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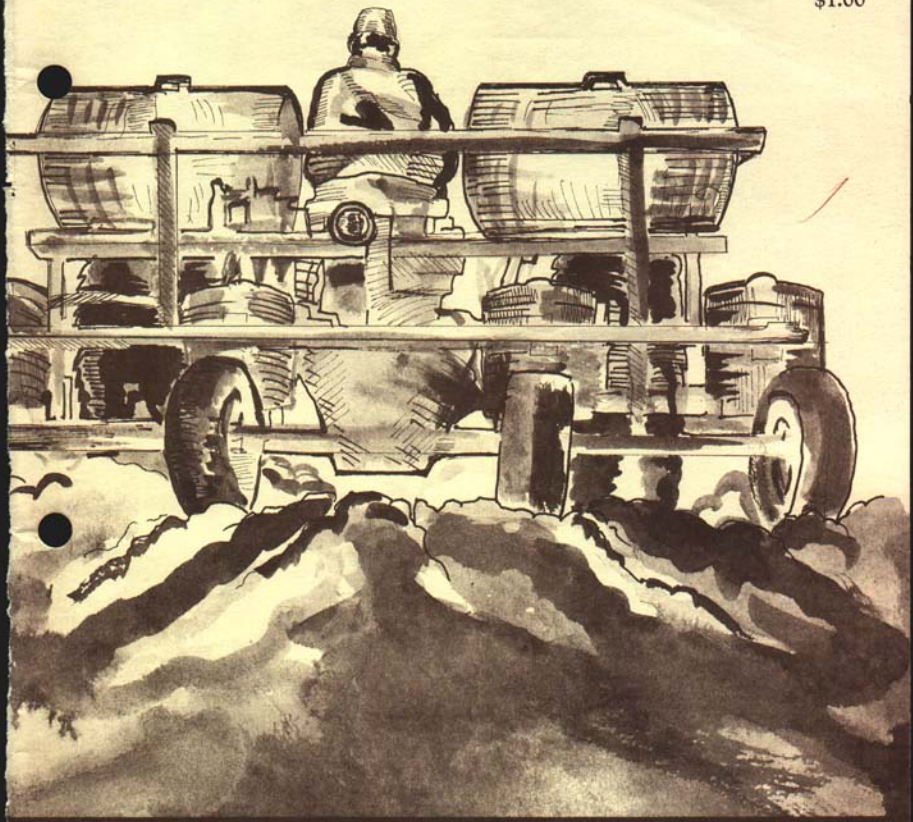

Fertilizer Recommendations:

Vegetable and Field Crops in Michigan

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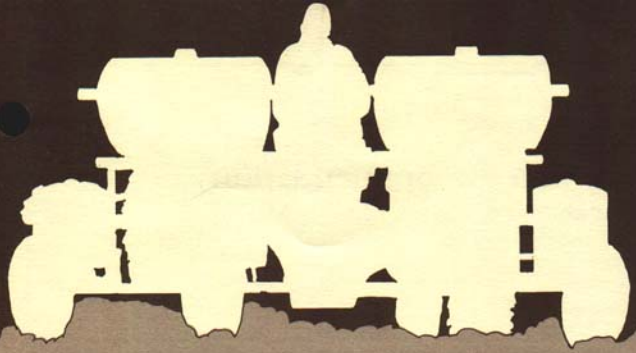

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Fertilizer Recommendations:
Vegetable and Field Crops in Michigan

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The Michigan State University soil testing service is part of a continuing soil fertility program of the Department of Crop and Soil Sciences and the Cooperative Extension Service. Soil samples can be submitted to the MSU Soil Testing Lab directly or through your county Cooperative Extension Service office.

Fertilizer recommendations given in this bulletin are based on a soil test, soil type, yield goal and past crop management. Each section—"Field Crops," "Vegetables" and "Organic Soils"—discusses the method of fertilizer application along with recommended rates. Applying recommended fertilizer rates with proper timing and incorporation will minimize the chance that fertilizers will be a source of surface or ground water pollution. Fertilizers applied nearest to the period of greatest plant uptake are utilized most efficiently. On sloping soils, incorporate or place fertilizers beneath the soil surface to reduce runoff loss.

Many types and grades of fertilizer are available, and the nitrogen, phosphorus and potassium requirements of crops can be met in a variety of ways. For additional information, see Extension bulletins E-896, "Fertilizer Types, Uses and Characteristics," and E-933, "Fluid Fertilizers—Liquids and Suspensions."

Soil Sampling

A soil test must be made from a representative soil sample. Soil test results and fertilizer recommendations will be no more representative of a field than the soil sample. For most field crops, sample and test soils at least once every three years. For high-value field or vegetable crops grown under intensive management, sample and test soils annually.

Soil samples may be taken at any time during the year when soil temperature and moisture conditions permit. Before sampling a field, check for differences in soil characteristics. A soil survey map will be helpful. Consider the productivity, topography, texture, drainage, color of topsoil and past management of the area to be sampled. If these features are uniform throughout the field, each composite sample of the topsoil can represent 10 to 15 acres.

Each composite sample should consist of at least 20 subsamples taken at random over the field. Avoid sampling close to gravel roads, dead furrows, previous locations of brush, lime or manure piles, burned muck, or any unusual areas. Mix the subsamples well, then place a pint of the soil in the sample box for mailing to the laboratory. Soil sample boxes are available from your county Cooperative Extension Service office.

Extension bulletins E-498, "Sampling Soils for Fertilizer and Lime Recommendations," and E-1616, "Soil Sampling for No-Till and Conservation Tillage Crops," provide additional information on how to take soil samples.

Soil Testing

Soil testing is vitally important to determine which plant nutrients to apply and to assure that nutrient deficiencies do not occur or limit plant growth. Applying fertilizer nutrients according to soil test results will help maximize crop yields, crop quality and economic returns. Many other factors must also be managed properly for optimum crop production, including soil physical properties, control of weeds, insects and diseases, timely planting, etc.

The following is a brief discussion of the procedures used in the Michigan

State University Soil Testing Laboratory.

Soil pH of mineral soils is measured with a 1:1 soil-to-water suspension; pH of organic soils, with a 1:2 soil-to-water suspension.

Available soil phosphorus is measured using the Bray-Kurtz P-1 (weak acid) extractant. Exchangeable potassium, calcium and magnesium are measured using the 1.0 N neutral ammonium acetate method. Recommendations for phosphorus and potassium fertilizer are based on soil test values obtained with these extractants.

Available manganese and zinc are determined upon a 0.1 N HCl extraction; copper on a 1.0 N HCl extraction (1:10 soil:extractant ratio). Micronutrient levels are expressed as parts per million (ppm).

Mineral soil samples submitted to the Michigan State University Soil Testing Laboratory are extracted on weighed samples. The amounts of nutrients extracted are expressed as parts per 2 million or pounds per acre, which assumes that one acre of loamy soil 6 2/3 inches deep weighs about 2 million pounds. Organic soil samples are measured by volume because such materials usually have much lower densities than mineral soils. Results for organic soils are expressed on a volume acre furrow slice basis (volume of 1 acre 6⅔ inches deep).

Available phosphorus, potassium, calcium and magnesium are expressed as actual pounds of available element (P, K, Ca, Mg) per acre. Available zinc, manganese and copper are expressed as parts per million (ppm). Some laboratories express all elements as parts per million. The factors to convert ppm to pounds per acre is 2 (i.e., 2 x ppm = lb/acre). To convert P to P_2O_5 and K to K_2O, the conversion factors are:

pounds P x 2.3 = pounds P_2O_5
pounds K x 1.2 = pounds K_2O

The fertilizer recommendations are given in pounds of phosphate (P_2O_5) and potash (K_2O) per acre because fertilizers are expressed and sold in these terms.

Basis for Recommendations

Numerous field studies conducted throughout the state each year provide the basis for these fertilizer recommendations. Soil test levels of the plow layer have been correlated with actual crop responses to fertilizer nutrients. Where direct field data are unavailable, nutrient recommendations are based on theoretical considerations combined with field data from similar soil and crop systems.

Phosphorus and potassium recommendations provided by the Michigan State University Soil Test Lab provide for a buildup when soil tests are low, maintain desirable nutrient levels when soil tests are medium to high, and allow for a gradual drawdown of available nutrient levels when soil tests are very high. To determine if a recommendation will result in a buildup or maintenance of the present soil test level, use Table 1. A maintenance recommendation will be equal to crop removal of nutrients, whereas a buildup recommendation will exceed

TABLE 1. Nutrient removal by several Michigan field crops.[1]

		Nutrient removal		(lb/acre)	
Crop		Yields	N	P_2O_5	K_2O
Corn	(Grain)	150 bu	135	53	40
	(Stover)	4.5 tons	100	37	145
	(Silage)	25 tons	235	90	195
Soybeans[2]	(Grain)	40 bu	150	35	55
Wheat	(Grain)	40 bu	50	25	15
	(Straw)	1.5 tons	20	5	35
Oats	(Grain)	80 bu	50	20	15
	(Straw)	2 tons	25	15	80
Rye	(Grain)	30 bu	35	10	10
	(Straw)	1.5 tons	15	8	25
Sorghum	(Grain)	60 bu	50	25	15
	(Stover)	3 tons	65	20	95
Sugar beets	(Roots)	15 tons	60	20	60
Potatoes	(Tubers)	500 cwt	167	67	316
Field beans	(Seed)	18 cwt	75	25	25
Alfalfa[2]	(Hay)	5 tons	225	50	225
Bromegrass	(Hay)	3 tons	90	18	140

1 Source: USDA Miscellaneous Publication No. 369 and "Feeds and Feeding" by Morrison. 22nd edition.

2 Legumes get most of their nitrogen from air.

crop removal. When soil test levels of phosphorus or potassium are low to medium, the total amount of phosphorus or potassium fertilizers recommended includes both the buildup and maintenance recommendations. A gradual buildup to a desirable soil test level will occur in approximately five years.

When available phosphorus or potassium levels are high, very little or no fertilizer is recommended, allowing the crop to utilize the nutrients available in the soil system. This will cause a gradual decrease in available P and K levels. The actual rate of decrease depends upon soil type, the crop grown and the yield. As the soil test level approaches the desirable range (medium to high), the recommendation again approaches maintenance. Additional information on phosphorus and potassium maintenance fertilizer recommendations is given in Extension bulletin E-1342, "Phosphorus and Potassium Maintenance Fertilizer Recommendations."

Retest soils every two or three years to check the fertility reserves of the soil. With high-value crops, testing every year is desirable. Before going to a conservation tillage system of crop production, it is desirable to build up available phosphorus and potassium to medium or high levels.

Yield potentials in Tables 31 and 32 represent practical yields under good management. These yields are based on field experiences with average management and climatic conditions for the various soil management groups. Yield potential on individual fields can vary substantially from these averages, depending upon management. Variations in management and yield potential are accommodated in later tables, where increasing quantities of fertilizer nutrients are recommended over a range of increasing yield goals.

Past experience and good judgment must be used in selecting the yield goal for a given field. Fertilizing to try to reach a yield goal that cannot be attained because of some other limiting factor or factors only incurs needless costs. Accumulation of nutrients above a level where crop response occurs may lead to deleterious effects on the soil and the crop. It may also increase the potential for environmental pollution due to possible erosion and/or leaching of nutrients into surface or ground waters.

Fertilizers are most effective on well drained soils with favorable structure that promotes deep rooting. Too much tillage can cause compaction, destroy soil structure and lower fertilizer efficiency.

Soil Acidity and Liming

Soil acidity is expressed in terms of "pH." A soil having a pH of 7.0 is neutral—neither acid nor alkaline. A soil having a pH of 6.0 is mildly acid; pH 5.0 is more strongly acid, while pH 8.0 is mildly alkaline. Most well drained Michigan soils, in their natural state, have a pH lower than 7.0. This is desirable from the standpoint of availability of most nutrients.

Plant nutrients, particularly phosphorus, are most available in mineral soils having a pH between 6.0 and 7.0. For general field crops, it is recommended that acid soils be limed to pH 6.5. If alfalfa is to be grown, lime the soil to pH 6.8.

The estimated lime requirement of acid soil samples submitted to the Michigan State University laboratory is determined by measuring the total soluble and exchangeable hydrogen and aluminum content. The degree of acidity is reported as the "lime index." This method of determining lime requirement is more precise than estimates made from soil pH measurements alone, because it measures total acidity instead of just the active acidity of the soil. Table 2 shows the amount of limestone recommended based upon the lime index value for mineral soils. For organic soils, see Table 23.

Applying less than 1 ton of lime per acre is of questionable economic value. When the lime requirement is less than 1 ton per acre, soil pH is usually adequate for optimum crop production. Retest these soils in two to three years to determine the lime needs.

Do not apply more than 6 tons of lime per acre in any one season. Applying more may cause localized zones of high alkalinity, reducing the availability of essential nutrients. Retest soil with a lime index of 6.4 or below two years after application to determine if additional lime is needed. When the lime need is greater than 4 tons per acre, applying the lime in a split application—i.e., half before plowing and half after plowing—will be more effective in neutralizing the acidity in the plow layer than one large application.

For potatoes, the soil is generally limed to pH 6.0. If there is no history of scab, or if it is not suspected because you're growing resistant varieties, consider liming to pH 6.5. Do not exceed 2 tons of lime per acre at any one time, and apply it in the fall. For no-till crop production systems, apply lime based on the pH of the top 3 inches to neutralize the acidity in the surface 3 inches. For no-till production, the lime rate will be one-third of that given in Table 2.

Further information on liming can be found in MSU Extension bulletins E-471, "Facts About Lime: Answers to Commonly Asked Questions," and E-1566, "Lime for Michigan Soils."

TABLE 2. Tons of limestone needed to raise the soil pH of mineral soils to pH 6.0, 6.5 or 6.8 as determined by the lime index method.

