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

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

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

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

Basis for Recommendations

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

Nitrogen, phosphorus and potassium are the nutrients most likely to be limiting crop growth. The nitrogen status in the soil is quite dynamic, and predicting its availability over time is difficult. The availability of phosphorus and potassium in the soil is fairly stable over time unless major additions are made. Soils in Michigan are naturally quite low in available levels of phosphorus and potassium. Additions of these two elements over time in manures and commercial fertilizers have caused significant increases in the available levels in the soil. In 1962, the median soil test value (Bray-Kurtz P1) for phosphorus in Michigan soils was 12 ppm. This gradually increased over time. Since the early 1980s, the median value has fluctuated around 53 ppm. Similar values for potassium soil test values (1 *N* neutral ammonium acetate) are 56 ppm in the early 1960s and near 91 ppm in recent years.

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

Development of Nutrient Management Programs

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

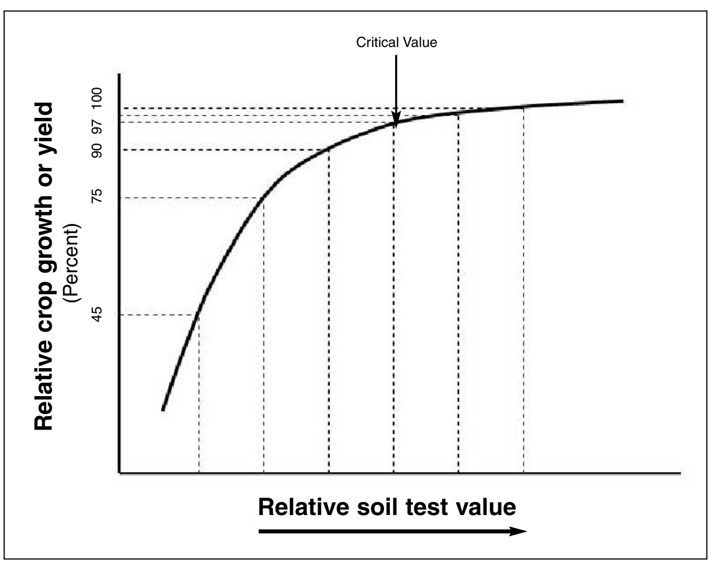

Figure 1. Relative growth or yield response to increasing soil test levels.

Soil Sampling

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

The first step in collecting soil samples from a field is to map the field and identify areas with similar physical features and similar historical management practices. Within each designated sampling area, collect about 20 cores to a depth of 8 inches and mix them thoroughly. Banding fertilizer contributes to variability of chemical soil properties. Where the location of the bands is still apparent, avoid sampling in the band. Where the location of the bands is not discernible, collect soil cores from additional random locations. Collecting one soil sample for at least every 15 to 20 acres will provide good information about the nutrient status of fields. More intense sampling will provide more information about the variability in a field. In vegetable crop production, it may sometimes be desirable to collect one sample for every 5 to 10 acres. As the number of acres represented by one composite sample increases, the probability that the sample is truly representative of the sampled area decreases. In fields that appear uniform, the maximum area that one composite sample should represent is 40 acres, but fewer acres are better. This approach will result in samples and test results representative of the designated field areas. When only shallow tillage (< 4 inches) or no tillage is used, collect an additional sample from the 0- to 3-inch depth to assess the acidity of the surface soil. Surface soil pH is critical to the efficacy of some herbicides. (More information on soil sampling is available in MSU bulletins E-498 and E-1616, and NC Multistate Report 348). Send 1½ to 2 cups of soil to a reliable soil test lab for analysis.

