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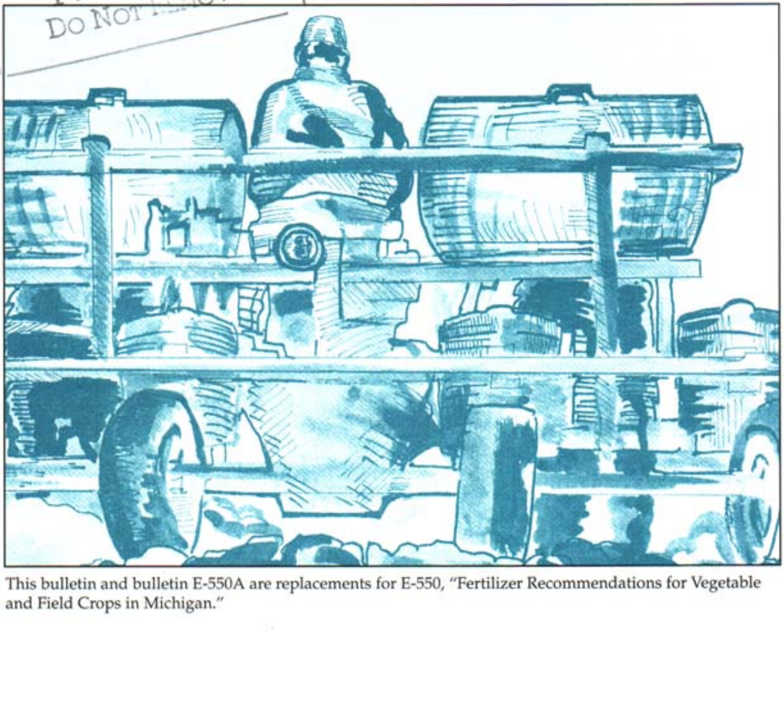
Fertilizer Recommendations for Vegetable Crops in Michigan



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Fertilizer Recommendations for Vegetable Crops in Michigan

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The Michigan State University Soil Testing Laboratory is an essential part of soil fertility educational programs of the departments of Crop and Soil Sciences and Horticulture through the Cooperative Extension Service. Soil samples can be submitted to the MSU Soil Testing Lab directly or through your county Cooperative Extension office.

Information presented in this bulletin allows Michigan vegetable growers to develop effective supplemental nutrient use programs. Nutrient recommendations are based on a soil test, soil type, yield and past crop management. Applying the recommended nutrient rates with proper timing and incorporation minimizes the potential that fertilizers will be a source of surface or groundwater contamination. For example, nutrients applied near the time of greatest uptake demand by the crop are used most efficiently.

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.

This bulletin contains recommendations for both mineral and organic soils. Any soil containing more than 30 percent organic matter is considered to be an organic soil. Soils containing less than 20 percent organic matter are considered mineral soils. Those with organic matter contents between 20 and 30 percent may fall into either category, depending on the clay content. The MSU Soil Testing Lab uses a bulk density of 0.80 g/cm^3 to classify soils; those above 0.80 are handled as mineral soils and those below 0.80 are handled as organic soils.

Nutrient Management and Water Quality

Agriculture is coming under closer scrutiny as a contributor to non-point source pollution. When nutrients are added to the soil-plant system in great excess of what the crop and soil biology can use, the risk of losing nutrients to groundwater and surface waters increases. Climate, soil type, slope of the land, ground cover and soil fertility levels, as well as farming methods, can influence the fate of nutrients applied to the soil. For instance, on sloping land conservation tillage practices and fertilizer incorporation or placement beneath the soil surface reduces runoff loss.

Adding excess nutrients to soil can cause phosphorus to accumulate in the upper soil profile and increases the risk of contaminating surface waters with phosphorus where runoff and erosion occur. It also can lead to nitrates being leached through the soil and into groundwater, create nutrient imbalances in soils which may cause poor plant growth, and result in economic loss for the producer. Avoid adding excess nutrients by soil testing at regular intervals, giving nitrogen credits for previous legume crops, giving credit for nutrients from additions of manures and organic materials, establishing realistic yield goals and following the fertilizer recommendations discussed in this bulletin.

As phosphorus concentrations in soils increase, the risk of losing phosphorus bound to soil particles under erosive conditions also increases. Therefore, implement adequate soil and water conservation practices which control runoff and erosion. For example, conservation tillage can enhance infiltration of water into soils, thereby reducing runoff, soil erosion and associated phosphorus loadings to surface waters.

Loss of nitrates to groundwater is a major concern since water with a concentration in excess of 10 parts per million nitrate-nitrogen may pose a health hazard. Since about half of all Michigan residents obtain drinking water from groundwater, maintaining good quality groundwater is important. Therefore, do not exceed the nitrogen fertilizer recommendations given for vegetable crop production.

Make an all-out effort to adopt nutrient management practices that provide the necessary quantities of nutrients to achieve optimum yields without adding excessive nutrients that may increase the risk of polluting surfacewater and groundwater. Adding quantities of nutrients that supply the needs of the crop without causing excessive nutrient loading achieves two desirable goals. First, efficient use of nutrients for crop production will yield economic benefits to the crop producer. Second, protecting surface water and groundwater quality from potential non-point source contamination, due to agriculture activities, can best be accomplished when nutrients are applied at recommended rates. See Extension bulletin WQ-25 and NCR Research Publication 310 listed in the references section for additional information.

Soil Sampling

Soil samples must be representative of the field, otherwise the soil test results and fertilizer recommendations are not reliable or useful. Collect each soil sample with care. Fields on which annual vegetables are grown should be sampled annually, or at least every other year. For perennial vegetable crops, such as asparagus, sampling every third year is acceptable.

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 crop management of the field to be sampled. If these features are uniform throughout the field, collect one composite sample of the topsoil for each 10 acres. For non-uniform fields, collect a composite soil sample for each distinctly different area of significant economic size. For a small market garden grower this may be a quarter acre. For a large cucumber grower this may be 2 acres. In most situations sample to a depth of 8 or 9 inches. Soil samples are most easily collected with a soil probe.

Each composite sample should consist of at least 20 subsamples taken at random over the field or designated area. Avoid sampling close to gravel roads, dead furrows, previous locations of brush, lime or manure piles or any unusual areas. Mix the subsamples well, breaking apart the soil cores or chunks, then place a pint of the soil into a sample box and return to your County Cooperative Extension Service (CES) office or mail to the MSU Soil Testing Lab, Plant and Soil Sciences Building, East Lansing, MI 48824-1325. Soil sample boxes, soil probes and instructions for taking soil samples are available from your County CES office.

Mineral Soils: Soil samples may be taken at any time during the year when the soil temperature and moisture conditions permit. In fields intensively farmed for a long time, phosphorus and potassium levels may have increased substantially in the subsurface soil. If the soil tests are in the medium range in the subsoil the phosphorus and/or potassium recommendation may be decreased by 20 percent, especially for deep-rooted crops. Collect a soil sample from the 9 to 16 inch depth every five years to monitor subsoil nutrient levels.

Organic Soils: On organic soils that have been in crop production for more than three years, the time of sampling is important. Considerable amounts of potassium may leach over winter. The potassium recommendations given in Table 15 are for samples collected in the fall and assume the potassium test level will decrease 25 percent over the winter and early spring months because of leaching. For samples collected between March and June, decrease these potassium recommendations by 25 percent. Acid and marl layers occur in some organic soils. As these soils subside, existing acid or marl will eventually occur in the rooting zone. Sample the subsoil every five years to determine the pH and monitor the nutrient status.

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 fertilizers according to soil test results helps maximize crop yields, crop quality and economic returns. Many other factors also must be managed properly for optimum crop production, including soil physical properties, irrigation, drainage, weeds, insects, diseases, timely planting, etc.

The following is a brief discussion of the procedures used in the Michigan State University Soil Testing Laboratory.

Soil pH is determined on mineral soils in a 1:1 soil:water suspension. For organic soils a 1:2 soil:water suspension is used.

Lime requirement is determined using the Shoemaker-McLean-Pratt (SMP) buffer method. See the section on "Acidity and Liming" for more information.

Soil test values do not indicate the actual level of nutrients available in a soil. Available nutrient levels as determined by soil testing extractants provide an indication or index of the available nutrient status of a soil.

Available soil phosphorus is extracted with the Bray-Kurtz P-1 (weak acid) extractant except for "marly organic" soils and calcareous mineral soils. For these soils phosphorus availability is determined with 0.5 N sodium bicarbonate (Olsen extractant). Exchangeable potassium, calcium and magnesium are extracted with 1.0 N neutral ammonium acetate. Recommendations for phosphorus and potassium fertilizers are based on soil test values obtained with these extractants.

Available manganese and zinc are determined by extraction with 0.1 N HCl. Copper availability is determined by 1.0 N HCl extraction. Micronutrient levels are expressed as parts per million (ppm).

Mineral soil samples submitted to the Michigan State University Soil Testing Laboratory are extracted from 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 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 one acre 6 2/3 inches deep).

Available phosphorus, potassium, calcium and magnesium are expressed as actual pounds of available element (P, K, Ca, Mg) per acre. However, some laboratories express all nutrient soil test values as parts per million. For mineral soils, 2 lb/A = 1 ppm. For all soils the exact conversion relation varies with the bulk density of the soil, but this is most apparent with organic soils. For example, for an organic soil with a bulk density of 0.33 g/cm^3, 0.5 lb/A = 1 ppm. For soils with a bulk density of 0.66 g/cm^3, 1 lb/A = 1 ppm.

