equal to crop removal will help maintain the available phosphorus in the soil when the soil test value is above the critical value of 15 ppm. Inclusion of phosphorus in starter fertilizer when the soil phosphorus 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 phosphorus and potassium required to build up the soil levels (see tables 6 and 8).

Nitrogen may be managed with a combination of application times: preplant, planting time and/or sidedress. Apply preplant nitrogen as close to planting time as possible to reduce the risk of nitrogen loss. Fall application of nitrogen is not recommended because of the potential for leaching loss, even with a nitrification inhibitor. Sidedress nitrogen application on the basis of a soil nitrogen test when the corn is 6 to 12 inches tall provides the most efficient use of nitrogen inputs. The total amount of nitrogen to apply depends on the expected corn yield (yield goal). Base yield goal on the yield history of the field, such as a five-year running average.

Irrigation of corn influences the fertilizer requirements because it increases the yield potential. These increased requirements are accounted for by the greater yield goals. A significant portion of the nitrogen may be applied through the irrigation system. One approach is to apply two-thirds of the nitrogen in

Table 13. Phosphorus recommendations for selected yields of corn.

	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

Table 14. Phosphorus recommendations for selected yields of corn silage.

	Yield (T/A)	
Soil test	20	30
ppm	- - - - lb P_2O_5/A - - - -	
5	200	200
10	189	200
15-30	164	200
15-30	164	200
35	82	123
40	0	0

Numbers highlighted are maintenance amounts.

Table 15. Potassium recommendations for selected yields of corn.

	140 bu/A				180 bu/A			
Soil test 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

Table 16. Potassium recommendations for selected yields of corn silage.

	20 T/A				30 T/A			
Soil test CEC	4	8	12	16	4	8	12	16
ppm	- -- - - - lb K_2O/A - - - - - -				- - - - - - - lb K_2O/A - - - - - -			
40	210	233	260	291	272	295	300	300
80	162	177	196	219	224	239	258	281
85	156	170	188	210	218	232	250	272
95	156	156	172	192	218	218	234	254
105	156	156	156	174	218	218	218	236
115	156	156	156	156	218	218	218	218
125	78	156	156	156	109	218	218	218
135	0	78	156	156	0	109	218	218

Numbers highlighted are mainenance amounts.

some combination of preplant, planting time and/or sidedress applications and the remainder through the irrigation system.

Soybeans

Phosphorus and potassium recommendations are given in tables 17 and 18.

Soybean is a legume that can meet its nitrogen need by symbiotic fixation of atmospheric nitrogen. In general, soybeans will not benefit from supplemental nitrogen 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 nitrogen fixation. 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 phosphate and potash prior to planting. For no-till soybeans, use a band-placed starter fertilizer or broadcast the required fertilizer prior to planting. On lakebed soils and dark-colored soils where the soil pH is above 6.5, manganese application will usually improve soybean growth and yields. Include 2 pounds of manganese (or the recommended amount based on a soil test) in the

Table 17. Phosphorus recommendations for selected yields of soybean.

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

Table 18. Potassium recommendations for selected yields of soybean.

Soil test	40 bu/A CEC 4	8	12	16	60 bu/A 4	8	12	16
ppm	- - - lb K_2O/A - - -				- - lb K_2O/A - -			
40	110	133	160	191	138	161	188	200
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.

starter fertilizer or apply one or two applications of 1 to 2 pounds Mn per acre to the foliage. Broadcast applications made to the soil are not effective.

Dry Edible (Field) Beans

Phosphorus and potassium recommendations are given in tables 19 and 20.

Dry beans, like soybeans, are legumes and can fix nitrogen. Nitrogen fixation in dry bean can be unreliable, however, because of environmental conditions and variability between varieties. Therefore, applying 40 to 60 pounds N per acre is recommended to achieve maximum yield. Apply 60 pounds N per acre 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 pounds N per acre. Applying excess nitrogen can delay bean maturity and may create greater potential for white mold if the crop canopy is dense.

Dry beans are sensitive to low levels of available zinc. Providing adequate amounts of zinc fertilizer, if needed, is important because even mild zinc deficiency can delay maturity. Use a soil test to determine available zinc levels and calculate the amount to apply from the equation: Zn rec. (lb/A) = (5.0 x pH) – (0.4 x ST ppm) – 32. In the absence of a soil test, apply 1 pound Zn per acre if the previous crop was sugar beets or if the soil pH is above 6.5.