Fall and spring tend to be the best and most practical times to collect soil samples. Available nutrient levels are usually increased before or at planting and then gradually decrease during the growing period because of plant uptake. By fall, the nutrient status is more stable. For long-term nutrient management planning, it is best to take soil samples at the same time of year each time a field is sampled. Sampling while the crop is growing is most appropriate for checking available nitrogen levels; one such test is the presidedress soil nitrate test (PSNT). Most vegetable crops are grown quite intensively, so sampling and testing the soil at least every 2 years, if not annually, is recommended. On organic soils, considerable amounts of potassium may leach from the soil over winter, especially when the spring thaw occurs. Therefore, soil test potassium levels will usually be lower for organic soil samples taken in the spring than in the fall. (For more information on soil sampling, see MSU Extension bulletin E-471.)

Soil Test Procedures

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

An index of zinc and manganese availability is determined by extraction with 0.1 N hydrochloric acid. DTPA is used as an alternative extracting solution, especially for calcareous soils. The hot water extraction procedure is used for boron. Sulfur is determined by extraction with a calcium phosphate solution.

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

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

Conversion Factors:

Most soil testing labs report soil test values in ppm P and K. Recommendations are usually given as pounds per acre (lb/A) of P_2O_5 and K_2O because fertilizer grades are expressed as percent N – P_2O_5 – K_2O. The factors for converting from one to the other are:

ppm x 2.0 = lb/A-6 2/3 inches
ppm x 3.6 = lb/A-ft
P x 2.3 = P_2O_5 or P_2O_5 x 0.43 = P
K x 1.2 = K_2O or K_2O x 0.83 = K

Soil pH Management

Soil pH indicates the acidity or alkalinity of a soil. A pH of 7.0 is neutral, neither acid or alkaline. Values below 7.0 indicate acid soils; values above 7.0 indicate alkaline soils. Soil with a pH of 6.0 is mildly acidic, a pH of 5.0 is strongly acidic, and a pH of 8.0 is mildly alkaline.

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

Liming Soils:

Soils contain soluble and insoluble sources of acidity. The soil pH indicates the soluble or active hydrogen ion concentration in the soil. Changing the pH of acid soils requires neutralizing the insoluble or bound sources of acidity, usually aluminum and iron compounds. The amount of this reserve acidity is determined with the SMP (Shoemaker, McLean, Pratt) buffer and is reported as the "lime index". Table 2 shows how much lime is needed to raise the soil pH up to 6.0, 6.5 or 6.8 when lime is mixed with the top 9 inches of soil according to the lime index. Clayey soils tend to be more resistant to pH change (lower lime index) than sandy soils and require more lime at a given soil pH. Recommended lime rates are based on agricultural lime with a neutralizing value (NV) of 90 percent. Adjust the lime rate on the basis of the NV of the liming material. Do this by multiplying the recommended amount of lime by 90 and dividing by the NV of the liming material being used — i.e., (lime rate x 90) ÷ NV of liming material.

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

Weakly buffered soils:

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

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

Crop	Mineral soils	Organic soils
Asparagus crowns	6.8	6.0
Asparagus, new planting	6.8	- -
Asparagus, established	6.8	- -
Beans, snap	6.5	5.8
Beets, red	6.5	5.5
Broccoli	6.5	5.5
Brussels sprouts	6.5	5.5
Cabbage, fresh market	6.5	5.5
Cabbage, processing	6.5	5.5
Cabbage, Chinese	6.5	5.5
Carrots, fresh market	6.5	5.3
Carrots, processing	6.5	5.3
Cauliflower	6.8	5.8
Celeriac	6.8	5.8
Celery, fresh market	6.8	5.8
Celery, processing	6.8	5.8
Cucumber, pickling		
hand harvested	6.5	5.5
machine harvested	6.5	5.5
Cucumber, slicers	6.5	5.5
Dill	6.5	5.5
Eggplant	6.0	- -
Endive	6.0	5.3
Escarole	6.0	5.3
Garden, home	6.5	5.3
Garlic	6.5	5.3
Ginseng	6.5	- -
Greens, leafy	6.5	5.3
Horseradish	6.5	5.5
Kohlrabi	6.5	5.8
Leek	6.5	5.5
Lettuce, Boston, bib	6.5	5.5
Lettuce, leaf	6.5	5.5
Lettuce, head	6.5	5.5
Lettuce, romaine	6.5	5.5
Market garden	6.5	5.5
Muskmelon	6.5	5.8
Onion, dry bulb	6.5	5.3
Onion, green	6.5	5.3
Pak choi	6.5	5.8
Parsley	6.5	5.3
Parsnip	6.5	5.3
Peas	6.5	5.3
Pepper, bell	6.5	5.5
Pepper, banana	6.5	5.5
Pepper, hot	6.5	5.5
Potato	6.0	5.3
Pumpkin	6.5	5.5
Radish	6.5	5.3
Rhubarb	6.0	- -
Rutabaga	6.5	5.3
Spinach	6.5	5.5
Squash, hard	6.5	5.8
Squash, summer	6.5	5.8
Sweet corn	6.5	5.3
Sweet potato	6.0	- -
Swiss chard	6.5	5.3
Tomato, fresh market	6.5	- -
Tomato, processing	6.5	- -
Turnip	6.5	5.3
Watermelon	6.0	- -
Zucchini	6.5	5.8