A few laboratories report phosphorus and potassium test values in terms of P_2O_5 and K_2O. The factors to convert between P and P_2O_5 and between K and K_2O are:
pounds P x 2.3 = pounds P_2O_5; or pounds P_2O_5 x 0.44 = pounds P
pounds K x 1.2 = pounds K_2O; or pounds K_2O x 0.83 = pounds K.

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

Field studies conducted over the years provide the basis for these nutrient recommendations. Nutrient soil test levels have been correlated with responses of crops to applied nutrients. Where insufficient field data are available, nutrient recommendations are based on considerations of crop removal and soil test levels combined with field data from similar soil and crop systems. Phosphorus and potassium recommendations provided by MSU provide for a buildup when soil tests are low, maintain desirable nutrient levels when soil tests are medium to high, and allow for gradual drawdown of available nutrient levels when soil tests are very high. To determine if a recommendation will result in buildup or maintenance of the present soil test level use Table 1. A maintenance recommendation is equal to crop removal of nutrients, whereas buildup occurs when the recommendation exceeds crop removal. When the soil test levels of phosphorus and potassium are low to medium, the total amount of phosphorus and potassium recommended includes both the buildup and maintenance amounts. A gradual buildup to an optimal level occurs in about five years. Applying more nutrients than recommended results in a more rapid buildup.

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. This causes a gradual decrease in phosphorus and potassium levels. The actual rate of decrease depends on the 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. Soil testing each field annually helps monitor changes in available nutrient levels. Before adopting a conservation tillage system of crop production, build up available phosphorus and potassium to medium or high levels.

Within the limits of a given management system, the available nutrient level in the soil and the rate of nutrients applied affect the quality and yield of many vegetable crops. However, with high available nutrient levels in the soil, applying more fertilizer will not result in higher yields. Under this situation higher yields will only come with improvements in the management system. For example, a tomato grower produces 30 tons per acre with a good fertility program, and increasing the fertilizer application rate does not increase the yield. By going to twin rows on raised beds, a yield of 40 tons/A is produced. Additional nutrients need to be applied to maintain the level of nutrients in the soil. In this and similar vegetable production situations, the yield affects the fertilizer rate rather than the fertilizer rate affecting the yield. The phosphorus and potassium recommendations given in this bulletin are for good yields (see bulletin E-1565, "Yields of Michigan Vegetable Crops") of the listed vegetables. When higher yields than these are produced consistently over 3-5 years, increase the nutrient recommendation by the amount necessary to maintain the nutrient status of the soil (see Table 1).

The yield potential of a given field must be based on past experience and good judgment. Fertilizing to reach a yield that cannot be attained because of other limiting factors only incurs needless costs. Nutrients accumulated above a level where crop response occurs may lead to deleterious effects on the soil and the crop. It also may increase the potential for environmental pollution due to erosion and/or leaching of nutrients into surface water or groundwater.

Table 1. Approximate nutrient removal in the harvested portion of several Michigan vegetable crops.

Crop	Yield	--- lb/acre ---			--- lb/cwt ---		
	tons/A	N	P_2O_5	K_2O	N	P_2O5	K_2O
Asparagus	1.5	20	6	15	.67	.20	.50
Beans, snap	4.0	40	18	40	1.20	.12	.55
Broccoli	5.0	20	5	55	.20	.05	.55
Cabbage	20.0	140	32	140	.35	.08	.35
Carrots	17.5	70	32	120	.17	.09	.34
Cauliflower	8.0	55	21	55	.33	.13	.33
Celery	30.0	150	60	480	.25	.10	.80
Cucumbers	10.0	20	12	36	.10	.06	.18
Lettuce	20.0	100	40	180	.24	.10	.45
Muskmelon	9.0	75	18	100	.42	.10	.55
Onions	20.0	100	50	95	.25	.13	.24
Peas, shelled	1.5	30	7	15	1.00	.23	.50
Peppers	12.5	50	18	70	.20	.07	.28
Pumpkins	20.0	80	22	135	.20	.06	.34
Sweet Corn	9.0	75	25	50	.42	.14	.28
Squash	15.0	55	24	100	.18	.08	.33
Tomatoes	30.0	120	25	210	.20	.04	.35

1 ton = 20 cwt

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 use efficiency.

Soil Acidity and Liming

Soil reaction is expressed as 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.

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 lime application to determine if more lime is needed. When the lime need is greater than 4 tons per acre, apply the lime in a split application; i.e., half before plowing and half after plowing. This is more effective in neutralizing the acidity in the plow layer than one large application.

When growing crops where scab is a potential problem, such as potato and radish, maintain the pH below 6.0. When lime is needed do not exceed 2 tons of lime per acre at any one time and apply it in the fall. For no-till production, base lime need on the pH of the top 3 inches of soil and the lime rate will be one-third of that given in Table 2.

Mineral Soils: Plant nutrients, particularly phosphorus, are most available in mineral soils having a pH between 6.0 and 7.0. For most vegetable crops, it is recommended that acid soils be limed to pH 6.5.

The estimated lime requirement of acid soil samples submitted to the MSU laboratory is determined by measuring the total soluble and exchangeable hydrogen and aluminum content. This is determined using the SMP buffer method. The degree of acidity is reported as the lime index. This method of determining the 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.

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 annually to determine when liming is necessary.

Organic Soils: Within each organic soil series, acidity or alkalinity varies, except that Greenwood is always quite acid. Liming most organic soils does not benefit the production of most crops unless the soil pH is below 5.3 (1:2 soil:water suspension). Celery is the exception, requiring a pH of 5.8 or higher. Lime recommendations are given in Table 2 for soils with a pH below 5.3. In some cases, the top foot of soil may have a pH around 5.5 and the second foot a pH around 4.5, or it may be alkaline. If the soil is plowed deeply enough to bring some of the subsoil to the surface, the plow layer pH and lime requirement will change. Therefore, the lime requirement is best based on a soil sample taken after plowing. Periodic sampling of the subsoil provides a forewarning of potential pH changes.

Table 2. Tons of limestone needed to raise the soil pH of mineral soils to pH 6.0, 6.5, or 6.8 as related to Lime Index and tons of limestone needed to raise soil pH of organic soils to 5.2 as related to soil pH.

Mineral Soils				Organic Soils	
Lime Index	Raise Soil pH to: 6.0	6.5	6.8	Soil pH	Lime Needed
	---- tons/acre ----				tons/acre
70	0.0	0.0	0.0	5.2	0.0
68	1.2	1.6	1.8	5.0	1.5
66	2.7	3.5	3.9	4.8	2.9
64	4.3	5.3	5.9	4.4	5.8
62	5.8	7.2	8.0	4.2	7.2
60	7.4	9.1	10.0	3.8	10.0

Recommendations are based on the following equations and rounded to the nearest tenth of a ton:

Mineral Soils:

To pH 6.0 XL = 54.2 - (0.78 x LI)
To pH 6.5 XL = 65.5 - (0.94 x LI)
To pH 6.8 XL = 71.2 - (1.02 x LI)

Organic Soils:

XL = 37.0 - (7.1 x pH)

where: XL = Lime recommendation in tons/acre
LI = Lime Index
pH = soil pH

Major Nutrients

NITROGEN (N): A reliable soil test for determining long-term nitrogen availability has not been developed in the Great Lakes states. However, a pre-sidedress soil nitrate test can help determine the appropriate rate of nitrogen to apply at that time. Nitrogen need depends on the crop to be grown, yield goal and previous management practices. Nitrogen recommendations for vegetables grown on mineral and organic soils are given in Table 9 and 13, respectively.

Give credit for all nitrogen sources present in a crop management system. Although legumes are not commonly part of vegetable production systems, they are a source of nitrogen. 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 + (0.60 times percent stand) where 5 to 6 plants per square foot is considered to be a 100 percent stand. When soybean is the previous crop, take a nitrogen credit of 40 lb/A. Base nitrogen credit for animal manures on an analyses of the manure since the nitrogen content varies with manure type and the handling system.

Several nitrogen carriers are suitable for vegetable crop production. Studies with a number of different vegetable crops show yields and quality to be best when nitrogen is present in both the ammonium and nitrate forms. Under special conditions, such as for plants growing in cold soils or on recently fumigated land, nitrate-containing fertilizers are preferred. Once soils have warmed above 50° F, the microbial conversion of nitrogen from ammonium to nitrate occurs quite readily. Hence, for most vegetable production situations, the various nitrogen carriers are equally effective and can be purchased on the basis of cost, convenience of handling and supply. Using calcium nitrate on sandy soils low in exchangeable calcium can help alleviate blossom-end-rot and tipburn problems for sensitive vegetable crops. Sidedressing celery, which has a high potassium requirement, with potassium nitrate can be beneficial. These are examples of situations where the more expensive double-nutrient nitrogen carriers can be used effectively.

Improve the efficiency of supplemental nitrogen and minimize nitrate pollution of surface water and groundwater by using recommended nitrogen rates and timely nitrogen application. Fall nitrogen application for vegetable production is not recommended. Applying nitrogen as close as possible to the time of maximum crop demand increases the efficiency of use and minimizes the potential for leaching loss. Apply preplant nitrogen as close to planting time as possible. Include some nitrogen in the starter fertilizer and sidedress the majority of the nitrogen prior to peak demand. A pre-sidedress soil nitrate test can help determine the most effective nitrogen rate. Supplemental nitrogen also can be applied through the irrigation system. Proper scheduling of irrigation water to minimize leaching minimizes nitrogen loss by leaching and denitrification and maximizes efficiency.