Lime index	Lime recommendations (9 - inch plow depth) tons/acre		
	to pH 6.0	to pH 6.5	to pH 6.8
70	0.0	0.0	0.0
69	0.0	0.6	0.8
68	1.2	1.6	1.8
67	1.9	2.5	2.9
66	2.7	3.5	3.9
65	3.5	4.4	4.9
64	4.3	5.3	5.9
63	5.1	6.3	6.9
62	5.8	7.2	8.0
61	6.6	8.2	9.0
60	7.4	9.1	10.0

To convert lime recommendations to a depth of plowing other than 9 inches, divide the above rates by 9 and multiply by the depth of plowing. The maximum lime application for one season is 6 tons. Recommendations are calculated from the following formulas and rounded to the nearest tenth of a ton:

XL = 54.2 - .78 * LI to pH 6.0
XL = 65.5 - .94 * LI to pH 6.5
XL = 71.2 - 1.02 * LI to pH 6.8

Where: XL = Lime recommendation in tons/acre
LI = lime index

TABLE 3. Nitrogen fertilizer recommendations for corn grain.

Yield goal	Previous crop or manure application				
	No alfalfa No manure	100% alfalfa	60% alfalfa	10 tons manure	20 tons manure
bu/acre	lb N/acre				
100	110	10	30	70	30
125	140	40	60	100	60
150	180	80	100	140	100
175	210	110	130	170	130
200	250	150	170	210	170
225	280	180	200	240	200

Recommendations are calculated from the following formula and rounded to the nearest 10 pounds:

XN = [-27 + (1.36 * YG)]-(40 + 60 * PS)-(4 * TM)

Recommendations for corn silage may be calculated using the formula:

XN = [-25 + (8.33 * YG)]-(40 + 60 * PS)-(4 * TM)

Where: XN = lb N/acre recommended
YG = yield goal in tons/acre
PS = percent stand of alfalfa
TM = tons of manure applied

Recommendations For Field Crops On Mineral Soils

Crop response to increasing levels of soil fertility or applied fertilizer is a continuous function—that is, yield increases do not occur in a stepwise manner but rather increase gradually with increasing levels of available nutrients. The fertilizer recommendation tables in this bulletin present recommendations for specific soil test levels. Equations used in determining the appropriate recommendations are given as footnotes to each table.

Major Nutrients

NITROGEN (N)—A reliable nitrogen soil test has not been developed for use in the Great Lakes states. Nitrogen needs depend on the crop to be grown, yield goal and previous management practices. Nitrogen fertilizer recommendations based on these factors are given in Tables 3-5.

Bacteria living symbiotically in alfalfa and clover root nodules use atmospheric nitrogen in their growth and development. Some of this "fixed" nitrogen is available directly to the host plant and some is excreted into the soil, where it is available for plant uptake. When the bacteria die and the nodules decompose, additional nitrogen becomes available. Because of this "nitrogen fixation" by the bacteria, leguminous crops do not usually need or respond to nitrogen fertilizer.

When alfalfa or clover is the previous crop, a nitrogen credit is given, based on percent stand according to the equation: pounds of N credit equals 40 + (60 times percent stand), where over 5 to 6 plants per square foot is considered to be a 100 percent

TABLE 4. Nitrogen fertilizer recommendations for small grains.

Yield goal	Oats	Barley	Wheat
bu/acre		lb N/acre	
40	20	20	40
50	20	30	50
60	20	40	70
70	30	40	80
80	30	50	90
90	40	60	110
100	40		120
110	40		
120	50		
130	50		
140	60		
150	60		

Recommendations are calculated from the following formula and rounded to the nearest 10 pounds:

XN = A + B * YG

Where: XN = lb N/acre
YG = yield goal, bu/acre
for oats A = 0 and B = .4
for barley A = -12 and B = .8
for wheat A = -13 and B = 1.33

TABLE 5. Nitrogen fertilizer recommendations for potatoes and sugar beets.

Potatoes		Sugar beets	
Yield goal	N recommendation	Yield goal	N recommendation
cwt/acre	lb/acre	tons/acre	lb/acre
200	120	18	70
250	140	20	80
300	150	22	90
350	170	24	100
400	180	26	100
450	200	28	110
500	210		
550	230		

Recommendations are calculated from the following formula and rounded to the nearest 10 pounds:

XN = A + B * YG.

Where: XN = lb N/acre
for potatoes A = 60 and B =.30
for sugar beets A = 0.0 and B = 4.0

stand. Animal manure is credited with supplying 4 pounds of N per ton applied. Applying a small quantity of nitrogen at planting time is desirable for certain crops, even when the nitrogen credit from a legume or manure is adequate for crop needs. Where straw or mature grass cover crops are plowed down, extra nitrogen (30-40 lb/A) may be needed for orderly decomposition of the crop residues and growth of the new crop.

Several sources of nitrogen fertilizer are suitable for crop production (see Extension bulletin E-896, "N-P-K Fertilizers: Types, Uses and Characteristics"). The materials are usully equally effective and should be purhased on the basis of cost per pound of actual nitrogen, convenience of application and supply. Under special conditions—for plants growing in cold soils or on recently fumigated land—nitrate fertilizers are preferred.

Efficiency of nitrogen fertilizer use can be improved and nitrate pollution of surface and ground waters can be minimized by using recommended nitrogen rates, timely nitrogen application and ammonium forms for fall application. Fall nitrogen applications are best made after the soil temperature has dropped below 50 degrees F. Do not fall apply nitrogen on sandy soils or apply nitrogen on frozen sloping ground. Proper scheduling of irrigation water for irrigated crops to minimize leaching will also minimize nitrogen losses and maximize efficiency.

Most nitrogen carriers leave an acidic residue in the soil. It requires 1.8 to 2 pounds of limestone to neutralize the acidifying effect of each pound of nitrogen derived from ammonium nitrate, urea, anhydrous ammonia or nitrogen solutions, and 5.5 pounds if ammonium sulfate is used.

PHOSPHORUS (P)—Phosphorus fertilizers show their greatest benefits for fast growth of small seedlings, par-

ticularly when soil temperatures are cold. For crops such as barley, corn, sugar beets and wheat, which are seeded when soil temperatures are low, applying 25 pounds P_2O_5 per acre in the starter fertilizer is desirable. Applying starter phosphorus in soils testing high in phosphorus frequently improves early season plant growth but seldom results in any yield increase. Once a crop develops a good root system, it can effectively utilize the available soil phosphorus.

Studies have shown that 5 to 11 pounds of P_2O_5 per acre are required to increase the soil test by 1 pound P per acre in loamy sand and sandy loam soils. To increase the P soil test 1 pound per acre in loams and clay loams requires 12 to 18 pounds of P_2O_5 per acre. These values can be used to determine the amount of phosphate fertilizer required to build up the P soil test to a desired level. Phosphorus recommendations given in this bulletin provide for buildup of low-phosphorus soils over a five-year period. More rapid or immediate buildup can be accomplished by using the values given above.

Currently more than 50 percent of the soils in Michigan used for field crop production test very high in available phosphorus. Some drawdown can be allowed to occur without reducing crop yields. The rate of drawdown will be similar to that required for buildup. Phosphorus (P_2O_5) recommendations based on soil test results for the various field crops are given in Tables 6-13.

The primary phosphorus carriers used in fertilizers are developed by treating rock phosphate with phosphoric acid to form triple superphosphate or by neutralizing phosphoric acid with ammonia to form monoammonium phosphate or diammonium phosphate. Dry phosphate fertilizers are generally over 90 percent water soluble, and liquid phosphate fertilizers are nearly 100 percent water

TABLE 6. Annual phosphorus (P_2O_5) and potassium (K_2O) recommendations for alfalfa grown on mineral soils.

Soil test	Yield goal, tons/acre					
	3	4	5	6	7	8
	Phosphorus recommendation, lb P_2O_5/acre					
10 lb P/acre	70	80	90	110	120	130
20	60	70	80	90	110	120
30	40	60	70	80	90	110
40	30	40	60	70	80	90
50	20	30	40	60	70	80
60	0	20	30	40	60	70
70	0	0	20	30	40	60
80	0	0	0	20	30	40
90	0	0	0	0	20	30
100	0	0	0	0	0	20
110	0	0	0	0	0	0
	Potassium recommendation, lb K_2O/acre on sandy loams and loamy sands					
25 lb K/acre	290	310	340	360	390	410
50	260	290	310	340	360	390
75	240	260	290	310	340	360
100	210	240	260	290	310	340
125	190	210	240	260	290	310
150	160	190	210	240	260	290
175	140	160	190	210	240	260
200	110	140	160	190	210	240
225	90	110	140	160	190	210
250	60	90	110	140	160	190
275	40	60	90	110	140	160
300	0	40	60	90	110	140
325	0	0	40	60	90	110
350	0	0	0	40	60	90
375	0	0	0	0	40	60
400	0	0	0	0	0	40
	Potassium recommendation, lb K_2O/acre on loams, clay loams and clays					
25 lb K/acre	270	320	370	420	470	520
50	240	290	340	390	440	490
75	200	250	300	350	400	450
100	160	210	260	310	360	410
125	120	170	220	270	320	370
150	90	140	190	240	290	340
175	50	100	150	200	250	300
200	0	60	110	160	210	260
225	0	20	70	120	170	220
250	0	0	40	90	140	190
275	0	0	0	50	100	150
300	0	0	0	0	60	110
325	0	0	0	0	20	70
350	0	0	0	0	0	40
375	0	0	0	0	0	0

Recommendations are calculated from the following formulas and rounded to the nearest 10 pounds:

$$XP = 44 + 12.5 * YG - 1.25 * ST$$
$$XKs = 238 + 25 * YG - 1.00 * ST$$
$$XKc = 162 + 50 * YG - 1.50 * ST$$

Where:
XP = lb P_2O_5/acre
XKs = lb K_2O/acre sandy loams, and loamy sand
XKc = lb K_2O/acre loams, clay loams and clays
YG = Yield goal, tons/acre
ST = Soil test, lb/acre

TABLE 7. Annual phosphorus (P_2O_5) and potassium (K_2O) recommendations for wheat grown on mineral soils.

Soil test	Yield goal, bu/acre 50	60	70	80	90	100
	Phosphorus recommendation, lb P_2O_5/acre					
10 lb P/acre	100	110	120	130	140	150
20	80	90	100	120	130	140
30	70	80	90	100	110	120
40	60	70	80	90	100	110
50	50	60	70	80	90	100
60	30	40	50	70	80	90
70	20	30	40	50	60	70
80	0	20	30	40	50	60
90	0	0	20	30	40	50
100	0	0	0	20	30	40
110	0	0	0	0	0	20
	Potassium recommendation, lb K_2O/acre on sandy loams and loamy sands					
25 lb K/acre	130	140	150	160	180	190
50	120	130	140	150	160	170
75	110	120	130	140	150	160
100	90	110	120	130	140	150
125	80	90	100	110	130	140
150	70	80	90	100	110	120
175	60	70	80	90	100	110
200	40	60	70	80	90	100
225	30	40	50	60	80	90
250	20	30	40	50	60	70
275	0	20	30	40	50	60
300	0	0	20	30	40	50
325	0	0	0	0	30	40
350	0	0	0	0	0	20
	Potassium recommendation, lb K_2O/acre on loams, clay loams and clays					
25 lb K/acre	200	210	230	250	260	280
50	180	200	210	230	240	260
75	160	180	190	210	230	240
100	140	160	170	190	210	220
125	120	140	160	170	190	200
150	100	120	140	150	170	190
175	90	100	120	130	150	170
200	70	80	100	120	130	150
225	50	60	80	100	110	130
250	30	50	60	80	90	110
275	0	30	40	60	80	90
300	0	0	20	40	60	70
325	0	0	0	20	40	50
350	0	0	0	0	20	40
375	0	0	0	0	0	20

Recommendations are calculated from the following formulas and rounded to the nearest 10 pounds:

$$XP = 53 + 1.0 * YG - 1.25 * ST$$
$$XKs = 90 + 1.0 * YG - .50 * ST$$
$$XKc = 135 + 1.63 * YG - .75 * ST$$

Where: XP = lb P_2O_5/acre
XKs = lb K_2O/acre sandy loams & loamy sands
XKc = lb K_2O/acre loams, clay loams and clays
YG = Yield goal, bu/acre
ST = Soil test, lb/acre

soluble. When water-soluble phosphate, whether from a dry or liquid carrier, is added to soil, it immediately reacts with the soil system to form insoluble phosphorus compounds. Very little water-soluble phosphorus remains unless the fertilizer was banded in high concentrations. Research has shown no crop production differences among phosphate fertilizers that have greater than 50 percent water solubility.

Triple superphosphate has a low salt index but can delay seed germination because it readily absorbs soil moisture. This often happens in dry seasons when fertilizer is applied in direct contact with the seed, such as with a fall seeding of wheat.

Ammonium phosphates have high salt effects and must be placed away from seeds or plants. Diammonium phosphate is more hazardous than monoammonium phosphate because of the possible release of ammonia into the soil solution.

POTASSIUM (K)—Recommended potash (K_2O) rates for the various field crops are given in Tables 6-13.

The potassium-supplying ability of a soil is related to the types and amounts of clay minerals present. Depending upon soil texture, 2 to 6 pounds K_2O are required to increase the soil test by 1 pound K per acre. The present soil test used for potassium can adequately predict the potassium-supplying ability of most Michigan soils. Some soils, however, fix potassium in forms that are not readily available to plants. Routine soil testing does not determine the various types of clay minerals or the fixing ability of a soil. Soils containing vermiculitic clays may require higher than recommended rates of potash (K_2O) to build up the available soil potassium. Once such soils have a medium to high potassium test level, they will continue to supply potassium for some time, even though crop removal may be considerable.

Potassium fertilizer can be broadcast in the fall for buildup on the finer textured soils. Potassium may be leached through loamy sand and sand soils, so fall potassium applications should not be made on these sandy soils.

Potassium chloride (muriate of potash), which contains 60 percent K_2O, is the most common and cheapest source of potassium. It is highly effective for nearly all field crops. Potassium sulfate, potassium-magnesium sulfate and potassium nitrate are other effective carriers that are used for specialty crops such as potatoes, blueberries and greenhouse tomatoes and in potting soil mixes. These are used to help maintain low chloride levels and prevent soluble salt accumulation.

Small seedlings have less need for potassium than for phosphorus. On the other hand, once plants start to grow rapidly, they utilize large amounts of potassium. Crop removal of potassium is particularly heavy when the whole plant is harvested, as with hay, summer forages, corn for silage or celery.