- Liming the soil above the target pH would not be expected to improve crop yield unless the subsoil pH is less than 6.0 for mineral soils and less than 4.8 for organic soils.
- When crops with different target pHs are being grown in rotation, lime the soil for the crop with the highest target pH.

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

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

Recommendations are based on the following equations.

Mineral soils:
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:
To pH 5.3: XL = 37.6 - 7.1 x pH
Target pH >5.3 XL = (37.6 - 7.1 x pH) + (target pH - 5.3) x 0.5)

where:
XL = Lime recommendation in tons/acre
LI = Lime index
pH = Soil pH

Weakly buffered soils: Refer to the text for lime recommendations on weakly buffered soils.

Nitrogen Recommendations

Applying the correct amount of nitrogen (N) is important for profitable crop production, vegetable quality, water quality and energy conservation. Nitrogen recommendations are based on crop nitrogen utilization and response to applied nitrogen rates. Table 3 indicates an average amount of nitrogen removed in the harvested portion of various field crops. Nitrogen recommendations for vegetable crops grown on mineral and organic soils are listed in Table 4. Because of additional mineralization of N in organic soils, the N recommendations for most crops grown on organic soils are 40 to 50 lb/A less than those for mineral soils.

Including cover crops in vegetable crop rotations is encouraged to improve soil quality and cycle nutrients. Legumes can contribute nitrogen to the soil. Clover seeded in late July or early August can provide 50 to 80 pounds of available nitrogen, depending on stand and the amount of growth that occurs in the spring prior to incorporation. Vegetable growers are increasingly interested in rotating with field crops to minimize disease problems. Table 5 provides the nitrogen credits that can be taken when various legume crops precede a vegetable crop. Nitrogen credit for animal manures should be based on an analysis of the manure because nitrogen content varies with the manure type and the handling system. Approximately 50 percent of the total N will become available during the first growing season after application. Nitrogen contained in composted manures has been stabilized so that only about 10 percent of the total nitrogen will become available during the first year after application.

Several nitrogen carriers are suitable for vegetable crop production. Studies with a number of 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 grown in cold soils or on recently fumigated land, nitrate-containing fertilizers are preferred. Once soils have warmed above 55 degrees F, the microbial conversion of nitrogen from ammonium to nitrate occurs quite readily. Therefore, 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, such as pepper, tomato, squash and lettuce.

Nitrogen fertilizers and other inputs should be used in a manner that improves crop use efficiency and minimizes the potential for loss into surface and subsurface waters. Apply recommended rates as close to the time of maximum crop demand as possible. Apply preplant nitrogen (less than 50 lb N/A) as close to planting time as possible. One option is to include the nitrogen in the planting time fertilizer. Topdress the remainder of the needed nitrogen in one or more applications after the crop is well established and actively growing. Most transplanted crops begin to grow rapidly about 4 weeks after transplanting. For seeded crops, the rapid growth phase may not occur until 5 to 6 weeks after emergence. A pretopdress (sidedress) soil nitrate test (PSNT) can help determine the most effective nitrogen rate. Supplemental nitrogen can also be applied through the irrigation system, sprinkler or trickle. Proper scheduling of irrigation water to minimize leaching reduces the potential for loss of nitrogen by leaching or denitrification and improves the efficiency of water and nitrogen use.