Most nitrogen carriers leave an acidic residue in the soil. It requires about 2 pounds of limestone to neutralize the acidifying effect of each pound of nitrogen derived from urea, ammonium nitrate or nitrogen solutions, and 5.5 pounds for each pound of ammonium sulfate. Calcium nitrate and potassium nitrate have a very slight alkaline residue which has little effect on the soil pH.

PHOSPHORUS (P): Phosphorus fertilizers provide their greatest benefit in stimulating the growth of small seedlings, particularly early in the spring when the soil is cold. For crops seeded or transplanted when the soil is rather cool, below 55° F, band the required phosphorus (up to 100 lb P_2O_5 / A) one inch to the side and one to two inches below the seed or transplant. This decreases phosphorus fixation and stimulates early growth. In soils with a phosphorus soil test above 180 lb P per acre, including phosphorus in the starter fertilizer usually does not improve growth, quality or yield. Phosphorus recommendations for vegetable crops grown on mineral and organic soils are given in Tables 10 and 14, respectively.

Phosphorus recommendations provide for phosphorus buildup in low phosphorus soils over a five-year period. Studies show 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. In loam and clay loam soils, 12 to 18 pounds of P_2O_5 per acre are required. Use these values to determine the amount of phosphate fertilizer required to build up the P soil test to a desired level.

Currently, more than 40 percent of the soils in Michigan used for vegetable production have very high levels of available phosphorus. In these soils some drawdown can be allowed until the soil test P level reaches an optimum level for the crops being grown. At this point maintenance rates of phosphorus can be used. The rate of drawdown is about equal to the rate of buildup.

The primary phosphorus fertilizers are equally effective for vegetable production. Dry phosphate fertilizers marketed today are over 90 percent water-soluble, and liquid phosphate fertilizers are nearly 100 percent water-soluble. When water-soluble phosphate, whether from a dry or liquid carrier, is added to soil it immediately reacts with the soil to form insoluble phosphorus compounds. Very little water-soluble phosphorus remains unless the fertilizer was banded in high concentrations.

Concentrated superphosphate (0-46-0) has a low salt index but can delay seed germination because it readily absorbs soil moisture. Placement of this material is especially critical in dry soil conditions.

Ammonium phosphates have high salt effects and must be placed away from the seeds or transplants. More caution is required with diammonium phosphate (DAP) than the monoammonium (MAP) form because of the possible release of ammonia into the soil system. With adequate soil moisture this hazard is minimal.

POTASSIUM (K): The potassium-supplying ability of a soil is related to the types and amounts of clay minerals present. Depending on soil texture, 2 to 6 pounds of potash (K_2O) are required to increase the soil test by 1 pound K per acre. The present potassium soil test can predict the potassium-supplying ability of most Michigan soils. However, some soils high in vermiculite fix potassium in forms that are not readily available for plant uptake. Routine soil testing does not determine the various types of clay minerals or the fixing capacity of a soil. Soils containing vermiculitic clays may require very high rates of potash (K_2O) to build up the available soil potassium. Once these soils have a medium to high potassium test level they continue to supply potassium for some time, even though crop removal may be high. Potassium fertilizer can be broadcast in the fall for buildup on fine-textured soils. Fall application of potash is not recommended on loamy sand, sand and organic soils due to potentially significant leaching loss.

Potassium chloride which contains 60 percent K_2O is the most common and cheapest source of potassium. It is effective in producing most vegetable crops. Potassium sulfate, potassium-magnesium sulfate and potassium nitrate are other effective potassium carriers that are used for special cropping situations. These are used to maintain a low chloride level and provide one of the other essential elements.

Young developing vegetable seedlings and transplants require less potassium than phosphorus. However, when plants reach the rapid growth stage they use large amounts of potassium. Crop removal of potassium is particularly heavy when a large proportion of the plant is harvested, especially with celery, cabbage and lettuce.

Potassium applied in banded fertilizer is equally effective or superior to broadcast potassium. The amount of potassium that can be applied in a band near the seed is limited because of possible salt injury. For this reason broadcast the bulk of the potassium needed, but include some (up to 50 lb K_2O/A) in the banded starter fertilizer.

Secondary Nutrients

MAGNESIUM (Mg): Apply magnesium when the exchangeable magnesium level is below 75 lb/A; or when potassium exceeds magnesium as a percent of the total exchangeable bases (calcium + magnesium + potassium, expressed in chemical equivalents); or when the soil magnesium level as a percent of total bases is less than 3 percent. Any one of these three criteria indicates a potential magnesium deficiency. Thus magnesium deficiency may be induced by high rates of potassium. On acid soils apply dolomitic limestone at the rate needed to raise the soil pH to near 6.5. On acid soils not needing pH adjustment, broadcast 1000 pounds of dolomitic lime per acre. On non-acid soils needing magnesium use 70 to 100 pounds of magnesium per acre broadcast, or 10 to 20 pounds banded near the row. Magnesium sulfate, potash-magnesium sulfate and finely ground magnesium oxide are satisfactory non-lime sources of magnesium.

Magnesium also can be applied in a foliar spray. Use 10 to 20 pounds of magnesium sulfate (Epsom salts) per acre in at least 30 gallons of water. This supplies 1 to 2 lb actual magnesium per acre.

Mineral Soils: Magnesium deficiency is most likely to occur in acid soils with sandy loam, loamy sand or sand surface soil texture and a coarse or coarser subsoil. Deficiency also occurs in similar soils limed with calcitic limestone or marl. A magnesium soil test will indicate when a dolomitic (magnesium-containing) limestone is needed. A higher percentage of the soils in western and southwestern Michigan tend to test low in magnesium than in other parts of the state. Responsive crops include cauliflower, celery, muskmelons, potatoes, peas and sweet corn.

Organic Soils: High calcium levels in organic soils contribute to magnesium deficiency in responsive crops. Apply supplemental Mg on soils having a Mg soil test less than 150 lb/A.

CALCIUM (Ca): Disorders such as blossom-end rot in peppers and tomatoes, black heart in celery, and internal tip burn of cabbage and lettuce are attributed to calcium deficiency. These disorders often occur on soils high in calcium. They are more related to environmental factors that influence calcium uptake and movement within the plant than to low calcium levels in the soil. Calcium deficiency frequently is preceded by a period of moisture stress within the plant. Maintaining a very high soil potassium level also can contribute to calcium-related disorders. Having all of the nitrogen supplied to the root in the ammonium form contributes to calcium-related disorders. However this situation rarely occurs in a natural soil system. Because ammonium nitrogen is converted readily to the nitrate form, the form of nitrogen has minimal effect on calcium uptake by vegetables in field soils.

Mineral Soils: Well-limed soils contain high levels of available calcium. Even soils needing lime to neutralize excess acidity generally contain sufficient soluble calcium for good plant growth. Poor growth of plants on acid soils is usually due to excess soluble manganese, iron or aluminum rather than calcium deficiency. Available (exchangeable) calcium levels are related directly to the clay content of a soil. Thus, the lowest available calcium levels occur in sandy soils. Vegetable crops grown on sandy soils having a calcium soil test of less than 500 lb/A may benefit from applying supplemental calcium. Band applications, either prior to planting or by sidedressing, or foliar application are more effective than broadcast applications.

Organic Soils: Organic soils contain high levels of exchangeable and water-soluble calcium.

SULFUR (S): Sulfur is an essential nutrient found in plants in about the same concentration as phosphorus. Sulfur deficiency may be expected in intensive cropping systems, such as vegetable production, as the result of increased use of fertilizers low in sulfur and from the cleanup of industrial smokestacks which were a source of sulfur. However, field studies with a number of responsive crops on several potentially sulfur-deficient sites across Michigan have not shown any benefit from sulfur application. Even though the surface soils on these sites tested low, the subsurface soils supplied more than adequate quantities of sulfur to meet plant needs.

Sulfur deficiency in vegetable crops is most likely to occur on light-colored sandy soils.

Micronutrients for Mineral and Organic Soils

Micronutrient recommendations are based on a soil test, soil pH and crop response. Many vegetables benefit from the application of appropriate micronutrients if conditions and a soil test indicate potential need. Table 3 lists many vegetables grown in Michigan and how they respond to the key essential micronutrients. The recommended rates given in the respective tables (Tables 4 to 7) for the various micronutrients are for the highly responsive crops. Recommended rates for medium-responsive crops are proportionately lower. A brief discussion of each micronutrient follows.

MANGANESE (Mn): Manganese deficiency is probably the most common micronutrient deficiency in vegetable crops grown in Michigan. Crops most likely to show signs of manganese deficiency include lettuce, onions, potatoes, radishes, spinach and table beets.

Tables 4 and 5 provide guidelines for rates of manganese to apply in a band with starter fertilizer for responsive crops. Suitable carriers are manganese sulfate, chelated materials (mineral soils only) and finely ground manganous oxide. Neither granular manganous oxide nor any of the manganic forms are acceptable. Finely

Table 3. Relative response of selected vegetable crops to micronutrients. The crops listed respond, as indicated, to applications of the listed micronutrient when the soil test for that micronutrient is low.