The effectiveness of potassium applied in the row is equal or superior to that of potassium applied broadcast. The amount of potassium that can be applied near the seed is often limited, however, because of possible salt injury to the seed. For this reason, broadcast application is most often recommended.

Secondary Nutrients

MAGNESIUM (Mg)—Magnesium deficiency is most likely to occur in acid soils with a sandy loam, loamy sand or sand surface soil texture and a subsoil as coarse or coarser than the surface. It also occurs in similar soils limed with calcic limestone or marl. Responsive crops are cauliflower, celery, muskmelons, potatoes, peas, oats and corn. Magnesium deficiency is a common disorder in greenhouse tomatoes.

TABLE 8. Annual phosphorus (P_2O_5) and potassium (K_2O) recommendations for oats grown on mineral soils.

Soil test	Yield goal, bu/acre					
	40	60*	80	100	120	140
	Phosphorus recommendation, lb P_2O_5/acre					
10 lb P/acre	30	50	60	80	100	110
20	20	30	50	70	80	100
30	0	20	40	50	70	90
40	0	0	20	40	60	70
50	0	0	0	30	50	60
60	0	0	0	20	30	50
70	0	0	0	0	20	40
80	0	0	0	0	0	20
90	0	0	0	0	0	0
	Potassium recommendation, lb K_2O/acre on sandy loams and loamy sands					
25 lb K/acre	70	80	100	120	130	150
50	50	70	90	100	120	140
75	40	60	70	90	110	120
100	30	50	60	80	100	110
125	20	30	50	70	80	100
150	0	20	40	50	70	90
175	0	0	20	40	60	70
200	0	0	0	30	50	60
225	0	0	0	20	30	50
250	0	0	0	0	20	40
275	0	0	0	0	0	20
300	0	0	0	0	0	0
	Potassium recommendation, lb K_2O/acre on loams, clay loams and clays					
25 lb K/acre	100	130	150	180	200	230
50	80	110	130	160	180	210
75	60	90	110	140	160	190
100	40	70	90	120	140	170
125	30	50	80	100	130	150
150	0	30	60	80	110	130
175	0	0	40	60	90	110
200	0	0	20	40	70	90
225	0	0	0	30	50	80
250	0	0	0	0	30	60
275	0	0	0	0	0	40
300	0	0	0	0	0	20
325	0	0	0	0	0	0

Recommendations are calculated from the following formulas and rounded to the nearest 10 pounds:

$$XP = 8 + .83 * YG - 1.25 * ST$$
$$XKs = 46 + .83 * YG - .50 * ST$$
$$XKc = 69 + 1.25 * YG - .75 * ST$$

Where: XP = lb P_2O_5/acre
XKs = lb K_2O/acre sandy loams and loamy sands
XKc = lb K_2O/acre loams, clay loams, and clay
YG = Yield goal, bu/acre
ST = Soil test, lb/acre

* Recommendations in this column apply to rye, buckwheat, millet and grass pasture.

Application of magnesium is recommended if a soil test indicates that the exchangeable magnesium level is below 75 pounds per acre; or that potassium exceeds magnesium as a percent of the total exchangeable bases (calcium plus magnesium plus potassium, expressed as milliequivalents per 100 grams of soil); or that the soil magnesium as a percent of total bases is less than 3 percent.

TABLE 9. Annual phosphorus (P_2O_5) and potassium (K_2O) recommendations for soybeans grown on mineral soils.

	Yield goal, bu/acre				
	30	40	50	60	70
Soil test	Phosphorus recommendation, lb P_2O_5/acre				
10 lb P/acre	50	60	80	90	100
20	40	50	60	80	90
30	30	40	50	60	80
40	0	30	40	50	60
50	0	0	30	40	50
60	0	0	0	30	40
70	0	0	0	0	30
80	0	0	0	0	0
	Potassium recommendation, lb K_2O/acre on sandy loams and loamy sands				
25 lb K/acre	100	110	130	140	150
50	90	100	110	130	140
75	80	90	100	110	130
100	60	80	90	100	110
125	50	60	80	90	100
150	40	50	60	80	90
175	30	40	50	60	80
200	0	30	40	50	60
225	0	0	30	40	50
250	0	0	0	30	40
275	0	0	0	0	30
300	0	0	0	0	0
	Potassium recommendation, lb K_2O/acre on loams, clay loams and clays				
25 lb K/acre	110	130	150	170	190
50	90	110	130	150	170
75	70	90	110	130	150
100	60	70	90	110	130
125	40	60	70	90	110
150	20	40	60	70	90
175	0	20	40	60	80
200	0	0	20	40	60
225	0	0	0	20	40
250	0	0	0	0	20
275	0	0	0	0	0

Recommendations are calculated form the following formulas and rounded to the nearest 10 pounds:

$$XP = 25 + 1.25 * YG - 1.25 * ST$$
$$XKs = 75 + 1.25 * YG - .50 * ST$$
$$XKc = 74 + 1.89 * YG - .75 * ST$$

Where: XP = lb P_2O_5/acre
XKs = lb K_2O/acre sandy loams and loamy sands
XKc = lb K_2O/acre loams, clay loams and clays
YG = Yield goal, bu/acre
ST = Soil test, lb/acre

On acid soils where magnesium is needed, apply at least 1,000 pounds of dolomitic limestone. On non-acid soils, correct a magnesium deficiency with 50 to 100 pounds Mg per acre broadcast, or 10 to 20 pounds Mg per acre row applied. Magnesium sulfate (Epsom salts), potash-magnesium sulfate and finely ground magnesium oxide are all satisfactory sources of magnesium.

Magnesium can also be applied as a foliar spray. Suggested rates per acre are 10 to 20 pounds of magnesium sulfate (Epsom salts) in at least 30 gallons of water.

Magnesium deficiency may be induced by high rates of potassium fertilizer. In some states, agronomists strive for at least 10 percent magnesium of the total exchangeable bases (equivalent basis). These high rates are aimed at preventing "grass tetany" disorders in livestock that feed on lush grass. If you are concerned with grass tetany, avoid excessive rates of potassium fertilizer and feed legume hay, which is generally higher in magnesium. You might also consider magnesium carriers that can be mixed with grain or salt rations. Contact your animal feed specialist for amounts and sources. See Extension bulletin E-994, "Essential Secondary Nutrients: Magnesium," for more information on magnesium.

CALCIUM (Ca)—Well limed soils contain high levels of available calcium. Even soils needing lime to correct acidity generally contain sufficient calcium for plants. The poor growth of plants on acid soils is usually due to excess soluble manganese, iron and/or aluminum, rather than calcium deficiency. Available (exchangeable) calcium levels are directly related to the clay content of a soil. Hence, the lowest available calcium levels occur in the sandy soils.

The calcium content of soil water varies between 8 and 450 ppm and averages near 30 ppm. Assuming a

ratio of 400 to 1 as the amount of water needed to produce one pound of dry matter, even the lowest reading of 8 ppm would supply sufficient calcium to plant roots.

Disorders such as blossom end rot in peppers and tomatoes, black heart in celery, internal tip burn in cabbage and cavity spot in carrots are attributed to calcium deficiency. These disorders can occur even in plants grown on soils high in calcium and are more related to environmental factors that influence calcium uptake than to low soil calcium content. Calcium deficiency symptoms are many times preceded by a period of moisture stress. Florida workers report that calcium deficiency in vegetables most likely occurs when the calcium content of the soil water at saturation is less than 10 percent of the total soluble salts. If calcium is low, then potassium, ammonium and/or sodium are high. Maintaining very high potassium soil test levels can contribute to calcium-related disorders.

Studies in Ohio, Indiana, Michigan and Wisconsin have shown alfalfa and corn to yield equally well at a wide range of calcium to magnesium ratios. Therefore, adding calcium to improve the calcium to magnesium ratio is not necessary. See Extension bulletin E-996, "Essential Secondary Nutrients: Calcium," for more information on calcium.

SULFUR (S)—Sulfur is an essential nutrient found in plants in about the same concentration as phosphorus. You might suspect that sulfur deficiency could be widespread because of more intensive cropping, the increased use of fertilizers low in sulfur and the cleanup of industrial smokestacks.

Field studies with several sulfur-responsive crops on several sites throughout Michigan have not shown any benefit from sulfur applications. Even though the surface soils on these sites tested "low," the subsurface soils supply more than adequate quantities of sulfur to meet plant needs.

Sulfur deficiency in crops is most likely to occur on the sandy soils of northern Michigan. Additional information on sulfur is available in Extension bulletin E-997, "Essential Secondary Nutrients: Sulfur."

TABLE 10. Annual phosphorus (P_2O_5) and potassium (K_2O) recommendations for dry edible beans grown on mineral soils.

	Yield goal, cwt/acre					
	10	15	20	25	30	35
Soil test	**Phosphorus recommendation, lb P_2O_5/acre**					
10 lb P/acre	40	50	60	80	90	100
20	30	40	50	60	80	90
30	0	30	40	50	60	80
40	0	0	30	40	50	60
50	0	0	0	30	40	50
60	0	0	0	0	30	40
70	0	0	0	0	0	30
80	0	0	0	0	0	0
	Potassium recommendation, lb K_2O/acre on sandy loams and loamy sand					
25 lb K/acre	90	100	110	130	140	150
50	80	90	100	110	130	140
75	60	80	90	100	110	130
100	50	60	80	90	100	110
125	40	50	60	80	90	100
150	30	40	50	60	80	90
175	0	30	40	50	60	80
200	0	0	30	40	50	60
225	0	0	0	30	40	50
250	0	0	0	0	30	40
275	0	0	0	0	0	30
300	0	0	0	0	0	0
	Potassium recommendation, lb K_2O/acre on loams, clay loams and clays					
25 lb K/acre	90	110	130	150	170	190
50	70	90	110	130	150	170
75	60	70	90	110	130	150
100	40	60	70	90	110	130
125	20	40	60	70	90	110
150	0	20	40	60	70	90
175	0	0	20	40	60	70
200	0	0	0	20	40	60
225	0	0	0	0	20	40
250	0	0	0	0	0	20
275	0	0	0	0	0	0

Recommendations are calculated from the following formulas and rounded to the nearest 10 pounds:

$$XP = 25 + 2.50 * YG - 1.25 * ST$$
$$XKs = 75 + 2.50 * YG - .50 * ST$$
$$XKc = 74 + 3.77 * YG - .75 * ST$$

Where: XP = lb P_2O_5/acre
XKs = lb K_2O/acre sandy loams and loamy sands
XKc = lb K_2O/acre loams, clay loams and clays
YG = Yield goal, bu/acre
ST = Soil test, lb/acre

TABLE 11. Annual phosphorus (P_2O_5) and potassium (K_2O) recommendations for corn grown on mineral soils.

Soil test	Yield goal, bu/acre: 100	120	140	160	180	200
	Phosphorus recommendation, lb P_2O_5/acre					
10 lb P/acre	60	80	90	110	130	140
20	50	60	80	100	110	130
30	40	50	70	90	100	120
40	20	40	60	70	90	110
50	0	30	40	60	80	90
60	0	0	30	50	60	80
70	0	0	20	40	50	70
80	0	0	0	20	40	60
90	0	0	0	0	30	40
100	0	0	0	0	0	30
110	0	0	0	0	0	20
	Potassium recommendation, lb K_2O/acre on sandy loams and loamy sand					
25 lb K/acre	220	240	260	280	300	320
50	200	220	240	260	280	300
75	170	190	210	230	250	270
100	150	170	190	210	230	250
125	120	140	160	180	200	220
150	100	120	140	160	180	200
175	70	90	110	130	150	170
200	50	70	90	110	130	150
225	20	40	60	80	100	120
250	0	20	40	60	80	100
275	0	0	0	30	50	70
300	0	0	0	0	30	50
325	0	0	0	0	0	20
350	0	0	0	0	0	0
	Potassium recommendation, lb K_2O/acre on loams, clay loams and clays					
25 lb K/acre	240	270	300	320	350	370
50	210	240	260	290	320	340
75	180	210	230	260	290	310
100	150	180	200	230	250	280
125	120	140	170	200	220	250
150	90	110	140	170	190	220
175	60	80	110	130	160	190
200	30	50	80	100	130	150
225	0	20	50	70	100	120
250	0	0	0	40	70	90
275	0	0	0	0	40	60
300	0	0	0	0	0	30
325	0	0	0	0	0	0

Recommendations are calculated from the following formulas and rounded to the nearest 10 pounds:

$$XP = -10 + .83 * YG - 1.25 * ST$$
$$XKs = 141 + 1.04 * YG - 1.00 * ST$$
$$XKc = 145 + 1.30 * YG - 1.25 * ST$$

Corresponding formulas for silage are:

$$XP = 24 + 5.26 * YG - 1.25 * ST$$
$$XKs = 171 + 6.58 * YG - 1.00 * ST$$
$$XKc = 182 + 8.23 * YG - 1.25 * ST$$

Where: XP = lb P_2O_5/acre
XKs = lb K_2O/acre sandy loams and loamy sands
XKc = lb K_2O/acre loams, clay loams and clays
YG = Yield goal, bu/acre or tons/acre for silage
ST = Soil test, lb/acre

Micronutrients for Mineral Soils

Micronutrient fertilizer recommendations are based on soil pH, soil test and crop response for each. The recommended rates given in the respective tables (14, 15, 28, 29 and 30) for the various micronutrients are for the highly responsive crops. For medium responsive crops (see Table 27 and Extension bulletin E-486, "Secondary and Micronutrients for Vegetables and Field Crops"), the recommended rates will be less. A brief discussion of each is given. More detailed information is presented in bulletin E-486.

MANGANESE (Mn)—Mineral soils of Michigan may be deficient in manganese for the production of oats, beans, peas, potatoes, soybeans, sudangrass, sugar beets, spinach and wheat. In extreme cases, barley and many vegetables will respond to manganese. A deficiency is most likely to occur on dark-colored surface soils in lake bed or glacial outwash areas with a pH above 6.5. Manganese availability decreases as soil pH increases. Liming can, therefore, induce a manganese deficiency on soils with marginal available Mn levels. Determining precisely the Mn availability in soil is difficult because its availability changes with oxidation state. Flooding or fumigation of soils will temporarily increase Mn availability.