Most nitrogen carriers have a residual acidifying effect in the soil. It requires about 1.8 pounds of agricultural limestone to neutralize the acidifying effect of each pound of nitrogen applied as urea, ammonium nitrate or urea-ammonium nitrate (28 percent solution), and about 5 pounds for each pound of ammonium sulfate applied. Calcium nitrate and potassium nitrate have a slight alkaline residual effect that has little effect on the soil pH.

Table 3. Nutrient removal in the harvested portion of Michigan vegetable crops.

Crop	N	P_2O_5	K_2O
	- - - - lb/ton	- - - -	
Asparagus crowns	13.4	4.0	10.0
Asparagus, new planting	13.4	4.0	10.0
Asparagus, established	13.4	4.0	10.0
Beans, snap	24.0	2.4	11.0
Beets, red	3.5	2.2	7.8
Broccoli	4.0	1.1	11.0
Brussels sprouts	9.4	3.2	9.4
Cabbage, fresh market	7.0	1.6	6.8
Cabbage, processing	7.0	1.6	6.8
Cabbage, Chinese	7.0	1.6	6.8
Carrots, fresh market	3.4	1.8	6.8
Carrots, processing	3.4	1.8	6.8
Cauliflower	6.6	2.6	6.6
Celeriac	4.0	2.6	6.6
Celery, fresh market	5.0	2.0	11.6
Celery, processing	5.0	2.0	11.6
Cucumber, pickling			
hand harvested	2.0	1.2	3.6
machine harvested	2.0	1.2	3.6
Cucumber, slicers	2.0	1.2	3.6
Dill	3.5	1.2	3.6
Eggplant	4.5	1.6	5.3
Endive	4.8	1.2	7.5
Escarole	4.8	1.2	7.5
Garden, home	6.5	2.8	5.6
Garlic	5.0	2.8	5.6
Ginseng	4.6	1.2	4.6
Greens, leafy	4.8	2.0	6.0
Horseradish	3.4	0.8	6.0
Kohlrabi	6.0	2.6	6.6
Leek	4.0	2.6	4.8
Lettuce, Boston, bib	4.8	2.0	9.0
Lettuce, leaf	4.8	2.0	9.0
Lettuce, head	4.8	2.0	9.0
Lettuce, romaine	4.8	2.0	9.0
Market garden	6.5	2.8	5.6
Muskmelon	8.4	2.0	11.0
Onion, dry bulb	5.0	2.6	4.8
Onion, green	5.0	2.6	4.8
Pak choi	7.0	1.6	6.8
Parsley	4.8	1.8	12.9
Parsnip	3.4	3.2	9.0
Peas	20.0	4.6	10.0
Pepper, bell	4.0	1.4	5.6
Pepper, banana	4.0	1.4	5.6
Pepper, hot	4.0	1.4	5.6
Potato	6.6	2.6	12.6
Pumpkin	4.0	1.2	6.8
Radish	3.0	0.8	5.6
Rhubarb	3.5	0.6	6.9
Rutabaga	3.4	2.6	8.1
Spinach	10.0	2.7	12.0
Squash, hard	4.0	2.2	6.6
Squash, summer	3.6	2.2	6.6
Sweet corn	8.4	2.8	5.6
Sweet potato	5.3	2.4	12.7
Swiss chard	3.5	1.2	9.1
Tomato, fresh market	4.0	0.8	7.0
Tomato, processing	4.0	0.8	7.0
Turnip	3.4	1.2	4.6
Watermelon	4.8	0.4	2.4
Zucchini	4.6	1.6	6.6