Crop	Mn	B	Cu	Zn	Mo	Fe
Asparagus	low	low	low	low	low	medium
Bean, snap	high	low	low	high	medium	high
Broccoli	medium	high	medium		high	high
Cabbage	medium	medium	medium	low	medium	medium
Carrot	medium	medium	medium	low	low	
Cauliflower	medium	high	medium		high	high
Celery	medium	high	medium		low	
Corn, sweet	medium	low	medium	high	low	medium
Lettuce	high	medium	high	medium	high	
Onion	high	low	high	high	high	
Parsnip	medium	medium	medium		low	
Pea	high	low	low	low	medium	
Pepper	medium	low	low		medium	
Potato	high	low	low	medium	low	
Radish	high	medium	medium	medium	medium	
Rutabaga	medium	high	medium	low	low	
Spinach	high	medium	high	high	high	high
Table beet	high	high	high	medium	high	high
Tomato	medium	medium	high	medium	medium	high
Turnip	medium	high	medium		medium	

ground manganous oxide that has been regranulated is reasonably effective. Broadcast application of manganese is not recommended due to rapid fixation by soil when exposed to a large soil surface. Foliar application of manganese is effective if band application is not possible or does not completely alleviate the deficiency. Apply 1 to 2 pounds manganese per acre and reapply 7 to 10 days later if new growth shows signs of manganese deficiency.

Mineral Soils: Low levels of manganese are most likely in dark-colored surface soils in lake-bed or glacial outwash areas with a pH above 6.5. Since manganese availability decreases as soil pH increases, liming can induce a manganese deficiency on acid soils with marginal available manganese levels. Determining precise Mn availability in soil is difficult because its availability changes with oxidation state.
Manganese applied to soil is oxidized readily to relatively unavailable forms, especially when broadcast. Flooding or fumigation of soils temporarily increases Mn availability.

Organic Soils: Manganese deficiency is likely to occur on organic soils with a pH above 6.0. Very acid soils that have been limed usually show a greater need for supplemental Mn than do soils with a naturally high pH. Organic soils quickly fix manganese so broadcast applications are useless. Include manganese in the planting-time fertilizer placed near the seed or transplant. Apply manganese annually because there is very little carryover or residual buildup of available Mn.
Chelated forms of Mn are not effective in organic soils and in soils high in iron. The chelate increases the availability of iron, resulting in increased iron uptake which accentuates manganese deficiency.

BORON (B): Boron recommendations are based on crop response and soil pH. Three to 4 pounds of boron per acre is suggested for broccoli, cauliflower, celery, table beets, turnips and rutabagas. Vegetables with a medium level of responsiveness to boron (see Table 3) generally benefit from 1 to 2 pounds of boron per acre.

Table 4. Manganese recommendations (band applied) for responsive crops grown on mineral soils.

Soil Test	Soil pH						
	6.2	6.4	6.6	6.8	7.0	7.2	7.4
ppm				---------- lb Mn/acre ----------			
2	2	3	4	5	7	8	9
4	1	2	3	5	6	7	8
8	0	1	2	3	5	6	7
12	0	0	1	2	3	4	6
16	0	0	0	1	2	3	4
20	0	0	0	0	0	2	3
24	0	0	0	0	0	0	1

[1]Recommendations are calculated from the following equation and rounded to the nearest pound:

XMn = -36 + (6.2 x pH) - (0.35 x ST)

where: XMn = lb Mn/acre
pH = Soil pH
ST = Mn soil test in ppm

Table 5. Manganese fertilizer recommendations (band applied) for responsive crops grown on organic soils.

Soil Test	Soil pH						
	5.8	6.0	6.2	6.4	6.6	6.8	7.0
ppm				---------- lb Mn/acre ----------			
2	2	4	5	7	9	10	12
4	1	3	5	6	8	10	11
8	0	1	3	5	7	8	10
12	0	0	2	4	6	7	9
16	0	0	1	3	4	6	8
20	0	0	0	1	3	5	6
24	0	0	0	0	2	4	5
28	0	0	0	0	1	2	4
32	0	0	0	0	0	1	3
36	0	0	0	0	0	0	1

[1]Recommendations are calculated from the following equation and rounded to the nearest pound:

XMn = -46 + (8.38 x pH) - (0.31 x ST)

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

Mineral and Organic Soils: Plant-available boron occurs as a neutral compound or a negatively charged ion both of which are subject to leaching. Because boron does not accumulate in soils, especially sandy and organic soils, annual applications are necessary on these soils when growing responsive crops. Boron deficiency is most likely to occur on sandy loams, loamy sands, sand and organic soils. On the fine-textured soils, boron does not leach as readily, so required rates will be lower. The availability of boron decreases as soil pH increases. Therefore, the rates recommended are higher on the high pH soils. For responsive vegetable crops boron is recommended (in pounds per acre) according to the equation: 0.35 + (0.5 x pH).

Table 6. Zinc recommendations (band applied) for responsive crops grown on mineral and organic soils.[1]

Soil Test	Soil pH 6.7	7.0	7.3	7.6
ppm	lb Zn/acre			
1	1	3	4	6
2	1	2	4	5
4	0	1	3	4
6	0	0	2	4
8	0	0	1	3
10	0	0	0	2
12	0	0	0	1

[1]When chelates are used, these rates may be divided by 5. Recommendations are calculated from the following equation and rounded to the nearest pound:

$$XZn = -32 + (5.0 \times pH) - (0.4 \times ST)$$

where: XZn = lb Zn/acre
pH = Soil pH
ST = Zn soil test in ppm

For medium and low responsive vegetable crops, the boron recommendation is one-half (0.5) and one-tenth (0.1) of that for highly responsive crops. Never apply boron for beans, cucumbers and peas as they are subject to boron injury. Applying higher than recommended rates leaves the possibility of significant residual B carryover which could injure sensitive crops. This is most likely to occur following a dry fall and winter.

ZINC (Zn): Onions and sweet corn are the vegetable crops most responsive to zinc.

Extractable (0.1 N HCl) zinc coupled with soil pH is a very good indicator of zinc availability to plants. Zinc availability decreases as pH increases; therefore, more zinc is recommended at higher pH levels for a given zinc soil test level.

Recommended rates in Table 6 are for inorganic salts of zinc. Organic salts (chelates) are more effective and can be used at one-fifth the rates given. Granular forms of zinc oxide are not effective. However, finely ground zinc oxide that has been regranulated is 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. Retest the soil after applying zinc for 3 or 4 years. Foliar sprays of 0.5 pound zinc per acre as zinc sulfate effectively correct zinc deficiencies of growing plants.

Mineral Soils: Zinc deficiency is most common in responsive crops grown on the alkaline lake-bed soils of eastern Michigan. Other soils with a pH above 7.0 also may have low levels of available zinc. Zinc deficiency is often seen in crops growing on spoil banks and over tile lines where calcareous subsoil is exposed, or on soils testing high in available phosphorus.

Organic Soils: Zinc deficiency is most likely to occur on nearly neutral or alkaline organic soils.

COPPER (Cu): Lettuce, onions, spinach and table beets are the vegetable crops most responsive to copper. Recommended rates of copper for crops grown on organic soils are given in Table 7.

Mineral Soils: The mineral soils of Michigan contain adequate copper for growing vegetables.

Organic Soils: Organic soils are naturally low in copper. Copper applied to organic soils is not leached easily and contributes to a buildup of available soil Cu. Organic soils that have been in crop production for 10 or more years usually contain adequate available copper. Usually no further copper fertilization is needed once a total of 20 to 25 pounds per acre is applied for low- or medium-responsive crops, and 40 pounds per acre for highly responsive crops, or if the soil test exceeds 20 ppm. Copper sulfate or oxide are the forms most commonly used.

MOLYBDENUM (Mo): Molybdenum deficiency has been noted on cauliflower grown on mineral soils and on cauliflower, lettuce, spinach, cabbage and onions grown on organic soils. The need for

Table 7. Copper recommendations for crops grown on organic soils.

Soil Test	Crop Response		
	Low	Medium	High
ppm	-------- lb Cu/acre --------		
1	3	4	6
4	3	4	5
8	2	3	4
12	1	2	3
16	1	2	2
20	1	1	2
24	0	1	1

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

High Response crops $XCu = 6 - (0.22 \times ST)$
Medium Response crops $XCu = (6 - (0.22 \times ST)) \times 0.75$
Low Response crops $XCu = (6 - (0.22 \times ST)) \times 0.50$

where: XCu = lb Cu/acre
ST = Cu soil test in ppm

molybdenum is most acute in soils with a pH below 5.5. Soils with a high iron content also have a greater potential for needing supplemental molybdenum.

Foliar application is the most effective way to supply molybdenum to plants. Spray 2 ounces of sodium molybdate per acre in at least 30 gallons of water. Using a nonionic surfactant helps wet the leaves and enhances the absorption of molybdenum by the leaves. For sensitive crops, such as cauliflower, and/or sensitive varieties, apply every two weeks. Treating the seed with 0.5 ounce of sodium molybdate per acre is suggested for improving the Mo status of the developing seedling. Even with seed treatment one or more foliar applications may be necessary.

Foliar Nutrient Applications

Foliar application can be an effective way to meet the micronutrient needs of vegetable crops, especially when a fertilizer program or the growth stage of the crop does not allow the soil application of needed micronutrients. For responsive crops foliar sprays of manganese and molybdenum are essential supplements, even when these nutrients are applied to the soil. Recommended rates for foliar application of micronutrients using inorganic carriers are given in Table 8. Chelate carriers can be used, but be sure to use the labeled rate since applying too much can cause foliar injury. Some fungicides contain sufficient amounts of zinc, manganese and/or copper to partially or completely meet the need for these nutrients, especially if the deficiency is marginal. Foliar sprays of magnesium and calcium can benefit responsive crops under certain soil and/or environmental conditions (see the sections on Magnesium and Calcium for more information).