Table 14 provides general guidelines for rates of manganese to apply in a band with starter fertilizer for responsive crops. Suitable carriers are manganese sulfate, chelated materials and finely ground manganous oxide. Manganese chelates are no more effective and sometimes may be less effective than manganese sulfate. Neither granular manganese oxide nor any of the manganic forms are acceptable manganese materials. Finely ground

manganous oxide that has been regranulated may be reasonably effective, however. Manganese is fixed very readily in soil, so broadcast application is not recommended. Manganese can be applied to foliage if band application is not possible or does not completely alleviate the deficiency. Make an application of 1 to 2 pounds Mn per acre and repeat the application if new growth has deficiency symptoms after 7 to 10 days. For more information on manganese, see Extension bulletin E-1031, "Essential Micronutrients: Manganese."

BORON (B)—Boron recommendations are based on crop response. Two to three pounds of boron per acre may be needed for sugar beets, table beets, cauliflower, celery, turnips and rutabagas. Use 1 to 2 pounds per acre for alfalfa on sandy loams and sand soils. Lettuce, broccoli, spinach and cabbage generally need 1 pound of boron per acre. Plant-available boron occurs as a water-soluble anion subject to leaching. Hence, annual applications are essential for boron-responsive crops. Never apply boron for beans, cucumbers, soybeans, peas or small grains—they are sensitive to boron injury. Applying higher than recommended rates may result in residual boron carryover, which could injure sensitive crops. See Extension bulletin E-1037, "Essential Micronutrients: Boron," for more on boron.

ZINC (Zn)—Zinc is needed for beans and corn grown on alkaline soils of lake bed areas of eastern Michigan. Deficiency is especially noted on crops growing on spoil banks, over tile lines where calcareous subsoil is mixed in or where soils test high in phosphorus.

Extractable (0.1 N HCl) Zn, coupled with soil pH, provides a very good indicator for availability of zinc to plants. Zinc availability decreases as pH increases. Therefore, more Zn is recommended at higher pH levels for a given zinc soil test level. Recommended rates in Table 15 are for inorganic salts of zinc. Organic salts (chelates) are more effective and can be used at one-fifth the rates given in Table 15. Granular forms of zinc oxide have not been effective. However, finely ground zinc oxide that has been regranulated is reasonably effective. Band applications are suggested, but broadcast applications are acceptable at higher rates. Unlike manganese, zinc remains available in the soil. Annual applications of zinc will build up available zinc levels and gradually eliminate the need for supplemental zinc. Foliar sprays of 0.5 pound zinc per acre as inorganic salts have proven effective in correcting zinc deficiencies of growing crops. Extension bulletin E-1012, "Essential Micronutrients: Zinc," contains additional information on zinc.

TABLE 12. Annual phosphorus (P205) and potassium (K20) recommendations for potatoes grown on mineral soils.

Soil test	Yield goals, cwt/acre					
	300	350	400	450	500	550
	Phosphorus recommendation, lb P_2O_5/acre					
50 lb P/acre	130	150	160	180	200	220
100	100	120	140	160	180	200
150	80	100	110	130	150	170
200	50	70	90	110	130	150
250	30	50	60	80	100	120
300	0	20	40	60	80	100
350	0	0	0	30	50	70
400	0	0	0	0	30	50
450	0	0	0	0	0	20
500	0	0	0	0	0	0
	Potassium recommendation, lb K_2O/acre on sandy loams and loamy sands					
50 lb K/acre	280	300	330	350	380	400
100	230	250	280	300	330	350
150	180	200	230	250	280	300
200	130	150	180	200	230	250
250	80	100	130	150	180	200
300	30	50	80	100	130	150
350	0	0	30	50	80	100
400	0	0	0	0	30	50
450	0	0	0	0	0	0
	Potassium recommendation, lb K_2O/acre on loams, clays loams and clays					
50 lb K/acre	280	310	350	380	410	440
100	220	250	280	310	350	380
150	160	190	220	250	280	310
200	100	130	160	190	220	250
250	30	60	100	130	160	190
300	0	0	30	60	100	130
350	0	0	0	0	30	60
400	0	0	0	0	0	0

Recommendations are calculated from the following formulas and rounded to the nearest 10 pounds:

$$XP = 38 + .38 * YG - .50 * ST$$
$$XKs = 175 + .50 * YG - 1.00 * ST$$
$$XKc = 156 + .63 * YG - 1.25 * ST$$

Where: XP = lb P_2O_5/acre
XKs = lb K_2O/acre sandy loams and loamy sands
XKc = lb K_2O/acre loams, clay loams and clays
YG = Yield goal, bu/acre or tons/acre for silage
ST = Soil test, lb/acre

Manures/Wastes

Animal Manures

Manures are valuable for their plant nutrient content and are an excellent source of organic matter for improving soil physical conditions. Table 16 gives some average available nutrient figures for several kinds of common animal manures.

During the first year, about 50 percent of the nitrogen and phosphorus and nearly all of the potassium are available. At present, 4 pounds of nitrogen, 2 pounds of phosphate (P_2O_5) and 8 pounds of potash (K_2O) are credited for each ton of cattle manure applied per acre and may be deducted from the fertilizer recommendations given in Tables 3-13. For sheep and chicken manures, the nitrogen credit is 14 pounds per ton. The phosphorus credit for chicken manure is 12 pounds P_2O_5 per ton, and the potassium credit for sheep manure is 18 pounds K_2O per ton.

Test soils receiving manure frequently and adjust manure and fertilizer rates accordingly. Incorporate manures as soon as possible after application to prevent nutrient loss by volatilization or runoff. Manures may be incorporated by disking or plowing, and liquids may be knifed into the soil. Apply manures when soil is relatively dry to minimize soil compaction.

TABLE 13. Annual phosphorus (P_2O_5) and potassium (K_2O) recommendations for sugar beets grown on mineral soils.

	Yield goal, tons/acre					
	18	20	22	24	26	28
Soil test	Phosphorus recommendation, lb P_2O_5/acre					
20 lb P/acre	120	130	140	150	160	170
40	100	110	120	130	140	150
60	70	80	90	100	110	120
80	50	60	70	80	90	100
100	20	30	40	50	60	70
120	0	0	20	30	40	50
140	0	0	0	0	0	20
160	0	0	0	0	0	0
	Potassium recommendation, lb K_2O/acre on sandy loams and loamy sands					
50 lb K/acre	180	200	210	230	240	260
100	150	160	180	190	210	220
150	110	120	140	150	170	180
200	70	90	100	120	130	150
250	30	50	60	80	90	110
300	0	0	30	40	60	70
350	0	0	0	0	20	30
400	0	0	0	0	0	0
	Potassium recommendation, lb K_2O/acre on loams, clay loams and clays					
50 lb K/acre	200	220	240	260	280	300
100	150	170	190	210	230	250
150	100	120	140	160	180	200
200	50	70	90	110	130	150
250	0	20	40	60	80	100
300	0	0	0	0	30	50
350	0	0	0	0	0	0

Recommendations are calculated from the following formulas and rounded to the nearest 10 pounds:

$$XP = 58 + 5.00 * YG - 1.25 * ST$$
$$XKs = 87 + 7.45 * YG - .75 * ST$$
$$XKc = 65 + 10.00 * YG - 1.00 * ST$$

Where: XP = lb P_2O_5/acre
XKs = lb K_2O/acre sandy loams and loamy sands
XKc = lb K_2O/acre loams, clay loams and clays
YG = Yield goal, bu/acre or tons/acre for silage
ST = Soil test, lb/acre

Municipal Wastewaters and Sludges

Another source of plant nutrients for field crops is municipal sewage effluents and sludges. Table 17 gives the range of N, P and K concentrations found in these materials from over 50 Michigan municipalities. Wastewaters may also serve as a source of irrigation water.

Sludges can be a very beneficial soil amendment, providing nutrients and organic matter to the soil-plant system. Sludges vary in moisture content from a slurry of less than 1 percent solids to a dried sludge cake with greater than 40 percent solids. Sludges can also contain undesirable chemicals. Metals such as copper, zinc, nickel, chromium and others can be a problem if present in excessive concentrations.

The Michigan Department of Natural Resources is regulating the use of these materials on land. Any grower considering the use of wastewater and/or sludges should contact the DNR. Guidance in using these materials may also be obtained from the Soil Conservation Service and the Cooperative Extension Service.

Industrial Wastes

Some industrial wastes can be suitable soil amendments for improv-

ing the fertility status or physical condition of soils. If you are considering the use of industrial waste on your land, consult with the MSU Department of Crop and Soil Sciences for assistance in evaluating that waste as a soil amendment. Some industrial wastes contain substances toxic to plant growth and are unsuitable for application to agricultural land.

Suggested Fertilizer Management

Alfalfa, Alfalfa-Brome, Clover, Birdsfoot Trefoil (see Table 6)—Adjust soil pH to near 6.8 for mixtures containing alfalfa or sweet clover, and to pH 6.0 for red clover and birdsfoot trefoil. Apply needed lime at least six months prior to seeding and incorporate by tillage. If the pH is below 5.0, apply half before and half after plowing and incorporate. When sod seeding alfalfa on erosive sites, broadcast the lime without incorporation. Fertilizer recommendations for alfalfa seedings given in Table 6 are for spring or summer clear seeding. Base fertilizer rates on soil test results. Up to 100 pounds of phosphate and 50 pounds of potash may be applied in direct contact with the seed. If the fertilizer is placed 1 to 1½ inches below the seed, the seeding-time fertilizer may include all of the phosphorus and up to 250 pounds of potash per acre. Fertilizer required above these amounts may be plowed down or broadcast and incorporated. This fertilizer recommendation is sufficient to establish the legume and to provide for growth until the first cutting is removed. Beyond that point, additional fertilizer is required as a top-dress application.

At planting, allow the legume seed to fall on top of the soil above the fertilizer band and cover no more than 1/2 inch deep with press wheels or a

TABLE 14. Manganese fertilizer recommendations for responsive crops grown on mineral soils.

Soil test	Soil pH 6.1	6.3	6.5	6.7	6.9	7.1	7.3	7.5
ppm	lb Mn/acre							
2	0	2	4	5	6	7	9	10
4	0	2	3	4	5	7	8	9
6	0	0	2	3	5	6	7	8
8	0	0	0	3	4	5	6	8
10	0	0	0	2	3	5	6	7
12	0	0	0	0	3	4	5	6
14	0	0	0	0	2	3	4	6
16	0	0	0	0	0	2	4	5
18	0	0	0	0	0	2	3	4
20	0	0	0	0	0	0	2	3
22	0	0	0	0	0	0	2	3
24	0	0	0	0	0	0	0	2
26	0	0	0	0	0	0	0	0

Recommendations are calculated from the following formulas and rounded to the nearest pound:

$$XMn = -36 + 6.2 * pH - .35 * ST$$

Where: XMn = lb Mn/acre
pH = soil pH
ST = ppm Mn soil test

TABLE 15. Zinc fertilizer recommendations for responsive crops grown on mineral soils.[1]

Soil test	Soil pH 6.6	6.7	6.8	6.9	7.0	7.1	7.2	7.3	7.4	7.5	7.6
ppm	lb Zn/acre										
1	0	1	1	2	2	3	3	4	5	5	6
2	0	0	1	1	2	2	3	4	4	5	5
3	0	0	0	1	1	2	2	3	4	4	5
4	0	0	0	0	1	1	2	3	3	4	4
5	0	0	0	0	0	1	1	2	3	3	4
6	0	0	0	0	0	0	1	2	2	3	3
7	0	0	0	0	0	0	0	1	2	2	3
8	0	0	0	0	0	0	0	1	1	2	2
9	0	0	0	0	0	0	0	0	1	1	2
10	0	0	0	0	0	0	0	0	0	1	1
11	0	0	0	0	0	0	0	0	0	0	1
12	0	0	0	0	0	0	0	0	0	0	1
13	0	0	0	0	0	0	0	0	0	0	0

Recommendations are calculated from the following formula and rounded to the nearest pound:

$$XZn = -32 + 5 * pH - .4 * ST$$

Where: XZn = lb Zn/acre
pH = soil pH
ST = ppm Zn soil test

1 Recommendations in this table are for band application of an inorganic zinc carrier. When zinc chelates are used, these rates may be divided by 5.

TABLE 16. Average amounts of nitrogen, phosphorus and potassium and the combined value of manures from various animals.

Type of manure	N	P_2O_5	K_2O	Value	N	P_2O_5	K_2O	Value[1]
	Pounds per ton				Pounds per 1,000 gallons			
Chicken	30	18	9	12.90	74	68	27	38.06
Beef	14	8	13	6.98	24	13	24	12.00
Dairy	11	5	11	5.27	26	10	31	12.62
Hog	10	6	9	5.02	53	22	28	21.89
Horse	14	5	14	6.38	-	-	-	
Sheep	28	9	24	12.04	-	-	-	

1 Calculated assuming present retail costs per pound are: N = 25 cents; P_2O_5 = 24 cents; and K_2O = 12 cents.

TABLE 17. Range of N, P and K concentrations found in the sewage effluents and sludges from more than 50 Michigan municipalities.

Nutrient	Effluents: Concentration (ppm)1	Effluents: Pounds A - in[2]	Sludges: Concentration (percent)	Sludges: Pounds per dry ton[3]
Nitrogen	11 - 75	2.5 - 17	0.1 - 3.2	2.0 - 64
Phosphorus	0.1 - 8.1	0.02 - 1.8	0.1 - 3.3	2.0 - 66
as P_2O_5	0.23 - 18.6	0.05 - 4.1	0.23 - 7.6	4.6 - 152
Potassium	4.0 - 27	0.9 - 6.1	0.05 - 0.9	1.0 - 18
as K_2O	4.8 - 32	1.1 - 7.3	0.06 - 1.1	1.2 - 22

1 ppm = parts per million; 10,000 ppm = 1 percent.

2 A-in = acre-inch; one A-in of water equals about 27,000 gallons and would cover 1 acre to a depth of 1 inch.

3 Sludges can vary from less than 1 percent to greater than 40 percent solids.

cultipacker. To seed bromegrass, either mix the seed with a small grain or with the fertilizer.