Dry beans do not tolerate fertilizer applied with the seed. Up to 40 pounds of nitrogen, all of the phosphate and 60 pounds of potash 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 nitrogen 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 zinc deficiency that 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 zinc deficiency because the bean plant can not take up enough zinc on its own.

Table 19. Phosphorus recommendations for selected yields of dry edible beans.

Soil test	Yield (cwt/A) 20	30
ppm	- - - - lb P_2O_5/A - - - -	
5	74	86
10	49	61
15-30	24	36
35	12	18
40	0	0

Numbers highlighted are maintenance amounts.

Table 20.Potassium recommendations for selected yields of dry beans.

Soil test	20 cwt/A				30 cwt/A			
	CEC 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.

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

Small Grains

Wheat, Barley, Oats, Rye, Canola

Nitrogen recommendations are given according to the following equations:

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

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

Wheat A = – 13 and B = 1.33

Phosphorus and potassium recommendations for wheat and barley are given in tables 21, 22, 23 and 24. Phosphorus and potassium recommendations for oats are about 10 pounds P_2O_5 per acre and 5 pounds K_2O per acre more than those for barley at the same yield level. Recommendations for the other cereal grains can be calculated from the equations on pages 9 – 11 and the information in tables 7 and 9.

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 pounds per acre of nutrients (N + P_2O_5+ K_2O) in contact with the seed in sandy soils and no more than 140 pounds per acre in fine-textured soils. Broadcast and incorporate preplant fertilizer required in excess of that applied with the drill. The alternative is to broadcast and incorporate all the required fertilizer nutrients prior to seeding.

For winter wheat or barley, apply no more than 25 pounds of N per acre in the fall. This may be included in the preplant broadcast or planting time fertilizer. In the spring prior to green-up, topdress additional nitrogen based on yield potential of the field. For high-yielding wheat varieties and sites, this is usually 80 to 100 pounds per acre. Another option is to split the nitrogen between pre-green-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 pounds N per acre prior to spring green-up. No nitrogen 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 nitrogen, phosphorus and potassium prior to seeding. On slightly acidic sandy soils, foliar application of 1 to 2 pounds Mg per acre may be beneficial if the soil magnesium level is marginal or low (< 35 ppm).

Wheat, oats and barley grown on lakebed soils and dark-colored soils where the soil pH is above 6.5 may benefit from manganese application. 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 manganese and apply recommended amounts.

Table 21. Phosphorus recommendations for selected yields of wheat.

Soil test	Yield (bu/A)	
	60	90
ppm	- - - - lb P_2O_5/A - - - -	
5	123	134
10	98	109
15	73	84
20	48	59
25-40	23	34
45	11	17
50	0	0

Numbers highlighted are maintenance amounts.

Table 22. Phosphorus recommendations for selected yields of barley.

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

Table 23. Potassium recommendations for selected yields of wheat.

Soil test	60 bu/A CEC 4	8	12	16	90 bu/A 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

Table 24. Potassium recommendations for selected yields of barley.

Soil test	50 bu/A CEC 4	8	12	16	80 bu/A 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

For oats add 5 lb/A.

Numbers highlighted are maintenance amounts.

Sugar Beets

Nitrogen recommendations are calculated according to 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 25 and 26.

Nitrogen management in sugar beet production is critical to maximize sugar yield. Nitrogen is needed to produce high yields of beets, but too much nitrogen reduces the sugar quality of the harvested beet. Sugar yield is maximized by balancing high yield and quality. In general, 80 to 100 pounds of N per acre 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 nitrogen application rate by 30 pounds N per acre. It is likely that additional nitrogen is needed for beets after corn because corn is not a legume. Research results over the past two years support this recommendation. Sugar beets need a majority of the N early in the season to obtain canopy closure; then 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 x 2 band placement) should provide 30 to 40 pounds N per acre. Alternatively, the nitrogen can be applied prior to planting. However, some experiences suggest that, to reduce the risk of fertilizer adversely affecting germination, apply preplant no more than 50 pounds N per acre.