With a good soil fertility program, foliar sprays of nitrogen, phosphorus and potassium do not improve crop quality and yields. The amounts of these nutrients that can be supplied in foliar sprays are small compared with the amounts used by the vegetable crops. However, foliar application of nitrogen at 4 to 5 pounds per acre to vegetables can help vegetable crops through stress periods, especially saturated soil conditions when poor aeration may limit root activity and nutrient uptake.

Using Animal Manures and Other Organic Materials

Manures, cull vegetable produce and other organic materials (e.g., sewage sludge, septage, food processing wastes, fermentation wastes, leaves, etc.) can be a valuable source of essential plant nutrients and organic matter. The nutrient content of many of these materials varies greatly, depending on the source. Therefore, the use of average nutrient contents can be very misleading in calculating nutrient credits. Have the material being considered for land application analyzed by a reliable testing laboratory. The analyses should at least include: percent dry matter, ammonium-nitrogen, and total nitrogen, phosphorus and potassium. When used together with the

Table 8. Recommended rates of secondary and micro-nutrients for foliar application.

Nutrient	Lb. of element per acre	Common Sources[1]	% Element
Calcium	1-2	Calcium nitrate	19
Magnesium	1-2	Magnesium sulfate	9
Boron	0.1-0.3	Soluble sodium borate	20
		Boric acid	17
Copper	0.5-1.0	Basic copper sulfate	13-25
Manganese	1.0-2.0	Soluble manganese sulfate	24
Molybdenum	0.06	Sodium molybdate (2 ounces)	39
Zinc	0.3-0.7	Zinc sulfate	36
Iron	1.0-2.0	Ferrous sulfate	20-31

[1] Chelated materials can be used at labeled rates.
Use a minimum of 30 gallons of water per acre.

application rate, the analyses will let you determine the amount of nutrients being applied and the nutrient credits to take. Adjust the amount of fertilizer to be applied accordingly. Wise use of nutrient resources can provide economic benefits while maintaining the quality of the soil and water environment.

Recycling nutrients and organic matter, contained in organic waste materials, back to crop land is highly desirable. However, some hazards may be encountered when organic materials are applied to the soil-plant system for crop production if good management practices are not followed. These can include excessive loadings of nutrients, additions of trace elements and trace organic chemicals, pathogens, soil physical problems, odors and diseases. The MSU Department of Crop and Soil Sciences can help evaluate the benefits and/or risks of applying a specific organic material to crop land or contact your local county Cooperative Extension Service office.

A number of management practices are suggested for producers using animal manures and other organic materials for land application.

First, sample and test every one to two years those fields that are used for vegetable production and receiving frequent applications of manure and/or organic materials. Use the soil test results to determine the nutrient needs for the crops to be grown and to monitor the nutrient status of the soil system.

Second, have the manure or organic material being applied analyzed for its nutrient content. Subtract the quantity of nutrients supplied in the manure or organic material from the nutrient recommendations to determine the need for additional fertilizer nutrients.

Third, do not exceed the recommended nitrogen rate with the amount of available nitrogen in the manure or organic material plus the fertilizer used.

Fourth, follow soil and water conservation practices to reduce the risk of nutrients entering surface water. For practices used to control runoff and erosion for a particular site, consider factors such as type of manure or organic material being applied, surface residue or vegetative conditions, slope, soil type, and proximity to surface water. Incorporate as soon as possible applied materials to minimize odor problems and to prevent nutrient loss by volatilization or runoff.

Fifth, keeping records of material analyses, soil test reports, and rates of manure or organic material and fertilizer application for individual fields helps identify land areas needed for effectively utilizing the nutrients from all sources. Good record keeping demonstrates good management and may be helpful if management practices are challenged.

Suggested Fertilizer Management and Recommendations for Vegetable Crops

Most vegetable crops require relatively high levels of fertility for good yields and satisfactory quality. Recommended nutrient rates are designed to meet the needs of the growing vegetable crops and gradually build up low soil test levels over five years. Once optimum soil test levels are attained, develop a maintenance fertilization program by applying the nutrients removed by the vegetable crop. Table 1 lists the amounts of nitrogen (N), phosphate (P_2O_5) and potash (K_2O) removed by typical yields of some Michigan vegetable crops.

Supplemental nutrients may be applied for vegetable production in a combination of methods; broadcast and incorporated either before or after plowing, placed in bands near the seed or transplants, included in transplant water, sidedressed or topdressed, or applied to the foliage. Cover crops can cycle nutrients effectively. On sandy soils, use cover crops to take up residual nitrogen and soluble potassium to prevent leaching into groundwater and to prevent wind erosion. Apply only enough nutrients to a cover crop to ensure good establishment and reasonable growth.

Applying nitrogen as close as possible to the time of maximum crop demand increases the efficiency of use and minimizes the potential for leaching loss. Apply preplant nitrogen as close to planting time as possible. Include some nitrogen in the starter fertilizer and sidedress the majority of the nitrogen required prior to peak demand. Nitrogen recommendations are given in Table 9 for vegetable crops grown on mineral soils. For crops seeded or transplanted when the soil is still rather cool, band a high phosphorus fertilizer 1 inch to the side and 1 to 2 inches below the seed, unless the P soil test is higher than 180 lb/acre. Banding decreases phosphorus fixation and stimulates early growth. For soils testing higher than 180 lb/acre in available phosphorus, including phosphorus in the starter fertilizer usually does not improve growth, quality or yield. Phosphorus recommendations are given in Table 10.

Suggested Fertilizer Management on Mineral Soils

A good fertilizer program based on soil test information coupled with other good management practices, such as cover crops used for wind erosion control, will provide good yields of high-quality vegetables. General nitrogen recommendations are given in Table 9. Amounts of phosphate (P_2O_5) and potash (K_2O) recommended

Table 9. Nitrogen recommendations for vegetable crops grown on mineral soils.

	lb N/A		lb N/A		lb N/A
Asparagus, old	50	Greens, leafy	100	Radish	50
new	80	Horseradish	100	Rhubarb	100
crowns	80	Lettuce, head	120	Rutabaga	100
Bean, lima/snap	40	Lettuce, leaf	80	Spinach	100
Broccoli	140	Market garden	140	Squash	80
Brussels sprout	140	Muskmelon	100	Sweet corn	120
Cabbage	140	Onions, dry bulb	180	Sweet potato	60
Carrot	100	green	140	Swiss Chard	100
Cauliflower	140	Parsley	100	Table Beet	100
Celery	180	Parsnip	100	Tomato, fresh	120
Cucumber -slicers	80	Pea	40	processing	80
-pickling	60	Pepper	100		
Eggplant	100	Potato	180	Turnip	80
Endive	100	Pumpkin	80	Watermelon	90

for the various vegetable crops, based on soil tests, are given in Tables 10, 11 and 12.

Finding a nutrient recommendation in the tables is a two-step process. First, find the crop of interest in the upper part of the table. Second, go vertically downward in that column into the lower part of the table. In the left hand column of the lower part of the table find the soil test value which comes closest to your soil test value; then follow this line horizontally across to the column containing the crop of interest. The number given where these lines intersect is the phosphate or potash recommendation.

The following are general suggestions for fertilizer management programs for various vegetable crops. The actual amounts of phosphate and potash to apply depends on soil test levels.

Asparagus (crown production): Adjust the pH to 6.8 before planting, because aspara-

Table 10. Phosphate (P_2O_5) recommendations for vegetable crops grown on mineral soils.

Crop	Yield ton/A	Crop	Yield ton/A	Crop	Yield ton/A	Crop	Yield ton/A
Asparagus	(2)	Carrot	(15)	Asparagus	(1)	Celery	(30)
old beds		Endive	(15)	new beds		Onions	(20)
Lima bean	(2)	Lettuce	(20)	Broccoli	(4)	Tomato	(30)
Pea	(3)	Parsnip	(13)	Brussels spt	(5)	Market garden	
Snap bean	(4)	Pumpkins	(20)	Cabbage	(20)		
Turnip	(15)	Radish	(4)	Cauliflower	(8)		
Greens	(6)	Rutabaga	(18)	Cucumber	(15)		
(leafy)		Spinach	(6)	Eggplant	(10)		
		Sweet corn	(10)	Horseradish	(4)		
		Sw potato	(10)	Muskmelon	(9)		
		Squash	(15)	Pepper	(10)		
				Rhubarb	(15)		
				Swiss chard	(8)		
				Table beet	(13)		
				Watermelon	(11)		

Soil test lb P/A	Phosphate recommendation, lb P_2O_5/A			
30	110	150	190	230
50	90	130	160	200
70	60	100	140	180
90	40	80	110	150
110	10	50	90	130
130	0	30	60	100
150	0	0	40	80
170	0	0	10	50
190	0	0	0	30
210	0	0	0	0

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

$XP1 = 150 - 1.25 \times ST$

$XP2 = 188 - 1.25 \times ST$

$XP3 = 225 - 1.25 \times ST$

$XP4 = 263 - 1.25 \times ST$

where: XP1 = lb P_2O_5 /acre in column 1
XP2 = lb P_2O_5 /acre in column 2
XP3 = lb P_2O_5 /acre in column 3
XP4 = lb P_2O_5 /acre in column 4
ST = soil test in lb P/acre

Table 11. Potash recommendations for vegetable crops grown on sandy loam and loamy sand soils.