Boron is needed annually on established alfalfa growing on sandy loams, loamy sands and sand soils at the rate of 1 to 2 pounds per acre. Boron application for alfalfa grown on the finer-textured soils has not proven beneficial. Do not apply boron in combination seedings containing grass or small grains because it will injure these plants. Apply boron for the legume as a topdressing after the grass is well established or the grain crop harvested. Include 1 pound of zinc per acre in the topdress fertilizer when the soil pH is above 7.0 and the soil tests high in phosphorus.

Topdress alfalfa with potash in early spring while the plants are dormant, immediately after a hay harvest or in the fall. To maintain soil test levels, annual topdress applications should include 10 pounds of phosphate (P_2O_5) and 50 pounds of potash (K_2O) for each ton of alfalfa hay harvested per acre. Splitting K_2O rates below 400 pounds is not necessary.

Planting-time nitrogen is not suggested for spring or summer clear-seeded alfalfa, but be sure to reinoculate the seed for summer seedings.

Legume Seeding With Small Grain (see Tables 7 and 8)—Legume seedings are difficult to establish in high-yielding small grains. If legumes are seeded with small grains, do not lower the nitrogen rate, but increase the small grain fertilizer recommendations for P_2O_5 and K_2O by 25 and 50 pounds per acre, respectively. Banding 25 pounds P_2O_5 per acre under the seed may be beneficial even with high phosphorus soil tests. The fertilizer applied for the small grain should be sufficient to carry the legume through the first season. In the fall of the first year, topdress with potash at the rate indicated by a soil test. In the fall of the second year, apply the recommended rates of phosphate and potash.

Barley, Oats, Wheat, Rye (see Tables 7 and 8)—Proper fertilizer placement for small grains is 1 inch to the side and 1 inch below the seed. Many grain drills apply the fertilizer directly in contact with the seed. This placement can injure the seed when large amounts are applied, especially when the soil is dry. Do not drill in direct contact with the seed more than a total of 100 pounds of plant nutrients ($N + P_2O_5 + K_2O$) for sandy soils and 140 pounds per acre for fine-textured soils. If additional amounts are needed, apply in a separate operation.

On winter grains, apply no more than 25 pounds of nitrogen per acre in the fall. This amount may be included in the planting-time fertilizer. In the spring prior to green-up, topdress additional nitrogen, usually 80 to 100 pounds N per acre for high-yielding wheat varieties and sites. Refer to Table 4 for suggested rates based on yield goal.

For spring-seeded small grains, apply the nitrogen prior to and/or at seeding.

Application of manure prior to wheat has many times resulted in increased incidence of root rot and lodging. Therefore, it is best not to apply manure prior to wheat. Wheat does best following field beans, soybeans or silage corn.

Manganese is recommended in the band fertilizer for wheat, oats and barley growing on lake bed soils and dark-colored flats where pH is above 6.5. Use 5 to 6 pounds of manganese per acre for soils with a pH of 6.5 to 7.0, and 7 to 8 pounds per acre for soils with a pH above 7.0.

Soybeans, Field Beans (see Tables 9 and 10)—Beans are very sensitive to fertilizer applied in contact with the seed. Apply row fertilizer 2 inches to the side and 2 inches below the seed. For dry beans, include 40 pounds N, all the phosphorus and as much potassium as possible in the starter fertilizer. Broadcast and incorporate preplant the additional potash (K_2O) needed.

Soybeans well inoculated with *Rhizobium* bacteria prior to seeding or grown in soil containing a sufficient population of natural *Rhizobia* have rarely shown any yield response to nitrogen fertilization. In the presence of the proper *Rhizobium* species, soybeans develop root systems nodulated with effective nitrogen-fixing bacteria. These bacteria supply adequate nitrogen for the soybean crop. Hence, nitrogen fertilization is not recommended. Be sure to inoculate the soybean seed if a well nodulated soybean crop has not been grown in that field in the past four years.

These crops often need manganese when grown on organic soils and dark-colored sandy soils with a pH higher than 5.8 and lake bed soils and depressional areas having gray subsoil with a pH above 6.5. To prevent manganese deficiency, apply 4 to 8 pounds of manganese with the row fertilizer on mineral soils. Foliar applications are also effective and often preferred, especially in the production of soybeans on organic soils.

Field beans grown on soils with a pH of 7.2 or higher have proven highly responsive to zinc fertilizer. The deficiency is particularly noticeable on land previously planted to sugar beets, or where calcareous subsoils are exposed by land leveling or after tiling. To prevent the deficiency, apply 3 to 4 pounds of inorganic zinc per acre in the row fertilizer. If zinc chelates are used, apply 0.5 to 0.8 pounds of zinc per acre.

Corn, Corn Silage (see Table 11)—Irrigation of corn influences the fertilizer requirements primarily as it increases the yield potential. Plow down or broadcast and incorporate phosphorus and potassium fertilizer that is required in excess of that banded at planting time. Place planting-time fertilizer 2 inches to the side and 2 inches below the seed. At this placement fertilizer injury is unlikely, even with high rates. A typical starter fertilizer program may include up to 60 pounds of nitrogen and 100 pounds of potash per acre and all the recommended phosphorus. Including phosphorus in the row fertilizer when the available soil phosphorus is high may stimulate early season growth but seldom increases the corn yield.

When changing to a no-till corn production system, be sure to soil test and apply appropriate amounts of phosphorus and potassium to build up their levels in the soil.

Harvesting corn for silage removes large amounts of plant nutrients. In a Michigan study, corn yielding 140 bushels of grain removed 120 pounds of nitrogen, 52 pounds of phosphate and 27 pounds of potash per acre. The same crop harvested for silage removed 196 pounds of nitrogen, 69 pounds of phosphate and 206 pounds of potash per acre. A comparison of the two illustrates that nutrient removal, especially of potash, is much greater when silage is harvested. Therefore, maintaining available soil phosphorus and potassium levels when harvesting corn silage rather than corn grain requires an additional 20 pounds P_2O_5 and 175 pounds K_2O per acre.

Nitrogen management for corn may involve a combination of application times: fall, spring, planting time and/or sidedress. Refer to Table 3 for rates based on yield goal. Nitrogen applied as close as possible to the time when the crop is growing is used most efficiently. Additional information on nitrogen management for corn can be found in Extension bulletin E-802, "The Effect of Nitrogen Fertilizer on Corn Yield."

Because of the high potential for leaching loss, do not apply nitrogen in the fall on sands, loamy sands or sandy loams. Similarly, do not broadcast nitrogen on frozen ground with greater than a 3 percent slope. When applying anhydrous ammonia, be sure to completely trap the gas in the soil. Broadcast or spray applications of liquid nitrogen should not exceed 10 pounds of nitrogen per acre after emergence of the corn—applications of greater than 10 pounds per acre can cause leaf burn. Because many solutions are compatible with herbicides, it may be convenient to apply a preemergence herbicide and supplemental nitrogen together. Some combinations are incompatible, however, so use caution (see Extension bulletin E-1296, "Herbicide-Fertilizer Combinations," to determine compatibility).

Sunflowers—Sunflowers grown in Michigan have nutrient requirements similar to a 100-bushel corn crop.

Nitrogen, phosphorus and potassium fertilizer needs can be determined from the appropriate columns in Tables 3 and 11. Place row fertilizer 2 inches to the side and 2 inches below the seed. Broadcast fertilizer required beyond the row-placed fertilizer. Sidedress with 50 pounds of nitrogen when plants are 6 to 12 inches tall.

Grass (pasture or hay, see Table 8)—Before establishing a new grass seeding, broadcast and incorporate 50 pounds of nitrogen per acre and the amounts of phosphorus and potassium fertilizer indicated by a soil test. Established grasses grown for pasture or hay generally require high nitrogen fertilizer, such as a 20-10-10 or 20-5-10. This fertilizer is best topdressed in early spring. For maintenance of grass pastures, apply 60 pounds of nitrogen per acre. Grasses intensively managed for high production and carrying capacity will require an additional 40 to 50 pounds of nitrogen per acre topdressed midseason after cutting or pasturing.

Grass waterways need good fertility levels to maintain a dense, uniform cover throughout the year. Follow the guidelines for seeding and maintaining a productive grass pasture. To prevent runoff loss, drill in topdress fertilizer.

For establishment and maintenance of cover vegetation on "critical areas" as defined by the Soil Conservation Service, follow fertilizer and lime recommendations identical to those for productive areas.

Potatoes (see Table 12)—Based on soil test information, up to 60 pounds of nitrogen, 200 pounds of phosphate and 100 pounds of potash per acre may be applied in bands 2 inches to the side and level with or slightly below the seed pieces. Plow down or disk in additional amounts when needed. Supplemental nitrogen can be either plowed down, sidedressed or applied in the irrigation water. Nitrogen applications made after plant emergence are generally more efficient than nitrogen plowed down. For suggested nitrogen rates, see Table 5. Excess nitrogen use may result in nitrate leaching into groundwater, especially on sandy soils. After harvest, establish cover crops to take up any residual nitrogen and protect the soil against wind erosion.

Manganese may be needed when mineral soils test above pH 6.5. A soil test can help determine the need for manganese. See Table 14 for recommendations.

Fall applications of potash are not recommended on loamy sand and sand soils because of potential loss by leaching. Spring plow-down applications are suggested when high rates of potassium are required. Potassium sulfate and potassium nitrate are the preferred potassium carriers when potassium is applied just prior to planting, but they are more expensive than potassium chloride.

Potato varieties show differences in fertility requirements. Russet Burbanks require 25 percent more nitrogen and potassium than Sebagos and Katahdins to produce similar yields. Therefore, fertilizer recommendations given in Tables 5 and 12 need to be increased by 25 percent for Russet Burbanks. Application of manure immediately prior to a potato crop may increase the incidence of scab. Therefore, do not apply manure on fields where potatoes will be grown as the next crop.

Sorghum, Sudangrass—Sorghum and sudangrass grown for summer pasture or chopped forage have nutrient requirements similar to those of corn silage. In estimating fertilizer requirements, use the formulas for corn silage and the appropriate yield goal (see footnotes of Tables 3 and 11).

Sugar Beets (see Table 13)—Fertilizer for sugar beets should be applied in bands 2 inches to the side and 2 inches below the seed. Part of the fertilizer may be broadcast before plowing.

If the soil pH is above 6.8, manganese and boron are recommended and may be applied as part of the band fertilizer. Recommended rates are 1½ to 3 pounds per acre for boron and 4 to 6 pounds per acre for manganese, depending on soil test level.

The quality of sugar beets is affected very markedly by applied nitrogen. Research studies have shown sugar content and yield are maximized by using 4 pounds of nitrogen per acre for each ton of expected yield. This amounts to 80 to 100 pounds N per acre for yields of 20 to 25 tons per acre. See Table 5 for specific nitrogen recommendations.

Recommendations for Vegetable Crops on Mineral Soils

Most vegetable crops require relatively high levels of fertility for optimum yields of satisfactory quality. Recommended fertilizer rates are designed to meet the needs of the growing vegetable crops and gradually build up low soil test levels. Once desired soil test levels are attained, a maintenance fertilization program can be developed by applying the nutrients removed by the vegetable crop. Table 18 lists the amounts of nitrogen, phosphorus and potassium removed by typical yields of some Michigan vegetable crops. Recommended nitrogen rates are given in Table 19. Phosphate and potash recommendations are given in Tables 20, 21 and 22. Fertilizer may be applied for vegetable production in one or more of the following ways: at time of planting to the green manure or cover crop preceding the vegetable crops; plowed down; drilled in or broadcast after plowing; placed in bands near the seed; used in starter solutions; sidedressed or topdressed; or applied to the leaves (foliar feeding).

Apply only enough fertilizer to a cover crop to ensure reasonable growth. On sandy soils, use fall cover crops to take up residual nitrogen and potassium and so prevent their leaching into the ground water. Nutrients taken up by a cover crop become available as the crop residues decompose. Cover crops minimize non-growing season wind erosion and may serve as the basis for no-till crop production of certain vegetables.

Applying nitrogen as close as possible to the time the crop will use it increases the efficiency of use and minimizes the possibility of leaching

TABLE 18. Nutrient removal by several Michigan vegetable crops.

Crop	Yield	lbs/acre		
		N	P_2O_5	K_2O
Asparagus	15 cwt*	10	3	7
Beans, snap	45 cwt	90	9	12
Cabbage	200 cwt	70	15	70
Carrots	300 cwt	70	20	65
Cauliflower	60 cwt	20	8	20
Celery	450 cwt	115	95	335
Cucumbers	100 cwt	10	5	18
Lettuce	200 cwt	50	22	90
Onions	400 cwt	95	50	90
Peas	30 cwt	30	7	10
Tomatoes	400 cwt	110	35	155

* 20 cwt = 1 ton

TABLE 19. Nitrogen recommendations for vegetables grown on mineral soils.

	lb N/A		lb N/A		lb N/A		lb N/A
Asparagus		Endive	75	Horseradish	100	Lettuce	125
old beds	50	Pumpkins	75	Muskmelons	100	Sweet corn	125
new & crowns	75	Squash	75	Rutabagas	100	Tomatoes	
Peas	50	Watermelons	90	Parsnips	100	Hand pick	125
Radishes	50			Peppers	100	Machine harvest	75
Turnips	50	Cabbage	100	Rhubarb	100	Broccoli	140
Cucumbers		Carrots	100	Spinach	100	Brussels sprouts	140
<50,000 pl/A	60	Chard	100	Table beets	100	Cauliflower	140
>50,000 pl/A	75	Eggplant	100				
Sweet potatoes	60					Onions	175
Snap beans	60					Celery	175

TABLE 20. Phosphorus (P_2O_5) recommendations for vegetable crops grown on mineral soils.