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

Crop	Mineral soil	Organic soil
Asparagus crowns	80	40
Asparagus, new planting	80	—
Asparagus, established	50	—
Beans, snap	40	20
Beets, red	100	40
Broccoli	140	90
Brussels sprouts	140	90
Cabbage, fresh market	140	90
Cabbage, processing	140	90
Cabbage, Chinese	120	90
Carrots, fresh market	100	60
Carrots, processing	120	60
Cauliflower	140	90
Celeriac	150	100
Celery, fresh market	200	150
Celery, processing	200	150
Cucumber, pickling		
hand harvested	100	60
machine harvested	60	20
Cucumber, slicers	80	40
Dill	60	20
Eggplant	120	—
Endive	100	60
Escarole	100	60
Garden, home	140	90
Garlic	120	70
Ginseng	50	—
Greens, leafy	100	50
Horseradish	100	50
Kohlrabi	140	90
Leek	150	100
Lettuce, Boston, bib	100	60
Lettuce, leaf	100	60
Lettuce, head	140	90
Lettuce, romaine	140	90
Market garden	140	90
Muskmelon	100	—
Onion, dry bulb	190	140
Onion, green	130	80
Pak choi	120	70
Parsley	100	
Parsnip	100	50
Peas	40	20
Pepper, bell	100	—
Pepper, banana	100	—
Pepper, hot	100	—
Potato	180	120
Pumpkin	80	40
Radish	50	20
Rhubarb	100	—
Rutabaga	100	50
Spinach	170	120
Squash, hard	80	40
Squash, summer	80	40
Sweet corn	120	70
Sweet potato	60	—
Swiss chard	100	50
Tomato, fresh market	120	—
Tomato, processing	80	—
Turnip	90	40
Watermelon	100	—
Zucchini	80	40

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

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

Phosphorus Recommendations

Phosphorus, along with nitrogen, provides benefit in stimulating growth of small seedlings and transplants, especially early in the spring when the soil is cold. For crops seeded or transplanted when the soil temperature is below about 55 degrees F, band the required amount of phosphorus (up to 100 lb P_2O_5/A) 1 inch to the side and 2 inches below the transplant or seed. This decreases phosphorus fixation and enhances early growth. In soils with a Bray P1 soil test above 70 ppm, including phosphorus in the starter fertilizer will usually not improve growth, quality or yield.

Response of vegetable crops to additions of P and K is a continuous function (Figure 1). When inadequate available phosphorus or potassium is present in the soil, plants respond to P and/or K additions with increases in biomass and/or vegetable produce according to the general response curve shown in Figure 1. The degree of response to each unit of P or K added decreases as the soil test value increases. At the critical soil test level (CL), crop yield will usually be near 95 to 97 percent of maximum. Recommendations in this bulletin follow the buildup, maintenance and draw-down philosophy presented in "Tri-State Fertilizer Recommendations," bulletin E-2567. These recommendations provide for buildup of available P and K levels when the soil test level is below the critical soil test value (Figure 2). Maintenance recommendations (amount equal to crop removal) are given to keep the available P and K at the optimum level and provide insurance against variations caused by sampling or soil variability. Beyond the maintenance zone, recommendations are less than crop removal to allow drawdown of soil nutrient levels to occur.

Crop yield plays an important role in these recommendations. In the buildup zone, the amount of P or K recommended is a combination of the amount required to build up the level in the soil to the optimum range plus the amount that will be removed in the harvested portion of the crop. It is very important to provide realistic yield goals to the MSU Soil and Plant Nutrient Lab so that you receive nutrient recommendations