Crop	Yield ton/A	Crop	Yield ton/A	Crop	Yield ton/A	Crop	Yield ton/A
Asparagus old beds	(2)	Asparagus new beds	(1)	Cabbage,fr.	(20)	Broccoli	(4)
Bean, lima	(2)	Carrot,fr.	(15)	Cabbage,pr.	(35)	Brussels spt.	(5)
Bean, snap	(4)	Carrot,pr.	(35)	Cucumber,hand	(15)	Cauliflower	(8)
Pea	(3)	Endive	(15)	Cucumber,mech	(9)	Celery	(30)
Pumpkin	(20)	Lettuce,head	(20)	Eggplant	(10)	Tomato	(30)
Radish	(4)	Lettuce,leaf	(13)	Horseradish	(4)	Market garden	
Squash	(15)	Onion, green	(10)	Muskmelon	(9)		
Turnip	(15)	Sweet corn	(10)	Onion, bulb	(20)		
Greens (leafy)	(6)			Parsnip	(13)		
				Pepper	(10)		
				Rhubarb	(15)		
				Rutabaga	(18)		
				Spinach	(6)		
				Sweet potato	(10)		
				Swiss Chard	(8)		
				Table beets	(13)		
				Watermelon	(11)		

Soil Test lb K/A	Potash recommendation, lb K_2O/acre			
75	160	200	250	290
100	130	180	220	270
125	110	160	200	250
150	90	130	180	220
175	70	110	160	200
200	40	90	130	180
225	20	70	110	160
250	0	40	90	130
275	0	20	70	110
300		0	40	90
325			20	70
350			0	40
375				20
400				0

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

XK1 = 225 - .90 x ST where: XK1 = lb K_2O/acre for column 1
XK2 = 270 - .90 x ST XK2 = lb K_2O/acre for column 2
XK3 = 315 - .90 x ST XK3 = lb K_2O/acre for column 3
XK4 = 360 - .90 x ST XK4 = lb K_2O/acre for column 4
ST = soil test in lb K/acre

Table 12. Potash recommendations for vegetable crops grown on loam, clay loam, clay and similar type soils.

Crop	Yield ton/A	Crop	Yield ton/A	Crop	Yield ton/A	Crop	Yield ton/A
Asparagus old beds	(2)	Asparagus new beds	(1)	Cabbage, fr.	(20)	Broccoli	(4)
Bean, lima	(2)	Carrot, fr.	(15)	Cabbage, pr.	(35)	Brussels Spt.	(5)
Bean, snap	(4)	Carrot, pr.	(35)	Cucumber,hand	(15)	Cauliflower	(8)
Pea	(3)	Endive	(15)	Cucumber,mech	(9)	Celery	(30)
Pumpkin	(20)	Lettuce,head	(20)	Eggplant	(10)	Tomato	(30)
Radish	(4)	Lettuce,leaf	(13)	Horseradish	(4)	Market garden	
Squash	(15)	Sweet corn	(10)	Muskmelon	(9)		
Turnip	(15)	Onion, green	(10)	Onion, bulb	(20)		
Greens (leafy)	(6)			Parsnip	(13)		
				Pepper	(10)		
				Rhubarb	(15)		
				Rutabaga	(18)		
				Spinach	(6)		
				Sweet potato	(10)		
				Swiss Chard	(8)		
				Table beets	(13)		
				Watermelon	(11)		

Soil Test lb K/A	Potash recommendation, lb K_2O/acre			
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	20	70
325			0	50
350			0	20
375				0

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

$XK1 = 225 - 1.0 \times ST$
$XK2 = 275 - 1.0 \times ST$
$XK3 = 325 - 1.0 \times ST$
$XK4 = 375 - 1.0 \times ST$

where: XK1 = lb K_2O/acre for column 1
XK2 = lb K_2O/acre for column 2
XK3 = lb K_2O/acre for column 3
XK4 = lb K_2O/acre for column 4
ST = soil test in lb K/acre

gus does not grow well on soils below pH 6.0. Before seeding, disc in 50 pounds of nitrogen and the recommended amounts of phosphate and potash. When asparagus plants are about 6 inches high, sidedress with 50 pounds of nitrogen per acre.

Asparagus (new planting): The year before planting, test the soil and apply lime to attain a pH of 6.8. In the spring broadcast 50 pounds of nitrogen per acre and the recommended amounts of phosphate and potash and plow 12 inches deep. It is important to get adequate phosphorus below the crowns before planting. Apply 30 pounds of phosphate per acre in the furrow at the time of setting crowns. After the fern is 6 inches high, sidedress with 50 pounds of nitrogen per acre.

Asparagus (established plantings): Annual applications of nitrogen should be split between pre- and postharvest. The total amount of nitrogen should not exceed 80 pounds per acre. Every second year, apply potassium at 60 pounds of K_2O per acre or the rate indicated by a soil test. Applying phosphorus after establishment is not beneficial.

Lima Beans, Snap Beans: Row fertilizer, placed 2 inches to the side and 2 inches below the seed, may include 30 pounds of nitrogen, all the required phosphate and 40 pounds of potash. Most of the required potash is best plowed down or broadcast and incorporated prior to planting. Apply manganese either with the row fertilizer or as a foliar spray if a soil test or past cropping history indicates a potential manganese deficiency.

Carrots, Horseradish, Parsnip: Plow down 50 pounds of nitrogen and the required phosphate and potash and include 1 pound of boron per acre. Four to six weeks after seedling emergence topdress with 50 pounds of nitrogen per acre. On soils with a pH above 6.5, carrots may benefit from foliar application of 2 pounds of manganese per acre.

Table Beets, Rutabagas: At seeding, band 2 inches to the side and 2 inches below the seed 30 pounds of nitrogen, all the phosphate and 40 pounds of potash. Before planting, broadcast and incorporate the potash required above this amount. On sandy soils and on soils with a pH above 6.5, include 3 to 4 pounds of boron per acre in the fertilizer program. Topdress with 50 pounds of nitrogen per acre after the plants are well established.

Broccoli, Cabbage, Brussels Sprouts, Cauliflower: Incorporate after plowing 50 pounds of nitrogen per acre plus the potash indicated by a soil test. Include in the broadcast fertilizer the phosphate required in excess of that included in the starter solution. Include sufficient boron in the broadcast fertilizer to supply 3 to 4 pounds 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 three weeks after transplanting and again (except cabbage) three weeks later. Foliar application of sodium molybdate (2 ounces per acre) on a two-week schedule is essential for some cauliflower varieties.

Sweet Corn: Plow down or incorporate after plowing 50 pounds of nitrogen per acre and most of the required potash. At seeding, band 30 pounds of nitrogen, all the required phosphate and 40 pounds of potash per acre placed 2 inches to the side and 2 inches below the seed. Sidedress 40 to 50 pounds of nitrogen when the corn is 6 to 12 inches high.

Cucumbers: For slicing cucumbers and hand-picked pickling cucumbers, band a starter fertilizer 2 inches to the side and 2 inches below the seed that contains 30 pounds of nitrogen, all the required phosphorus and up to 40 pounds of potassium per acre. If the soil pH is above 6.7 and/or a soil test shows a need for manganese, include in the starter fertilizer sufficient manganese to supply 4 pounds per acre or the amount indicated by a soil test. Broadcast and incorporate most of the potash before planting. Topdress 30 to 40 pounds of nitrogen per acre just before tip-over. Nitrogen also can be applied effectively 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 and intended for mechanical harvest, broadcast and incorporate 30 pounds of nitrogen and all the required phosphate and potash fertilizer before planting, unless planting-time fertilizer will be applied. Topdress 30 pounds of nitrogen per acre just before tip-over and irrigate in, if possible. Broadcasting and incorporating all the nitrogen in a slow-release form before seeding is effective.

If a soil test or past history indicates a need for manganese, make a foliar application of 2 pounds of manganese per acre.

Muskmelons, Watermelons: Nearly all melons are grown on plastic mulch, so apply required nutrients to the soil before laying the plastic. Broadcast and incorporate or apply in bands, under where the plastic will be laid, all of the required nitrogen, phosphate and potash. The total suggested nitrogen rate is 75 to 90 pounds per acre. Nitrogen applied through trickle irrigation is used quite efficiently, so the preplant nitrogen rate can be reduced. Melons respond quite well to magnesium. If the soil-test magnesium level is marginal (below 100 pounds per acre) broadcast and incorporate 50 pounds of actual magnesium per acre or apply magnesium (2 pounds per acre) to the foliage every two to three weeks.

Peas: Broadcast and incorporate 40 pounds of nitrogen per acre plus the amounts of phosphate and potash recommended based on a soil test.

Peppers: Broadcast and incorporate 40 pounds of nitrogen per acre, and all the required phosphate and potash minus that applied in the transplanting solution. Use a high-phosphorus starter solution when setting the transplants. Sidedress with 30 to 40 pounds of nitrogen three to four weeks after transplanting and again after another four weeks or after the first harvest. A nitrate soil test can help determine whether or not to sidedress with additional nitrogen. Supplemental nitrogen can be effectively supplied through the irrigation (10 to 15 pounds per application). This is a very efficient way to supply nitrogen on very sandy soils.