Asparagus old beds	(20)*	Carrots	(300)	Asparagus new beds	(20)	Celery	(600)
Lima beans	(30)	Endive	(160)	Broccoli	(70)	Flower beds	
Peas	(30)	Lettuce	(400)	Brussels sprouts	(50)	Home gardens	
Snap beans	(80)	Parsnips	(200)	Cabbage	(400)	Onions	(400)
Turnips	(400)	Pumpkins	(300)	Cauliflower	(140)	Tomatoes	(400)
Strawberries	(100)	Radishes	(60)	Cucumbers	(300)	Market gardens	
		Rutabagas	(350)	Eggplant	(150)		
		Spinach	(120)	Horseradish	(80)		
		Sweet corn	(160)	Muskmelons	(150)		
		Sweet potatoes	(180)	Peppers	(200)		
		Squash	(300)	Rhubarb	(300)		
				Swiss chard	(150)		
				Table beets	(250)		
				Watermelons	(150)		

Soil test lb P/acre	Phosphorus recommendation, lb P_2O_5/acre			
10	130	170	210	250
30	110	150	180	220
50	80	120	160	200
70	60	100	130	170
90	30	70	110	150
110	0	50	80	120
130	0	20	60	100
150	0	0	30	70
170	0	0	0	50
190	0	0	0	20
210	0	0	0	0

* Figure in parentheses after the crop is the yield potential in cwt (100 lbs)/acre.

Recommendations are calculated from the following formulas and rounded to the nearest 10 pounds:

XP1 = 150 - 1.25 * ST
XP2 = 188 - 1.25 * ST
XP3 = 225 - 1.25 * ST
XP4 = 263 - 1.25 * ST

Where: XP1 = lb P_2O_5/acre column 1
XP2 = lb P_2O_5/acre column 2
XP3 = lb P_2O_5/acre column 3
XP4 = lb P_2O_5/acre column 4
ST = Soil test, lb/acre

loss. Make preplant broadcast nitrogen applications as close to planting time as possible. Include nitrogen in the starter fertilizer and sidedress additional nitrogen to meet the needs of the crop.

For crops seeded or transplanted when the soil is still rather cool, band a high-phosphorus fertilizer—e.g., 9-18-9 or 10-20-10—1 inch to the side and 2 inches below the seed. This will decrease phosphorus fixation and stimulate early growth. For soils testing high in available phosphorus, including phosphorus in the starter fertilizer for crops seeded after June 1 will not usually improve growth, quality or yield.

Foliar application is an efficient way to correct or prevent some micronutrient deficiencies. It is not recommended for applying phosphorus and potassium fertilizer because of excessive cost, inability to supply sufficient nutrients and possibility of plant injury.

Suggested Fertilizer Management

A good fertilizer program based on soil test information coupled with other good management practices will result in good yields of quality vegetables. Cover crops are used for wind erosion control on many vegetable-producing soils. When plowing under large amounts of plant residues or cover crops, including 40 pounds of nitrogen per acre may improve decomposition of the residues. Recommended amounts of phosphorus and potassium for the various vegetable crops, based on soil tests, are given in Tables 20, 21 and 22.

Asparagus (new planting, crowns)—Plow down 50 pounds of nitrogen and the recommended rates of phosphate and potash, and then apply 30 pounds of phosphate per acre in the trench before setting crowns.

TABLE 21. Potassium (K_2O) recommendations for vegetable crops grown on sandy loam and loamy sand.

Asparagus old beds	(20)*	Asparagus new beds	(20)	Cabbage	(400)	Broccoli	(70)
Lima beans	(30)	Carrots	(300)	Cucumbers	(300)	Brussels sprouts	(50)
Peas	(30)	Endive	(160)	Eggplant	(150)	Caulflower	(140)
Pumpkins	(300)	Lettuce	(400)	Flower beds		Celery	(600)
Radishes	(60)	Sweet corn	(160)	Horseradish	(80)	Home gardens	
Snap beans	(80)			Muskmelons	(150)	Tomatoes	(400)
Squash	(300)			Onions	(400)	Market gardens	
Turnips	(400)			Parsnips	(200)		
Strawberries	(100)			Peppers	(200)		
				Rhubarb	(300)		
				Rutabagas	(350)		
				Spinach	(120)		
				Sweet potatoes	(180)		
				Swiss chard	(150)		
				Table beets	(250)		
				Watermelons	(150)		

Soil test lb K/acre	Potassium recommendation, lb K_2O/acre			
25	200	240	290	330
50	180	220	270	310
75	150	200	240	290
100	130	180	220	270
125	110	150	200	240
150	90	130	180	220
175	60	110	150	200
200	40	90	130	180
225	20	60	110	150
250	0	40	90	130
275	0	20	60	110
300	0	0	40	90
325	0	0	20	60
350	0	0	0	40

* Figure in parentheses after the crop is the yield potential in cwt (100 lbs)/acre.

Recommendations are calculated from the following formulas and rounded to the nearest 10 pounds:

XK1 = 225 - .90 * ST
XK2 = 270 - .90 * ST
XK3 = 315 - .90 * ST
XK4 = 360 - .90 * ST

Where: XK1 = lb K_2O/acre column 1
XK2 = lb K_2O/acre column 2
XK3 = lb K_2O/acre column 3
XK4 = lb K_2O/acre column 4
ST = Soil test, lb/acre

Later, sidedress with 30 pounds of nitrogen per acre during cultivation.

Asparagus (established planting)—Alternate applications of 40 to 60 pounds of nitrogen one year with 50 pounds each of nitrogen and potash per acre on alternate years. Topdressing 50 pounds of phosphate every third or fourth year is optional and probably will not be beneficial if the soil phosphorus level is medium to high. Apply fertilizer near the end of the harvest season. Eliminate nitrogen application if manure is applied.

Lima Beans, Snap Beans—Row fertilizer placed 2 inches to the side and 2 inches below the seed may include 25 pounds of nitrogen, all the phosphorus and some potassium. Most of the potash (K_2O) required is best plowed down or broadcast and incorporated prior to planting. If the foliage becomes light green between the three-leaf stage and flowering, sidedress with 30 to 40 pounds of nitrogen per acre. Apply manganese either in the row fertilizer or as a foliar spray if a soil test or past cropping history indicates a possible manganese deficiency.

Carrots, Horseradish, Parsnips—Plow down 50 pounds of nitrogen and the required phosphorus and potassium fertilizer that supplies 1/2 pound of boron per acre. Four to six weeks after seedling emergence, topdress with 50 pounds of nitrogen

TABLE 22. Potassium (K_2O) recommendation for vegetable crops grown on loams, clay loams and clays.

Asparagus old beds	(20)*	Asparagus new beds	(20)	Cabbage	(400)	Broccoli	(70)
Lima beans	(30)	Carrots	(300)	Cucumbers	(300)	Brussels sprouts	(50)
Peas	(30)	Endive	(160)	Eggplant	(150)	Cauliflower	(140)
Pumpkins	(300)	Lettuce	(400)	Flower beds		Celery	(600)
Radishes	(60)	Sweet corn	(160)	Horseradish	(80)	Home gardens	
Snap beans	(80)			Muskmelons	(150)	Tomatoes	(400)
Squash	(300)			Onions	(400)	Market gardens	
Turnips	(400)			Parsnips	(200)		
Strawberries	(100)			Pepper	(200)		
				Rhubarb	(300)		
				Rutabagas	(350)		
				Spinach	(120)		
				Sweet potatoes	(180)		
				Swiss chard	(150)		
				Table beets	(250)		
				Watermelons	(150)		

Soil test lb K/acre	Potassium recommendation, lb K_2O/acre			
25	200	250	300	350
50	170	220	270	320
75	150	200	250	300
100	120	170	220	270
125	100	150	200	250
150	70	120	170	220
175	50	100	150	200
200	20	70	120	170
225	0	50	100	150
250	0	20	70	120
275	0	0	50	100
300	0	0	20	70
325	0	0	0	50

* Figure in parentheses after the crop is the yield potential in cwt (100 lbs)/acre.

Recommendations are calculated from the following formulas and rounded to the nearest 10 pounds:

XK1 = 225 - 1.0 * ST
XK2 = 275 - 1.0 * ST
XK3 = 325 - 1.0 * ST
XK4 = 375 - 1.0 * ST

Where: XK1 = lb K_2O/acre column 1
XK2 = lb K_2O/acre column 2
XK3 = lb K_2O/acre column 3
XK4 = lb K_2O/acre column 4
ST = Soil test, lb/acre

per acre. On soils with a pH above 6.5, carrots may benefit from foliar manganese application.

Table Beets, Rutabagas—Before seeding, broadcast and incorporate fertilizer that supplies 50 pounds of nitrogen plus the phosphorus and potassium requirements. A portion of the nitrogen and potassium and all the phosphorus may be applied in a band 1 inch to the side and 2 inches below the seed at planting time. On sandy soils and on soils with a pH above 6.5, include 2 pounds of boron per acre in the fertilizer program. Topdress with 50 pounds of nitrogen after the plants are well established.

Broccoli, Cabbage, Brussels Sprouts, Cauliflower—Plow down or incorporate after plowing 50 to 60 pounds of nitrogen plus the phosphorus and potassium indicated by a soil test. Include sufficient boron in the broadcast fertilizer to supply 1 to 2 pounds of boron per acre. Use a high-phosphorus starter solution when setting the transplants. For cauliflower, include 2 to 4 ounces of sodium molybdate per acre in the starter solution. Sidedress 40 pounds of nitrogen per acre two to three weeks after transplanting and an additional 40 pounds of nitrogen (except for cabbage) five weeks after transplanting. Foliar application of sodium molybdate (2 ounces per acre) on a two-week schedule is essential for some cauliflower varieties.

Sweet Corn—Plow down 60 pounds of nitrogen and sidedress with an additional 60 to 70 pounds of

nitrogen when the corn is 6 to 12 inches high. A starter fertilizer placed 2 inches to the side and 2 inches below the seed may include all the phosphorus plus some nitrogen and potassium. Recommended potassium is best broadcast and plowed down.

Cucumbers—For slicing cucumbers and hand-picked pickling cucumbers, band a high-phosphate fertilizer (if a soil test shows a need) 2 inches below and 2 inches to the side of the seed at planting. If the soil pH is above 6.7 and a soil test shows a need for manganese, use 2 percent manganese in the starter fertilizer. Broadcast and incorporate 30 pounds of nitrogen plus the recommended amount of potash (K_2O), if they are not included in the starter fertilizer. Sidedress with 30 to 40 pounds of nitrogen per acre just prior to tip-over. If the foliage becomes light green or yellowish or if rainfall has been excessive, topdress with an additional 30 pounds of nitrogen and irrigate it in. Nitrogen can also be efficiently applied through the irrigation system (10 to 15 pounds of nitrogen per acre per application).

For pickling cucumbers with plant populations exceeding 50,000 plants per acre in 10- to 28-inch rows for mechanical harvest, broadcast and incorporate all fertilizer. Topdress with 30 pounds of nitrogen just prior to when the cucumber plants tip over. Irrigate the nitrogen in, if possible. If a soil test or past crop history indicates a need for manganese, apply manganese in a foliar spray.

Muskmelons, Watermelons—Nearly all melons are being grown on plastic mulch, so broadcast and incorporate after plowing all the recommended nitrogen, phosphorus and potassium fertilizer. The total suggested nitrogen rate is 75 to 100 pounds per acre. Melons are quite responsive to magnesium. If soil test magnesium levels are marginal (below 100 pounds magnesium per acre), broadcast 40 to 50 pounds of actual magnesium per acre or apply foliar magnesium (2 pounds per acre) every two to three weeks.

Peas—Broadcast and incorporate 50 pounds of nitrogen per acre plus all the recommended amounts of phosphorus and potassium. If plants begin to look yellowish during the early growth stages, topdress with 20 to 30 pounds of nitrogen. To avoid leaf burn, apply only when the plants are dry.

Radishes, Turnips—Broadcast and incorporate 50 pounds of nitrogen plus the recommended amounts of phosphorus and potassium. If the pH is above 6.7, include 1 to 2 pounds of boron per acre in the broadcast fertilizer. Radishes are highly responsive to manganese. If past crop history or a soil test indicates a need for manganese, apply as a foliar spray (8 to 10 pounds of manganese sulfate per acre).

Tomatoes—The appropriate total amount of nitrogen to apply for tomatoes depends on many factors. Direct-seeded tomatoes will generally require less nitrogen than transplanted tomatoes. For machine-harvested processing tomatoes, 75 pounds of nitrogen per acre is adequate. Hand-picked, fresh market tomatoes require 125 pounds of nitrogen per acre, with 40 to 50 pounds of that amount sidedressed when the first fruits are about half dollar size. The very determinant tomato varieties respond well in yield to high nitrogen rates without producing excessive vegetative growth. With indeterminant varieties, high nitrogen rates tend to stimulate vegetative growth and delay fruit maturity. For the indeterminant types, use two sidedress applications of 30 to 40 pounds of nitrogen per acre. When tomatoes follow soybeans, the nitrogen rate may be reduced by 30 pounds of nitrogen per acre compared with rates for tomatoes following corn. On sandy soil, avoid large single nitrogen applications to reduce the potential for leaching loss.

Plow down or incorporate 6 inches deep 50 to 75 pounds of nitrogen (depending on management), plus the recommended rates of phosphorus and potassium, based on soil tests. Use a starter solution high in phosphorus when setting transplants.

Rhubarb—In early spring, apply 50 pounds of nitrogen plus the recommended amounts of phosphorus and potassium. Sidedress with an additional 50 pounds of nitrogen per acre two weeks after new growth begins.

Market Gardens—Plow down or incorporate 40 to 50 pounds of nitrogen per acre plus the amounts of phosphorus and potassium recommended according to a soil test (see Tables 20, 21 and 22). If a starter fertilizer is placed 2 inches to the side and 2 inches below the seed at planting, it may include all of the phosphorus plus some nitrogen and potassium. Make one or two side- or topdress nitrogen applications during the growing season, depending on the crops grown. Total nitrogen rates for individual crops are given in Table 19. For vegetables not listed, use 40 to 60 pounds of additional nitrogen per acre as indicated by foliage color. More nitrogen is needed for green leafy vegetables, tomatoes, peppers, sweet corn and rhubarb than for beans, peas, cucumbers, melons, root crops or asparagus.

Use a starter fertilizer solution when transplanting cabbage, tomatoes, celery, etc. High-analysis, water-soluble fertilizers are available in most garden supply stores. Starter solutions may also be used to stimulate growth of leafy vegetable crops when soils are cold and temperatures are low. Avoid overfertilizing, which may cause salt burn.