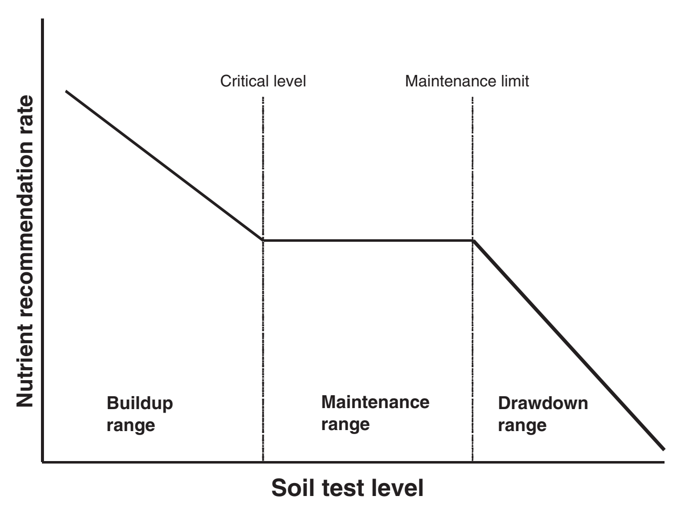

Figure 2. Nutrient recommendation scheme for phosphorus and potassium.

that are economically and environmentally sound. Table 3 provides a guide for average amounts of nitrogen (N), phosphate (P_2O_5) and potassium (K_2O) removed in the harvested portion of major agronomic crops grown in Michigan. The exact amounts may vary with stage of maturity, environmental conditions, and crop type or variety.

The buildup portion of the recommendation is based on building the soil up to the critical value or level (CL), where yield is 95 to 97 percent of maximum. The critical level varies with the crop and its response to phosphorus (Table 6). Buildup assumes that, on average, it takes 20 pounds of P_2O_5 to increase the soil test 1 ppm P or 5 lb/A/yr over a 4-year period. The P buildup recommendations for mineral and organic soils are given in tables 7 and 8. The maintenance plateau for most vegetable crops is 30 ppm on mineral soils and 15 ppm on organic soils. Maintaining the soil test P value in this maintenance zone helps ensure that P will not limit crop yield.

When the soil test P value is above the maintenance zone, the soil P level should be drawn down. Therefore, the recommendation is less than crop removal. The phosphorus critical levels (CL), maintenance plateau length (PL) and drawdown length (DDL) for vegetable crops grown on mineral and organic soils are given in Table 6. The maximum annual phosphorus recommendation is 200 lb P_2O_5/A.

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

Mineral soils:

Buildup: lb P_2O_5 /A = [(CL – ST) x 5] + (YP x CR)

Maintenance: lb P_2O_5 /A = (YP x CR)

Drawdown: lb P_2O_5 /A = {CR x YP} x {[(CL + PL + DDL) – (ST)] ÷ DL}

Organic soils:

Buildup: lb P_2O_5 /A = [(CL – ST) x 2] + (YP x CR)

Maintenance: lb P_2O_5 /A = (YP x CR)

Drawdown: lb P_2O_5 /A = {CR x YP} x {[(CL + PL + DDL) - (ST)] ÷ DL}

where:

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

Table 6. Values for key factors used in calculating the phosphorus recommendations for vegetable crops grown on mineral and organic soils.