Radishes, Turnips: Broadcast and incorporate 50 pounds of nitrogen per acre plus the recommended amounts of phosphorus and potassium. If the soil pH is above 6.7, include 1 pound of boron per acre for radishes and 2 pounds for turnips. Radishes are highly responsive to manganese. If a soil test or past cropping history shows manganese is needed, apply 2 pounds of manganese per acre (8 pounds of manganese sulfate) in a foliar spray 1 to 2 weeks after emergence.

Tomatoes: The appropriate amount of total nitrogen to apply for tomatoes depends on many factors. Direct-seeded tomatoes generally require less nitrogen (about 25 pounds per acre less) than transplanted tomatoes. When tomatoes follow soybeans, reduce the nitrogen rate by 30 pounds per acre. Avoid large single nitrogen applications on sandy soils to minimize the potential for leaching loss. Tomato yields depend on many management factors. When yields over 30 tons per acre are expected, increase the phosphate (P_2O_5) and potash (K_2O) rates by 5 and 30 pounds per acre, respectively, for each additional 5 tons of expected yield. Set realistic yield goals for the management system (the average of the three highest yields achieved over the last five years) to prevent unnecessary expenditures.

Processing: For machine-harvest processing tomatoes, 75 pounds of nitrogen per acre is usually adequate. However, an additional 25 pounds may be beneficial when anticipating high yields or when adverse weather conditions result in the loss of nitrogen by leaching or denitrification. Broadcast and incorporate 50 pounds of nitrogen plus the recommended amounts of phosphate (minus that in the transplant solution) and potash. Apply a solution high in phosphorus when setting transplants. Sidedress 25 pounds of nitrogen four weeks after transplanting. Additional nitrogen can be applied through the irrigation system (10 to 15 pounds nitrogen per application).

Fresh Market: Fresh market tomatoes may require up to 120 pounds of nitrogen per acre. Broadcast and incorporate 60 pounds of nitrogen plus the required phosphate and potash. Sidedress 30 pounds of nitrogen three weeks after transplanting and again three weeks later. Determinant tomato varieties produce good yields in response to high nitrogen rates without producing excessive vegetative growth. With indeterminate varieties, high nitrogen rates tend to stimulate vegetative growth and delay fruit set and maturity. For the indeterminant types, use two to three sidedress applications of 25 pounds of nitrogen per acre.

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 (mixture of crops): Plow down or incorporate 50 pounds of nitrogen per acre plus the recommended amounts of phosphate and potash according to a soil test. 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 30 pounds of nitrogen and 40 pounds of potassium. Make one or two sidedress applications of 30 to 40 pounds nitrogen during the growing season, depending on the vegetable crop being grown. Suggested total nitrogen rates are given in Table 9. For vegetables not listed, topdress additional nitrogen when the crop begins to look light green. More nitrogen generally is needed for the green leafy vegetables, tomatoes, peppers, sweet corn and rhubarb than for beans, peas, cucumbers, melons, root crops or asparagus. Avoid overusing nitrogen to minimize the accumulation of nitrates in the vegetables and to minimize the potential of leaching loss.

Use a high-phosphorus starter solution when setting vegetable transplants, unless the phosphorus soil test is above 180 lb/acre. Starter solutions tend to stimulate growth of leafy vegetable crops when soils are cold and air temperatures are low. Avoid overfertilizing; it may cause salt injury.

Suggested Fertilizer Management on Organic Soils

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

Many of the warm-season vegetable crops will grow on organic soils, but they are not recommended for commercial production on organic soils because of potential problems. Organic soils generally occur in low areas and are more subject to late spring and early fall frosts. The release of nitrogen from the organic matter and warm soil temperatures stimulate vegetative growth which may delay fruit set and maturity.

Nitrogen rates and fertilizer placement guidelines are given for each crop. Recommended nitrogen rates for vegetable crops grown on organic soils are given in Table 13. Apply phosphorus and potassium at rates given in Tables 14 and 15. Use soil test data and crop responses to determine micronutrient needs.

Broccoli, Cabbage, Cauliflower: Broadcast and incorporate 50 pounds of nitrogen and all of the phosphate and potash before 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 after transplanting and again (except cabbage) four weeks later. Some varieties of cauliflower benefit from foliar sprays of sodium molybdate (2 to 4 ounces per acre) on a two-week schedule.

Table 13. Nitrogen recommendations for vegetable crops grown on organic soils.

	lb N/acre		lb N/acre		lb N/acre
Beans	40	Endive	80	Parsnip	80
Broccoli	120	Greens, leafy	80	Potato	100
Brussels sprout	120	Horseradish	80	Radish	40
Cabbage	90	Lettuce, head	100	Carrot	60
Lettuce, leaf	70	Rhubarb	80	Rutabaga	40
Cauliflower	120	Mint	80	Spinach	80
Celery	150	Onion, bulb	150	Table Beets	40
Chard,Swiss	40	Onion, green	110	Turnip	40
Corn, sweet	80	Parsley	80		

Table 14. Phosphate (P_2O_5) recommendations for vegetable crops grown on organic soils.

	Crop	Yield ton/A	Crop	Yield ton/A	Crop	Yield ton/A
	Mint		Brussels sprout	(5)	Broccoli	(4)
	Snap bean	(4)	Cabbage, fr.	(20)	Cauliflower	(8)
	Radish	(4)	Carrot, fr.	(15)	Celery	(30)
	Sweet corn	(10)	Cucumber, hand	(15)	Market garden	
	Rutabaga	(18)	Endive	(15)	Onions	(20)
	Turnip	(15)	Horseradish	(4)	Potato	(20)
	Greens (leafy)	(6)	Lettuce, head	(20)		
			Parsnip	(13)		
			Spinach	(6)		
			Swiss Chard	(8)		
			Table beet	(13)		
			Grass Sod			
Soil test lb P/A			Phosphate recommendation, lb P_2O_5/acre			
30	120		190		230	
50	100		160		200	
70	70		140		180	
90	50		110		150	
110	20		90		130	
130	0		60		100	
150	0		40		80	
170	0		10		50	
190	0		0		30	
210	0		0		0	

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

$XP1 = 160 - 1.25 \times ST$
$XP2 = 225 - 1.25 \times ST$
$XP3 = 263 - 1.25 \times ST$

XP1 = lb P_2O_5 /acre for column 1
XP2 = lb P_2O_5 /acre for column 2
XP3 = lb P_2O_5 /acre for column 3
ST = soil test in lb P/acre

Table 15. Potash (K_2O) recommendations for vegetable crops grown on organic soils.

Crop	Yield ton/A	Crop	Yield ton/A	Crop	Yield ton/A
Snap bean	(4)	Asparagus	(2)	Broccoli	(4)
Sweet corn	(10)	Cabbage, fr.	(20)	Brussels Spt.	(5)
Turnip	(15)	Carrot, fr.	(15)	Cauliflower	(8)
Radish	(4)	Cucumber	(15)	Market garden	
Grass sod		Endive	(15)	Onion, bulb	(20)
Greens	(6)	Horseradish	(4)	Onion, green	(10)
(leafy)		Lettuce,head	(20)	Potato	(20)
.		Mint		Rutabaga	(18)
.		Parsnip	(13)	Spinach	(6)
.		.		Swiss Chard	(8)
.		.		Table beet	(13)

Soil Test lb K/A	Potash Recommendation, lb K_2O /acre		
150	200	260	360
225	140	200	300
300	80	140	240
375	20	80	180
450	0	20	120
525	0	0	60
600		0	0

Recommendation are calculated from the following equations and rounded to the nearest 10 pounds:

$XK1 = 320 - 0.8 \times ST$
$XK2 = 380 - 0.8 \times ST$
$XK3 = 480 - 0.8 \times ST$
$XK4 = 570 - 0.8 \times ST$

where: XK1 = lb K_2O /acre for column 1
XK2 = lb K_2O /acre for column 2
XK3 = lb K_2O /acre for column 3
XK4 = lb K_2O /acre for Celery
ST = soil test in lb K/acre

Carrots, Parsnips: Plow down or incorporate at least 6 inches deep 60 pounds of nitrogen per acre and all the recommended phosphate and potash. Include sufficient boron in the broadcast fertilizer to supply 1 pound per acre. If a soil test indicates the need for copper, include sufficient copper sulfate to supply 3 to 4 pounds copper per acre.

An alternative program is to plow down a fertilizer high in potash that contains the needed boron and copper. Band the nitrogen and phosphate 3 inches to the side and 3 inches below the seed at seeding, but do not exceed 300 pounds of fertilizer per acre in rows 21 inches or more apart. Sidedress additional nitrogen if plant growth and color indicate a need. On well-drained, high-organic soils, use a total of 60 pounds of nitrogen per acre. On sandy mucks and marly muck soils, use a total of 80 to 100 pounds of nitrogen.

Additional manganese may be needed periodically during the growing season, especially if the soil pH is above 6.5. Foliar apply 2 pounds of actual manganese per acre as manganese sulfate. If boron is not included in the broadcast fertilizer, one or two foliar sprays of 0.3 pound of boron per acre is beneficial.

Celery: Broadcast and incorporate 50 pounds of nitrogen per acre plus the recommended amounts of phosphate (minus the amount to be band near the transplant row) and potash. Banding a high phosphorus fertilizer near the transplant row when the soil is cool (average soil temperature at 4 inches is below 55° F) stimulates root development and plant growth. If the phosphorus soil test is above 180 lb/acre, banding additional phosphate usually is not beneficial. Once the soil warms to 60° F, usually by May 15 to June 1, banding a high-phosphorus fertilizer is not beneficial unless the soil tests low to medium in phosphorus. Include sufficient boron in the broadcast, or band fertilizer to supply 3 to 4 pounds per acre.