Beets generally will not respond to phosphorus fertilizer when soil test values are greater than 30 ppm (60 pounds P per acre). On high P soils, phosphorus is not needed in a starter fertilizer. If one wishes to use a starter fertilizer containing P_2O_5, then the amount of P_2O_5 applied should be less than crop removal (approximately 30 pounds P_2O_5 per acre). Beets are sensitive to low levels of available manganese, particularly when the soil pH is higher than 6.5. Use a soil test to determine available manganese levels and the amount of manganese to apply. Manganese applications are most effective in starter fertilizers. Foliar applications of manganese (1 pound per acre) can be used to remediate deficiencies that appear after crop establishment.

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 when soil pH is higher than 6.5, the incidence of root diseases is lower.

Table 25. Phosphorus recommendations for selected yields of sugar beets.

Soil test	Yield (T/A) 20	28
ppm	- - - - lb P_2O_5/A - - - -	
5	126	136
10	101	111
15	76	86
20	51	71
25-40	26	36
45	13	18
50	0	0

Table 26. Potassium recommendations for selected yields of sugar beets.

Soil test	20 T/A CEC 4	8	12	16	28 T/A 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.

Forage Crops

Legumes

Phosphorus and potassium recommendations for alfalfa and clover are given in tables 27, 28, 29, 30 and 31.

For legumes, be sure to adjust the soil pH to 6.5 or above by applying the appropriate rate of limestone. This is best done by applying and incorporating the lime about 6 to 12 months prior to seeding. When no-till seeding legumes on erosive sites, broadcast the lime without incorporation. Broadcast and incorporate the required phosphate and potash during seedbed preparation or apply it through the seeder. Base 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 phosphorus and up to 150 pounds K_2O per acre. For fertilizer placed directly with the seed, limit the amounts to 100 pounds P_2O_5 and 50 pounds K_2O per acre. Planting time nitrogen is not necessary for legume seedings, but be sure to inoculate the seed with the appropriate strains of Rhizobia before planting. Including 20 pounds of nitrogen per acre 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. The small grain nurse crop should be harvested as silage to reduce competition with the new legume seeding. The fertilizer applied for the small grain is sufficient to carry the legumes through the first season. Topdress the legume with appropriate amounts of phosphorus and potassium after the small grain nurse crop is removed as silage or after the first cutting of a clear seeding.

Boron is needed annually on sandy soils (CEC < 8.0) at a rate of 2 pounds per acre. Fine-textured soils can supply adequate boron, so boron applications have not proven beneficial. Where needed, apply boron in the topdressing fertilizer. Legumes remove large amounts of potassium (45 to 60 pounds K_2O per ton) from the soil. To replace potassium removed by the crop, topdress potash (K_2O) in the spring when the crop is dormant or after a harvest. Fall application is acceptable on all soils except loamy sands and sands, where significant leaching may occur. It is suggested to limit single applications to no more than 300 pounds K_2O per acre.

Table 27. Phosphorus recommendations for selected yields of alfalfa.

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 28. Phosphorus recommendations for selected yields of clover hay.

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

Table 29. Phosphorus recommendations for selected yields of clover-grass hay.

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

Table 30. Potassium recommendations for selected yields of alfalfa hay.

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	300	300	300	300
115	80	120	160	200	160	300	300	300
125	40	80	120	160	80	160	300	300
135	0	40	80	120	0	80	160	300

Numbers highlighted are maintenance amounts.
Maximum recommendation for a single application is 300 lb. K_2O/A.

Table 31. Potassium recommendations for selected yields of clover and clover-grass hay.

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.

Grass Hay or Pasture

The nitrogen recommendation for a grass hay and for an intensively grazed (rotational grazing) grass pasture is 150 to 200 pounds N per acre. Nitrogen should be applied in split applications of 40 to 50 pounds N per acre at green-up, June 1, August 1 and September 1. Phosphorus and potassium recommendations are presented in tables 32 and 33 for bromegrass. Phosphorus recommendations for other grasses are similar to those of bromegrass, but potassium recommendations are different because the various grasses take up different amounts of potassium (see Table 3).