Crop	Mineral soil			Organic soil		
	CL[1]	PL[2]	DDL[3]	CL[1]	PL[2]	DDL[3]
	- - - - - ppm - - - - -			- - - - - ppm - - - - -		
Asparagus crowns	30	30	10	100	15	15
Asparagus, new planting	40	20	10			
Asparagus, established	30	20	10			
Beans, snap	30	30	10	70	15	15
Beets, red	40	30	10	100	15	15
Broccoli	40	30	10	130	15	15
Brussels sprouts	40	30	10	100	15	15
Cabbage, fresh market	40	30	10	100	15	15
Cabbage, processing	40	30	10	100	15	15
Cabbage, Chinese	40	30	10	100	15	15
Carrots, fresh market	35	25	10	100	15	15
Carrots, processing	35	25	10	100	15	15
Cauliflower	40	30	10	130	15	15
Celeriac	45	35	10	120	15	15
Celery, fresh market	45	35	10	120	15	15
Celery, processing	45	35	10	120	15	15
Cucumber, pickling						
hand harvested	40	30	10	100	15	15
machine harvested	40	30	10	100	15	15
Cucumber, slicers	40	30	10	100	15	15
Dill	40	30	10	100	15	15
Eggplant	40	30	10			
Endive	35	25	10	100	15	15
Escarole	35	25	10	100	15	15
Garden, home	40	35	10	130	15	15
Garlic	40	35	10	120	15	15
Ginseng	30	20	10			
Greens, leafy	35	25	10	70	15	15
Horseradish	40	30	10	100	15	15
Kohlrabi	40	30	10	120	15	15
Leek	40	30	10	100	15	15
Lettuce, Boston, bib	35	25	10	100	15	15
Lettuce, leaf	35	25	10	100	15	15
Lettuce, head	35	25	10	100	15	15
Lettuce, romaine	35	25	10	100	15	15
Market garden	45	35	10	120	15	15
Muskmelon	40	30	10			
Onion, dry bulb	45	35	10	120	15	15
Onion, green	45	35	10	100	15	15
Pak choi	40	30	10	100	15	15
Parsley	35	25	10	100	15	15
Parsnip	35	25	10	100	15	15
Peas	30	20	10			
Pepper, bell	40	30	10			
Pepper, banana	40	30	10			
Pepper, hot	40	30	10			
Potato	60	40	25	120	50	20
Pumpkin	35	25	10	100	15	15
Radish	35	25	10	70	15	15
Rhubarb	40	30	10			
Rutabaga	35	25	10	70	15	15
Spinach	35	25	10	100	15	15
Squash, hard	35	25	10	100	15	15
Squash, summer	35	25	10	100	15	15
Sweet corn	35	25	10	70	15	15
Sweet potato	35	25	10			
Swiss chard	40	30	10	100	15	15
Tomato, fresh market	45	35	10			
Tomato, processing	45	35	10			
Turnip	30	20	10	70	15	15
Watermelon	40	30	10			
Zucchini	35	25	10	100	15	15

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

Table 7. Phosphorus buildup recommendations, mineral soils.

P soil test	CL values 25	30	35	40	45
ppm	- - - - - - - lb P_2O_5/A	- - - - - - -			
5	100	125	150	175	200
10	75	100	125	150	175
15	50	75	100	125	150
20	25	50	75	100	125
25	0	25	50	75	100
30	0	0	25	50	75
35	0	0	0	25	50
40	0	0	0	0	25

CL = critical soil test value.

Table 8. Phosphorus buildup recommendations, organic soils.

P soil test	CL values 70	100	110	120	130
ppm	- - - - - - - lb P_2O_5/A	- - - - - - -			
40	60	120	140	160	180
80	0	40	60	80	100
100	0	0	20	40	60
110	0	0	0	20	40
120	0	0	0	0	20
130	0	0	0	0	0

CL = critical soil test value

Potassium Recommendations

Potassium recommendations take into consideration the soil test level and the vegetable crop yield. The buildup portion of the recommendation also takes into account the cation exchange capacity (CEC) of the soil. The amount of potassium required to increase the available soil potassium level and reach the critical level (where yield is 95 to 97 percent of maximum) varies with the CEC (75 + [2.5 x CEC]). The critical values for organic soils vary by crop from 200 to 320 ppm. The buildup portion of the K recommendation for mineral and organic soils is given in tables 9 and 10. The maintenance plateau for most vegetable crops is 30 ppm for mineral soils and 40 ppm for organic soils. In the maintenance zone, the potassium recommendation equals crop removal. When the soil test K value is above the maintenance zone, crops should be allowed to use residual soil K and draw down the soil K level, so the K_2O recommendation is less than crop removal. For most crops, in mineral soils the K_2O recommendation goes to zero when the soil test level is 15 ppm beyond the upper maintenance soil test value. The critical levels (CL), maintenance plateau length (PL) and drawdown length (DDL) for vegetable crops are given in Table 11. The maximum annual potassium recommendation is 300 lb K_2O/A, except for celery.