Spray the foliage periodically with manganese (2 pounds per acre) if the soil pH is above 6.2 and/or past history or a soil test indicates a need for manganese.

Sidedress two to three times during the growing season with 40 to 50 pounds of nitrogen per acre per application. The number of applications depends on the season, drainage and type of muck. The color of the plant and plant tissue tests help determine the need for supplemental nitrogen. The highest rate of nitrogen uptake in celery occurs from six weeks after transplanting to harvest.

Certain celery varieties need magnesium applied as a foliar spray to prevent deficiency signs from appearing. Use magnesium sulfate (Epsom salts) at the rate of 10 pounds per acre every 10 days to two weeks. If this rate does not correct the magnesium-yellowing, increase the rate to 20 pounds. Foliar application of calcium frequently is needed to prevent black heart. Apply calcium nitrate at the rate of 15 pounds per acre, or calcium chloride at 10 pounds per acre. Directing the spray into the heart is most effective. If this is not possible, apply more frequently. Black heart is most likely to occur after environmental stress; such as high temperatures, or saturated soil (oxygen stress).

Lettuce (leaf and head), Spinach: Broadcast and incorporate after plowing the recommended rate of potash. Apply 40 pounds of nitrogen, all the required phosphate and 0.5 pound of boron in a band 1 inch to the side and 2 to 3 inches below the seed at planting time. If transplanting, place the fertilizer 2 inches to the side and 3 inches below the soil surface. Include manganese and copper in the banded fertilizer if a soil test indicates a need. On acid fibrous peats apply a foliar spray of 2 ounces of sodium molybdate after thinning or 2 to 3 weeks after transplanting. Sidedress with 60 pounds of nitrogen after thinning or 3 weeks after transplanting.

Onions, bulb: Broadcast and incorporate 60 pounds of nitrogen per acre and the recommended amount of potash. At seeding band 2 to 3 inches directly below the seed the fertilizer containing all the recommended phosphate plus some nitrogen and potash, and enough manganese to supply 4 pounds per acre or the amount indicated by a soil test. Depending on soil tests, copper and zinc may also need to be included in the banded fertilizer. Sidedress 80 to 90 pounds of nitrogen per acre in mid-June. Use a soil nitrate test as a guide in determining the appropriate rate of nitrogen to sidedress. On soils with a pH above 6.5, foliar application of 2 pounds of manganese per acre in early to mid-June and again two weeks later will be beneficial.

Peppermint, Spearmint: For row-mint, broadcast and incorporate 40 pounds of nitrogen per acre plus the recommended amounts of phosphate and potash before planting. In early June, topdress with 40 pounds of nitrogen. For meadow-mint, in the early spring before the crop emerges, drill in or broadcast the recommended amounts of phosphate and potash plus 30 pounds of nitrogen per acre. In early June topdress with 50 pounds of nitrogen per acre. 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 5 to 7 days.

If the pH is above 6.5, a foliar application of manganese may be required, depending on the soil test or past cropping history.

Potatoes: Plow down the recommended amount of potash. Include in the planting-time fertilizer, all the required phosphate plus 40 pounds of nitrogen and some potash, placed 2 inches to the side of the seedpiece. If a soil test indicates the need, include sufficient manganese to supply 4 pounds per acre or the recommended amount. Sidedress prior to or at hilling with 40 to 70 pounds of nitrogen. Use the lower rate on highly organic soils and the higher rate on sandy muck soils. Applying supplemental nitrogen through the irrigation system is effective (10 to 15 pounds per acre per application).

Foliar application of manganese (2 pounds per acre per application) may be beneficial during the growing season, especially if the pH is above 6.0.

Sweet Corn: Plant population goals should be 20,000 to

22,000 plants per acre. Broadcast and plow down the recommended amount of potash. At planting, band fertilizer containing all of the recommended phosphate plus 30 pounds of nitrogen and 40 pounds of potash per acre, 2 inches to the side and 2 inches below the seed. Include sufficient manganese and zinc to supply 4 and 2 pounds per acre, respectively, or the amounts indicated by a soil test. Sidedress with 50 pounds of nitrogen per acre when the corn is 6 to 12 inches high. On sandy muck soils increase the sidedress nitrogen rate by 20 pounds per acre.

Table Beets, Swiss Chard, Radishes, Turnips, Rutabagas: Broadcast and incorporate, before seeding, the recommended amounts of nitrogen, phosphate and potash. Include in the fertilizer: 1 pound of boron per acre for radishes, 2 pounds for turnips, rutabagas and Swiss chard, and 4 pounds for table beets. Use a soil test or past cropping history to determine the need for manganese. Foliar application of manganese is the most effective way to supply manganese to these crops. Spray 2 pounds of manganese per acre. More than one application may be needed when the pH is above 6.5, especially for radishes.

Grass Sod: Before seeding, broadcast and incorporate 30 pounds of nitrogen per acre plus the required amounts of phosphate and potash. After the grass is well established, topdress with 30 pounds of nitrogen per acre. The need for additional topdressings with nitrogen depends on the organic matter content of the soil and the amount of rain. Less nitrogen is required on high organic matter muck soils than on sandy or marginally organic soils. In general, apply 20 to 30 pounds of nitrogen per acre topdressed every 4 to 5 weeks during the growing season for a vigorous grass sod. Using frequent nitrogen applications at low rates minimizes the potential for nitrogen loss by leaching or denitrification.

Plant Tissue Analysis

Nutrient analysis of appropriate plant parts for each crop can help diagnose a plant growth problem during the season or in fine tuning long-term soil fertility management. Plants are the best indicator of whether or not they are able to take up adequate quantities of the essential nutrients. However, a low nutrient level in the plant does not always mean that there is an insufficient amount available in the soil. Other conditions, such as compact soil or poor drainage, may limit the root growth and nutrient uptake of plants.

Table 16 indicates the critical nutrient levels in the appropriate plant part of some vegetable crops. The appropriate plant part to sample varies with the crop and stage of growth. A more complete sampling guide is available from the Michigan State University Soil Testing Lab.

Table 16. General guidelines for sufficient nutrient levels in sampled plant tissue of some vegetable crops. (Adapted from Plant Analysis Handbook by Jones, Wolf and Mills, Micro-Macro Publishing, Inc.)[1]

Vegetable Crop	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
	%						ppm				
Asparagus	2.5	.25	1.5	.60	.25		40	5	40	25	20
Bean, snap	5.0	.35	2.3	1.50	.30		20	7	50	50	20
Broccoli	3.2	.30	2.0	1.00	.25	.30	30	5	70	25	35
Cabbage	3.6	.33	3.0	1.10	.40	.30	25	5	30	25	20
Carrot	2.1	.20	2.8	1.40	.30		30	5	50	60	25
Cauliflower	3.3	.33	2.6	2.00	.27		30	4	30	25	20
Celery	1.6	.30	7.5	2.20	.25		25	5	30	10	25
Cucumber	4.5	.34	3.9	1.40	.30	.40	25	4	30	50	25
Lettuce	3.8	.45	6.0	1.50	.36		25	7	50	25	25
Muskmelon	4.5	.30	4.0	2.3	.35	.25	25	7	50	50	20
Onion	4.5	.30	3.5	1.50	.25	.50	25	15	60	50	25
Pea	4.0	.30	2.0	1.20	.30		25	7	50	30	25
Pepper	4.0	.35	4.0	1.00	.30		25	6	60	50	20
Potato	3.0	.25	6.0	1.5	.70		40	7	40	30	30
Squash	4.0	.30	3.0	1.2	.30		25	10	50	50	20
Sweet corn	4.0	.60	3.5	0.5	20	.21	8	5	50	30	20
Tomato	4.0	.25	2.9	1.0	.40	.40	25	5	40	40	20

[1]Guidelines are for the youngest mature leaves, except celery which is for the youngest mature petioles. The values given are generally the critical values separating sufficient and deficient nutrient concentrations. The critical value may vary depending on the stage of growth when a sample is taken.

Reference Bulletins

For more information about fertilizing and testing soils, the following bulletins are available from county Cooperative Extension Service offices or from the Michigan State University Bulletin Office, 10 B Agriculture Hall, East Lansing, MI 48824-1039.

E-471 "Lime for Michigan Soils."

E-498 "Soil Sampling for Fertilizer and Lime Recommendations."

E-550A "Fertilizer Recommendations for Field Crops in Michigan."

E-896 "N-P-K Fertilizers."

E-933 "Fluid Fertilizers: Liquids and Suspensions."

E-1262 "Soil Management Units and Land Use Planning."

E-1566 "Facts About Lime: Answers to Common Questions."

E-1616 "Soil Sampling for No-Till and Conservation Tillage Crops."

E-2058 "Understanding MSU Soil Test Report: Results and Recommendations."

E-2220 "Best Management Practices for Potatoes: Potato Fertilizer Recommendations."

NCH-02 "The Philosophy of Soil Testing (Corn)."

NCH-12 "Managing Animal Manure as a Source of Plant Nutrients."

WQ-03 "Managing Organic Soils to Reduce Nonpoint Pollution."

WQ-12 "Livestock Manure Management for Efficient Crop Production and Water Quality Preservation."

WQ-25 "Nutrient Management to Protect Water Quality."

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