When grass is seeded for hay or pasture, the fertilizer may be broadcast and incorporated prior to 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 amounts of nutrients ($N + P_2O_5 + K_2O$) to 100 pounds per acre on sandy soils and 140 pounds per acre on fine-textured soils. Broadcast and incorporate any additional amounts of phosphate and potash. Include 30 to 40 pounds nitrogen per acre in the preplant or planting time fertilizer.

For established grass hay, annually topdress 200 pounds of nitrogen per acre in split applications plus maintenance amounts of phosphate and potash. For grass-legume hay with more than six legume plants per square foot, no additional nitrogen is needed. As the percent legume decreases, the need for nitrogen increases. With a legume stand of less than 40 percent (fewer than three plants per square foot), apply 100 pounds of nitrogen per acre.

Grass Pasture

Annually topdress with nitrogen plus maintenance amounts of phosphate and potassium. Apply, in split applications, 150 pounds N per acre for intensively grazed pastures (rotational grazing) and 200 pounds N per acre for extensively grazed pastures. When pastures contain more than 40 percent legume, additional nitrogen 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 pounds of nitrogen per acre. Broadcast and incorporate the recommended amounts of phosphorus and potassium prior to planting.

Grass Waterways and Critical Areas

Grass waterways, highly erodible soil and other critical areas need good fertility to maintain a dense, uniform cover through the year. 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 pounds N per acre and the required amounts of phosphate (P_2O_5) and potash (K_2O) prior to seeding, or, if the crop is already established, broadcast the fertilizer. To maintain vigor, annually topdress with up to 25 pounds N per acre.

Conservation Reserve

The Conservation Reserve Program (CRP) provides cost sharing for 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 prior to seeding. Required soil phosphorus and potassium levels are lower than those for forage hay production because there is no removal of biomass. Apply the amounts of phosphorus and potassium needed to build the soil level to the critical level (10 ppm P, 95 ppm K). No nitrogen is recommended for establishment of warm- or cool-season grasses with or without a legume. Studies have shown that nitrogen application increases weed competition. No maintenance fertilization is needed once ground cover is established

Table 32. Phosphorus recommendations for selected yields of bromegrass hay.

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

Table 33. Potassium recommendations for selected yields of bromegrass hay.

Soil test	4 T/A CEC 4	8	12	16	6 T/A 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 recommendation for a single application is 300 lb.

because nutrients taken up by the plants will be recycled as the biomass dies and decomposes.

Potato

Recommended nitrogen can be calculated as follows:

N rec = 150 + ((YG - 300) x 0.3) *where* YG is yield goal in cwt/A

For Russet Burbank, Snowden and other late-maturing varieties, increase the nitrogen recommendation by 40 pounds N per acre. Phosphorus and potassium recommendations are given in tables 34 and 35. Apply up to 60 pounds of nitrogen, all of the phosphorus and up to 100 pounds of potash (K_2O) per acre 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 banding on just one side. Prior to planting, broadcast and incorporate potash in excess of the amount applied in the fertilizer bands. Fall application of potassium 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 nitrogen needed. Nitrogen broadcast prior to planting has an increased risk of loss by leaching. Nitrogen applied after planting is usually used more efficiently than nitrogen applied preplant. It is best to supply needed nitrogen through a combination of applications at planting time and hilling and 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 nitrogen 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 manganese in the starter fertilizer or spray the foliage with 1 to 2 pounds Mn per acre at least twice during active growth.

Table 34. Phosphorus recommendations for selected yields of potato.

Soil test	Yield cwt/A 350	400	450
ppm	- - - - lb P_2O_5/A	- - - -	
20	245	252	258
40	145	152	158
60-100	45	52	58
120	9	10	11
140	0	0	0

Numbers highlighted are maintenance amounts.

Table 35. Potassium recommendations for selected yields of potato.

Soil test	340 cwt/A CEC 4	8	12	16	450 cwt/A 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	14	283
155	0	0	0	110	0	0	0	142
165	0	0	0	0	0	0	0	0

Numbers highlighted are maintenance amounts.

For more materials available online, visit the MSU Extension Web site at:
http://web2.msue.msu.edu/bulletins/intro.cfm

New 5/04 (Replaces E550)-3M-KMF/DP, $3.40, for sale only.