Recommendations for Organic Soils

Organic soils are classified as mucks and peats. The most important organic soil series in Michigan are Carlisle, Carbondale, Greenwood, Houghton, Kerston, Lupton and Rifle. Soils must have greater than 20 percent organic matter to be characterized as organic soils. In the MSU Soil Test Lab, soils with a bulk density below 0.8 gram per cubic centimeter are handled as organic soils.

Lime Requirements

Within each series, acidity or alkalinity varies, except that Greenwood is always very acid. Crop production does not benefit from liming unless soil pH is below 5.3 (1:2 soil:water suspension), except for celery, which requires a soil pH of 5.8 or above. Lime recommendations are given in Table 23 for soils with pH below 5.3. Blueberries benefit from lime applications if soil pH is below 4.0. Apply 4 tons of lime per acre for blueberries if the soil pH is below 4.0.

When the soil test magnesium level is less than 150 pounds per acre and lime is required, use dolomitic lime. Where lime is not required, broadcast 50 to 100 pounds Mg per acre or band 10 to 20 pounds Mg per acre near the row. Broadcasting 500 pounds of magnesium sulfate or potassium-magnesium sulfate or dolomitic lime per acre will provide adequate and equal amounts of magnesium.

In some cases, the surface foot of soil may have a pH around 5.5 and the second foot, around 4.5. If the soil is plowed sufficiently deeply to bring some of the acid soil to the surface, the plow layer soil pH and lime requirement will change. Therefore, lime according to a soil test on a sample taken after plowing. Lime requirements for organic soils are shown in Table 23.

Problem areas in some fields may be due to acid or alkaline layers in the rooting zone. In newly established fields and problem areas, check the soil pH at 6-inch intervals to a depth of 2 or 3 feet to determine pH variations.

TABLE 23. Lime requirements for organic soils.

Soil pH	Lime recommendation to pH 5.2
	tons/acre
5.2	0.0
5.0	1.5
4.8	2.9
4.6	4.3
4.4	5.8
4.2	7.2
4.0	8.6
3.8	10.0

Recommendations are calculated from the following formulas and rounded to the nearest tenth of a ton:

$$XL = 37 - 7.1 * pH$$

Where: XL = Lime recommendation in tons/acre
pH = soil pH

Effect of Time of Soil Sampling

In the case of newly reclaimed organic soils or soils that have not been heavily fertilized, there is little change in soil test levels from one time of the year to another. Consequently, time of sampling is not important on these soils.

On organic soils that have been fertilized for two or three years, the time of sampling is important. Considerable amounts of potassium may leach over winter. The potash recommendations in Table 26 are for samples collected in the fall and assume the potassium test level will be decreased 25 percent because of leaching. For samples collected between March and June, decrease these recommendations for potash by 25 percent.

Major Nutrients

NITROGEN (N)—Nitrogen requirements for crops grown on organic soil are given in Table 24. Additional details of management are given in the fertilizer management sections.

In organic soils, considerable nitrogen is mineralized—changed to the ammonium and nitrate forms—as the organic matter decomposes during each growing season. Because much of this nitrogen is lost by denitrification, net available nitrogen released ranges from 40 to 100 pounds per acre. The nitrogen recommendations in Table 24 assume an average release of 60 pounds of available nitrogen per acre. Nitrogen release from sandy or marginal mucks will be less. On these soils, apply an additional 30 to 40 pounds of nitrogen per acre. Other conditions that may suggest a need for additional nitrogen are: organic layers less than 18 inches deep, soil pH less than 5.3, heavy rainfall, high water table and low soil temperatures in the spring. Because heavy leaching of most organic soils occurs during the late winter and early spring months, do not fall apply nitrogen.

TABLE 24. Nitrogen recommendations for field and vegetable crops grown on organic soils.

	lb N/A		lb N/A		lb N/A
Clover	0	Snap beans	40	Spinach	75
Pasture	0	Turnips	40	Sweet corn	75
Rye	10	Chard	40		
Field beans	10			Lettuce	100
Soybeans	10	Carrots	60	Sod	100
Oats	10	Endive	60		
Asparagus				Broccoli	120
old beds	40	Cabbage	75	Brussels sprouts	120
new & crowns	60	Corn	75	Cauliflower	120
		Mint	75	Potatoes	120
Radishes	40	Rhubarb	75		
Rutabagas	40	Sorghum	75	Onions	150
Sugar beets	40			Celery	160
Table beets	40				

PHOSPHORUS (P) and POTASSIUM (K)—Phosphorus and potassium recommendations based on soil test data are given in Tables 25 and 26. In newly developed fibrous peats, phosphorus remains fairly mobile. Banded phosphorus applications are most effective. After being in production for three to five years, the organic materials are decomposed and form a more active fraction that ties up phosphorus. Available phosphorus levels can then be built up. For crops seeded before May 1, banding 25 to 40 pounds of phosphate (P_2O_5) per acre increases plant growth and frequently crop yields, even when soil test levels are high. Banding phosphorus for crops seeded during May may be beneficial. For crops seeded after June 1, the probability that banded phosphorus will improve crop growth and yield is quite low unless the level of available soil phosphorus is low. Response to banded phosphorus is related to soil temperatures and the rate of root system development.

Potassium is held rather loosely in organic soils and is subject to leaching loss, especially during late winter and early spring. DO NOT APPLY POTASH IN THE FALL ON ORGANIC SOILS. It is also unwise to build soil potassium to unnecessarily high levels. Broadcast most of the potassium prior to plowing for deep-rooted crops and after plowing for shallow-rooted crops.

Micronutrients

Organic soils are often low in manganese, boron, copper, molybdenum and zinc. High-value crops, particularly, should be fertilized with micronutrients if conditions and a soil test indicate possible need. The responsiveness of crops to the various micronutrients is given in Table 27.

Micronutrients can be absorbed through plant leaves. Where spray equipment is available, the cost of material used may be less and the nutrients may be utilized more efficiently than nutrients applied to the soil. Suggested foliar spray rates are discussed in Extension bulletin E-486.

MANGANESE (Mn)—Manganese deficiency is likely to occur on organic soils with a pH of 5.8 or above. Such a deficiency can be corrected by applying manganese salts or adding enough sulfur to acidify the soil. Very acid soils that have been limed usually show a greater need for manganese fertilization than do soils with a naturally high pH. The amount of manganese recommended based on a soil test is shown in Table 28. Soil fixation can be very great, particularly when the fertilizer is broadcast, so place the manganese in bands near the seed. If manganous oxide is used as the manganese carrier, use only finely ground or regranulated material with acid-forming fertilizers. Manganese must be applied yearly because there is very little carryover or residual buildup in the available form. Chelated forms of manganese have not been effective when applied to organic soils.

BORON (B)—The need to fertilize with boron on organic soils depends on the crop grown (see Table 29). Cauliflower, celery, table beets and turnips are highly responsive to boron application. Medium responsive vegetables include broccoli, cabbage, carrots, lettuce, parsnip, radish and

TABLE 25. Phosphorus (P_2O_5) recommendations for vegetable and field crops grown on organic soils.

Clover	(4 ton)	Asparagus	(20)	Bluegrass sod		Broccoli	(70)
Oats	(80 bu)	Snap beans	(80)	Brussels sprouts	(50)	Cauliflower	(140)
Pasture	(3 ton)	Corn	(130 bu)	Cabbage	(400)	Celery	(600)
Rye	(30 bu)	Mint	(70 lb)	Carrots	(300)	Home gardens	
Soybeans	(35 bu)	Radishes	(60)	Cucumbers	(200)	Market gardens	
		Sudan grass	(10 ton)	Endive	(160)	Onions- bunching	(200)
		Sweet corn	(160)	Horseradish	(80)	Onions - dry	(400)
		Turnips	(400)	Lettuce	(400)		
				Parsnips	(200)		
				Potatoes	(400)		
				Rutabagas	(350)		
				Spinach	(120)		
				Swiss chard	(150)		
				Sugar beets	(18 ton)		
				Table beets	(250)		

Soil test lb P/acre	Phosphorus recommendation, lb P_2O_5/acre			
10	80	120	210	250
30	60	100	180	220
50	30	70	160	200
70	0	50	130	170
90	0	20	110	150
110	0	0	80	120
130	0	0	60	100
150	0	0	30	70
170	0	0	0	50
190	0	0	0	20
210	0	0	0	0

* Figure in parentheses after the crop is the yield potential in cwt (100 lbs)/acre.

Recommendations are calculated from the following formulas and rounded to the nearest 10 pounds:

XP1 = 100 - 1.25 * ST
XP2 = 138 - 1.25 * ST
XP3 = 225 - 1.25 * ST
XP4 = 263 - 1.25 * ST

Where: XP1 = lb P_2O_5/acre column 1
XP2 = lb P_2O_5/acre column 2
XP3 = lb P_2O_5/acre column 3
XP4 = lb P_2O_5/acre column 4
ST = Soil test, lb/acre

spinach. Boron is best applied with the broadcast fertilizer before seeding and should not be banded near the seed. Corn, barley and beans are very sensitive to boron and may be injured by boron applications.

The availability of boron in the soil is affected by pH. For this reason, the amounts suggested in Table 29 are greater on high pH soils. In estimating boron needs, expect some residual effect for the succeeding crop. However, this will not injure sensitive crops if recommended rates are applied. For table beets, it may be necessary to use quantities greater than those suggested in Table 29.

COPPER (Cu)—Acid, peaty soils are usually low in copper. Liming will not decrease the need. The carriers used for fertilizers are usually either the sulfate or oxide forms. Copper applied to organic soils is not easily leached and contributes to a buildup of available soil copper. For this reason, no further copper fertilization is needed if a total of 20 pounds per acre has been applied for low or medium responsive crops and 40 pounds per acre for high responsive crops, or if the copper soil test level exceeds 20 ppm.

Additional copper will be needed if soil erosion is serious or the field is plowed deeply. In many instances, the copper level in the soil is ample because of repeated applications of copper fungicide dust or spray. Table 30 shows recommended copper rates based on soil test levels.

ZINC (Zn)—Zinc deficiency is more likely to occur on nearly neutral or alkaline organic soil. Onions, beans

TABLE 26. Potassium (K_2O) recommendations for vegetable and field crops grown on organic soils.

Oats	(80 bu)	Snap beans	(80)	Asparagus	(20)	Broccoli	(70)	Celery	(600)		
Pasture	(3 tons)	Clover	(4 ton)	Cabbage	(400)	Brussels sprouts	(50)				
Rye	(30 bu)	Corn	(130 bu)	Carrots	(300)	Cauliflower	(140)				
		Bluegrass sod		Cucumbers	(200)	Home gardens					
		Soybeans	(35 bu)	Endive	(160)	Market gardens					
		Sudan grass	(10 ton)	Horseradish	(80)	Onions - bunching	(200)				
		Sweet corn	(160)	Lettuce	(400)	Onions - dry	(400)				
		Turnips	(400)	Mint	(70 lb)	Potatoes	(400)				
				Parsnips	(200)	Rutabagas	(350)				
				Radishes	(60)	Spinach	(120)				
						Sugar beets	(18 ton)				
						Swiss chard	(150)				
						Table beets	(250)				

Soil test lb K/acre	Potassium recommendation, lb K_2O/acre				
75	150	250	300	400	500
150	100	200	250	350	450
225	50	150	200	300	400
300	0	100	150	250	350
375	0	50	100	200	300
450	0	0	50	150	250
525	0	0	0	100	200
600	0	0	0	50	150
675	0	0	0	0	100
750	0	0	0	0	50
825	0	0	0	0	0

* Figure in parentheses after the crop is the yield potential in cwt (100 lbs)/acre.

Recommendations are calculated from the following formulas and rounded to the nearest 10 pounds:

XK1 = 210 - 0.67 * ST
XK2 = 310 - 0.67 * ST
XK3 = 360 - 0.67 * ST
XK4 = 460 - 0.67 * ST
XK5 = 560 - 0.67 * ST

Where: XK1 = lb K_2O/acre column 1
XK2 = lb K_2O/acre column 2
XK3 = lb K_2O/acre column 3
XK4 = lb K_2O/acre column 4
XK5 = lb K_2O/acre column 5
ST = Soil test, lb/acre

and corn are most often affected under Michigan conditions. Apply 3 to 4 pounds of zinc annually for three or four years, then reduce the rate to 1 pound per acre. Rates based on soil test values are given in Table 15. Available zinc levels can be built up in soils. After applying zinc for five years, test the soil to determine if additional zinc is necessary.

MOLYBDENUM (Mo)—Molybdenum deficiency has been noted on lettuce, spinach, cauliflower, cabbage and onions. The organic soils that need molybdenum are below pH 5.5. Soils with high iron content also show a need for molybdenum.

The suggested treatment for molybdenum is a foliar spray application of 2 ounces of sodium molybdate per acre, or a seed treatment at a rate of 1/2 ounce of sodium molybdate per acre. For seed treatment, dissolve 1/2 ounce of sodium molybdate in 3 tablespoons of water and mix with seed required for one acre. Even with seed treatment, one or more foliar applications may be necessary.

Suggested Fertilizer Management

Nitrogen rates and fertilizer placement guidelines are given for each crop. Apply phosphorus and potassium at rates given in Tables 25 and 26 according to soil test information. Use soil test data to determine need for the micronutrients.

Broccoli, Cabbage, Cauliflower— Broadcast and incorporate 50 pounds of nitrogen and all of the phosphate and potash into the soil 4 inches deep prior to planting. Use a high-phosphorus starter solution when setting transplants. For cauliflower, include 2 to 4 ounces of sodium molybdate per acre in the starter solution. Sidedress the plants with 30 to 40 pounds of nitrogen per acre three weeks after transplanting and again four weeks later. Some varieties of cauliflower will benefit from foliar sprays of sodium molybdate (2 to 4 ounces per acre) on a two-week schedule.

Carrots, Parsnips—Plow down or incorporate at least 6 inches deep all the nitrogen, phosphorus and potassium fertilizer. Include 1/2 to 1 pound of boron per acre and copper, if a soil test indicates it is needed.

TABLE 27. Relative response of selected vegetable crops to micronutrients. [1]

Crop	Response to nutrient			
	Mn	B	Cu	Zn
Blueberries	low	low	medium	
Broccoli	medium	medium	medium	
Cabbage	medium	medium	medium	
Carrots	medium	medium	medium	low
Cauliflower	medium	high	medium	
Celery	medium	high	medium	
Lettuce	high	medium	high	
Onions	high	low	high	high
Parsnips	medium	medium	medium	
Peppermint	medium	low	low	low
Potatoes	high	low	low	medium
Radishes	high	medium	medium	
Spearmint	medium	low	low	low
Spinach	high	medium	high	
Sweet corn	medium	low	medium	high
Table beets	high	high	high	medium
Turnips	medium	high	medium	

[1] The crops listed will respond as indicated to applications of the respective micronutrient when that micronutrient concentration in the soil is low.

An alternative program is to plow down a fertilizer high in potassium that contains boron and copper. Use a starter fertilizer for the remainder of the fertilizer needs banded 3 inches to the side and 3 inches below the seed. Do not exceed 300 pounds of fertilizer in the row on 21-inch rows. Sidedress additional nitrogen if plant growth shows a need. On well drained, high-organic soils, use a total of 50 pounds of nitrogen. On sandy mucks and marly soils, use a total of 80 to 100 pounds of nitrogen.

Foliar manganese application may be needed periodically during the growing season, especially if the soil pH is above 6.5.

Celery—Broadcast and incorporate 50 to 60 pounds of nitrogen plus recommended amounts of phosphorus and potassium and 1 pound of boron per acre. For celery transplanted under paper or before May 1, banding a high phosphorus fertilizer under the row will stimulate early growth. Spray the foliage periodically with manganese if the soil pH is above 6.5 and a soil test shows a need.

Sidedress one to three times during the growing season at the rate of 40 to 50 pounds of actual nitrogen per acre per application. The number of applications will depend upon the season, drainage and type of muck. The color of the plant and plant tissue tests will help determine your nitrogen needs. Avoid excessive rates of ammonium forms of nitrogen in the spring if the soil has been fumigated. Ammonium fertilizers can be used after June 1. Ammonium nitrate that contains both ammonium and nitrate may be used anytime.

Certain celery varieties need magnesium applied as a spray. Use magnesium sulfate (Epsom salts) at the rate of 10 pounds per acre per week. If this rate does not correct the magnesium yellowing, increase the rate to 20 pounds. Calcium is needed to prevent black-heart disorder. Apply calcium chloride at the rate of 5 to 10 pounds per acre weekly. Direct calcium sprays into the heart of the plant.

Corn (field or sweet)—Plant population goals should be about 20,000 plants per acre. Broadcast and plow down the recommended amount of potash (K_2O). At planting, band 2 inches to the side and 2 inches below the seed fertilizer containing 30 pounds of nitrogen per acre and all the recommended phosphorus. Include manganese and zinc in the starter fertilizer if a soil test indicates they are needed. Sidedress 50 pounds of nitrogen when the plants are 6 to 12 inches high.

Head Lettuce, Spinach—Broadcast and incorporate after plowing the recommended rate of potassium. Apply 30 to 50 pounds of nitrogen, all the required phosphorus and 1/2 pound of boron in a band 1 inch to the side and 2 to 3 inches below the seed at planting time.

Depending on a soil test, manganese and copper may also need to be included in the banded fertilizer. On acid, fibrous peats, treat the seed with sodium molybdate (2 ounces per quantity of seed to plant an acre).

Onions—Broadcast and incorporate 60 to 80 pounds of nitrogen per acre and the recommended amount of potassium. Banded fertilizer placed 2 to 3 inches directly below the seed may include all the required phosphorus, some nitrogen and potassium, and 2 percent manganese. Depending on soil tests, copper and zinc may also need to be included in the banded fertilizer. Side- or topdress 80 pounds of nitrogen per acre in mid-June. On soils with a pH above 6.5, foliar application of manganese may be necessary throughout the growing season.

Peppermint, Spearmint—Drill in or broadcast the phosphate and potash in the spring before the crop emerges. Topdress with 70 pounds of nitrogen in early June. Use a pelleted form and apply when the foliage is dry. Irrigate in the nitrogen if rain is not likely to occur during the next five to seven days.

If soil pH is above 6.5, foliar application of manganese may be required, depending on soil test level.

Potatoes—Plow down 30 to 50 pounds of nitrogen per acre and the recommended amount of potash (K_2O). The planting-time fertilizer, placed 2 inches to the side and 2 inches below the seed pieces, should include all the recommended phosphorus, some nitrogen and potassium, and 2 percent manganese. Sidedress prior to or at hilling with 60 to 80 pounds of nitrogen per acre. For late-maturing potato varieties, apply an additional 30 to 50 pounds of nitrogen per acre in late June or early July. An alternative is to apply nitrogen through the irrigation system.

Foliar application of manganese (4 to 8 pounds of manganese sulfate per acre per application) may be necessary during the growing season.

Table Beets, Swiss Chard, Radishes, Turnips, Rutabagas—Broadcast and incorporate the recommended amounts of nitrogen, phosphorus and potassium fertilizer. Use 1 pound of boron per acre in the fertilizer for radishes, 2 pounds of boron for turnips, rutabagas and Swiss chard, and 4 pounds for table beets. If soil pH is above 6.0, use 5 to 10 pounds of manganese per acre in the fertilizer for all crops unless a soil test indicates otherwise. In-row or foliar application of manganese sulfate is especially beneficial for the production of radishes.

Beans, Soybeans—Broadcast and incorporate the nitrogen, phosphorus and potassium requirements. If a soil test indicates a need for manganese, band near the seed a starter fertilizer containing 2 percent manganese. Additional manganese may be needed for soybeans and can be applied as a foliar spray. Use 2 pounds of actual manganese in 15 or more gallons of water per acre. Use 1 to 3 pounds of zinc per acre in row fertilizer for field beans and soybeans if pH is above 6.5 or a soil test indicates a need.

Sod—Turfgrasses used in sod production are somewhat less responsive to phosphate and potash than most vegetable crops. Apply these nutrients

TABLE 28. Manganese fertilizer recommendations for responsive crops grown on organic soils.

Soil test	Soil pH 5.6	5.8	6.0	6.2	6.4	6.6	6.8	7.0
ppm	lb Mn/acre							
2	0	2	4	5	7	9	10	12
4	0	0	3	5	6	8	10	11
6	0	0	2	4	6	7	9	11
8	0	0	2	3	5	7	9	10
10	0	0	0	3	5	6	8	10
12	0	0	0	2	4	6	7	9
14	0	0	0	2	3	5	7	8
16	0	0	0	0	3	4	6	8
18	0	0	0	0	2	4	5	7
20	0	0	0	0	0	3	5	6
22	0	0	0	0	0	2	4	6
24	0	0	0	0	0	2	4	5
26	0	0	0	0	0	0	3	5
28	0	0	0	0	0	0	2	4
30	0	0	0	0	0	0	2	3
32	0	0	0	0	0	0	0	3
34	0	0	0	0	0	0	0	2
36	0	0	0	0	0	0	0	2
38	0	0	0	0	0	0	0	0

Recommendations are calculated from the following formulas and rounded to the nearest pound:

$$XMn = -46 + 8.38\ pH - .31\ ST$$

Where: XMn = lb/Mn/acre
pH = soil pH
ST = ppm Mn soil test

TABLE 29. Boron fertilizer recommendations for crops grown on organic soils.

Soil pH	Crop response		
	Low	Medium	High
	lb B/acre		
5.0	0.0	0.5	2.0
5.5	0.0	0.5	2.0
6.0	0.0	0.5	2.5
6.5	0.0	1.0	2.5
7.0	0.5	1.0	2.5
7.5	0.5	1.0	3.0
8.0	0.5	1.0	3.0

Recommendations are calculated from the following formulas and rounded to the nearest half pound:

XB = .36 + .33 * pH for high responsive crops
XB = (.36 + .33 * pH) * .33 for medium responsive crops
XB = (.36 + .33 * pH) * .17 for low responsive crops

Where: XB = lb B/acre
pH = soil pH

TABLE 30. Copper fertilizer recommendations for crops grown on organic soils.

Soil test	Crop response		
	Low	Medium	High
ppm	lb Cu/acre		
2	3	4	6
4	3	4	5
6	2	4	5
8	2	3	4
10	2	3	4
12	2	3	3
14	1	2	3
16	1	2	2
18	1	2	2
20	0	1	2
22	0	0	0

Recommendations are calculated from the following formulas and rounded to the nearest pound:

XCu = 6 - .22 * ST for high responsive crops
XCu = (6 - .22 * ST) * .5 for medium responsive crops
XCu = (6 - .22 * ST) * .25 for low responsive crops

Where: XCu = lb Cu/acre
ST = ppm Cu soil test

based on soil tests and work them into the soil before establishment.

After all seedings have emerged, topdress 30 to 40 pounds of nitrogen per acre. Suggested annual nitrogen rates for established sod are 90 to 150 pounds of nitrogen per acre for Merion Kentucky bluegrass, 80 to 120 pounds for other Kentucky bluegrasses, and 40 to 80 pounds for red fescues. Intermediate rates should be used for mixtures and blends of these grasses. Apply nitrogen at four- to six-week intervals during the growing season. DO NOT apply more than 40 pounds of nitrogen per acre at any one time.

A minimum of two applications of nitrogen per year are suggested, with more applications when higher rates are used. Use summer nitrogen applications primarily to maintain color and growth desired or to "green up" the sod before harvest.

Yield Potentials of Soil Management Groups

The potential of a soil to produce good crop yields depends on its properties and how they are managed. Soils with similar properties and yield potentials form soil management groups (SMG). A general discussion of soil management groups and a listing of 412 occurring in Michigan are given in Extension bulletin E-1262, "Soil Mapping Units and Land Use Planning."

Average yield potentials of the various soil management groups are given in Tables 31 and 32 for those areas of Michigan with over 140 frost-free days and with fewer than 140 frost-free days, respectively. With irrigation and good management, the average yield potentials for corn (in Table 31) will range from 150 to 175 bushels per acre going from sand soils (SMG 5.0) to clay loam soils (SMG 1.5).

TABLE 31. Average yield potentials for crops grown on various soil management groups under good management with adequate drainage but without irrigation in areas with growing season OVER 140 FROST-FREE DAYS ANNUALLY (southern Michigan).

Soil Management Group	Corn	Corn silage	Winter wheat	Oats	Field beans soybeans	Alfalfa 3 cuts	Sugar beets
	Bu/acre	Ton/acre	Bu/acre	Bu/acre	Bu/acre	Tons/acre	Tons/acre
Clays							
Oc	95	16	35	75	25	3.8	-
1a	100	17	45	80	28	4.2	-
1b	115	18	50	85	32	4.5	18
1c	125	19	55	90	35	4.8	20
Clay loams							
1.5a	110	18	55	85	35	5.0	-
1.5b	120	19	55	90	40	5.5	19
1.5c	130	20	60	100	42	6.0	23
Loams							
2.5a	120	19	60	95	35	4.8	19
2.5b	130	20	65	105	40	5.0	20
2.5c	140	22	65	115	45	5.5	23
Sandy loams over clay or loam							
3/2a	115	19	55	95	35	3.5	18
3/1b or 3/2b	125	20	60	100	40	4.8	20
3/acre or 3/2c	140	20	65	105	40	5.0	22
Sandy loams							
3a	105	18	45	85	30	4.0	16
3b	115	19	50	95	33	4.5	19
3c	120	19	55	100	35	4.8	21
3/Ra	95	16	40	80	28	3.8	-
Loamy sands over clay or loam							
4/2a	105	18	40	80	30	4.0	15
4/2b-4/1b	110	18	45	85	35	4.2	16
4/2c-4/1c	115	19	50	90	35	4.5	18
Loamy sands							
4a	80	14	30	60	25	3.5	-
4b	85	14	35	65	32	3.8	-
4c	95	16	45	75	32	4.0	-
4/Ra or 4/Rb	60	12	25	50	22	3.0	-
Sands							
5.0a	55	11	25	45	-	3.0	-
5b	65	12	30	55	-	3.5	-
5c	80	14	40	60	25	3.8	-

TABLE 32. Average yield potentials for crops grown on various soil management groups under good management with adequate drainage but without irrigation in areas with growing seasons of LESS THAN 140 FROST-FREE DAYS ANNUALLY (northern Michigan).

Soil Management Group	Corn silage	Corn	Winter wheat	Field beans	Oats	Alfalfa 2 cuts
	Tons/acre	Bu/acre	Bu/acre	Bu/acre	Bu/acre	Tons/acre
Clays						
0c	-	-	30	-	75	3.5
1a	12	75	35	25	70	3.5
1b	13	80	35	30	75	3.5
1c	14	85	40	35	75	3.5
Clay loams						
1.5a	13	80	40	30	75	3.7
1.5b	14	85	42	35	80	3.8
1.5c	15	90	45	40	85	4.0
Loams						
2.5a	16	95	45	35	80	4.0
2.5b	16	95	48	40	85	4.0
2.5c	17	100	50	45	90	4.5
Sandy loams over clay or loam						
3/2a	14	85	40	35	80	4.0
3/ab or 3/2b	15	90	45	37	85	4.0
3/ac or 3/2c	16	95	50	40	85	4.0
Sandy loams						
3a	13	80	35	25	75	3.5
3b	14	85	35	30	80	3.5
3c	15	90	40	35	85	3.5
3/Ra	12	75	30	25	70	3.0
Loamy sands over clay or loam						
4/2a	12	75	35	25	70	3.5
4/2b	14	85	40	28	75	3.5
4/2c-4/1c	14	85	40	30	75	3.5
Loamy sands						
4a	11	70	28	20	60	3.0
4b	11	70	40	25	65	3.0
4c	12	75	35	30	70	3.0
4/Ra or 4/Rb	10	50	25	-	40	2.5
Sands						
5.0a	9	50	25	-	40	2.5
5b	10	55	25	-	45	2.5
5c	11	70	30	-	50	3.0

COOPERATIVE
EXTENSION
SERVICE

(Revision-destroy all previous editions) 9:85-8M-LKM $1.00 for sale only.

File 22.04

O-15819