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

Mineral soils:

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

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

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

Organic soils:

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

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

Drawdown: lb K_2O/A = {CR x YP} x {[(CL + PL + DL) - (ST)] ÷ DL} *where:* CL = critical soil test (ppm); for mineral soils

CL = 75 + (2.5 x CEC)

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

ST = soil test value (ppm)

YP = yield potential or goal

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

PL = maintenance plateau length

DDL = drawdown length; recommendation is phased to zero

Organic soils: Soil test values for organic soils are handled and calculated on a volume basis. Organic soils have bulk densities much lower than those of mineral soils. On average, organic soils will have field bulk densities between 0.65 and 0.70 g/cm^3, but these vary considerably and may be as low as 0.3 g/cm^3. In general, multiplying the soil test value in ppm by 1.5 will approximate pounds per acre to a depth of 6 ⅔ inches. Therefore, the critical soil test values are higher for organic soils than for mineral soils.

Significant loss of potassium due to leaching may occur in organic soils between fall and spring. Potassium recommendations are based on soil samples taken from summer through early winter. For samples taken in mid-winter through spring, decrease the potassim recommendation by 25 percent.

Calcium Management

Michigan soils generally developed from calcareous parent material and therefore contain sufficient available calcium (Ca) for production of vegetable crops. Soils of the western Upper Peninsula, which developed from acidic parent materials, are the only major exception. Even soils that have become acidic and need lime generally contain sufficient calcium to meet the needs of vegetable crops. Poor plant growth in acid soils is usually due to excess uptake of aluminum and/or manganese rather than calcium deficiency. Available calcium levels are related to the clay content of a soil. Sandy soils are most likely to have low calcium levels. The best way to be sure that soils contain adequate calcium is to soil test regularly and apply lime as needed. Supplemental calcium may improve the quality of vegetables and potato tubers grown on sandy soils containing less than 300 ppm exchangeable calcium. Organic soils generally contain high levels of available calcium.

Disorders such as blossom-end rot in peppers, tomatoes and squash, blackheart in celery and tipburn in lettuce are attributed to calcium deficiency. These disorders often occur on soil high in calcium because they

Table 9. Potassium buildup recommendations, mineral soils.

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

CL = 75 + (2.5 x CEC).

Table 10. Potassium buildup recommendations, organic soils.

	CL values, ppm				
K soil test	200	220	240	260	300
ppm	- - - - - - - lb K_2O/A - - - - - - -				
120	120	150	180	210	270
160	60	90	120	150	210
200	0	30	60	90	150
220	0	0	30	60	120
240	0	0	0	30	90
260	0	0	0	0	60
280	0	0	0	0	30
300	0	0	0	0	0

Table 11. Values for key factors used in calculating the potassium recommendations for vegetable crops grown on mineral and organic soils.

Crop	Mineral soil CL[1]= 75+(2.5 x CEC) PL[2]	Mineral soil DDL[3]	Organic soil CL[1]	Organic soil PL[2]	Organic soil DDL[3]
	- - ppm - -		- - - - - ppm - - - - -		
Asparagus, crowns	30	20	260	30	30
Asparagus, new planting	30	20			
Asparagus, established	30	20			
Beans, snap	30	20	200	40	30
Beets, red	30	20	300	60	40
Broccoli	30	20	320	40	40
Brussels sprouts	30	20	320	40	40
Cabbage, Chinese	30	20	240	40	40
Cabbage, fresh market	30	20	240	40	40
Cabbage, processing	30	20	240	40	40
Carrots, fresh market	30	20	220	40	60
Carrots, processing	30	20	220	40	60
Cauliflower	30	20	320	40	40
Celeriac	30	20	320	40	40
Celery, fresh market	30	20	210	50	200
Celery, processing	30	20	320	50	200
Cucumber, pickling					
hand harvested	30	20	240	40	40
machine harvested	30	20	240	40	40
Cucumber, slicers	30	20	240	40	40
Dill	30	20	240	40	40
Eggplant	30	20			
Endive	30	20	220	40	60
Escarole	30	20	220	40	60
Garden, home	30	20	350	50	50
Garlic	30	20	240	40	40
Ginseng	30	20			
Greens, leafy	30	20	200	40	30
Horseradish	30	20	260	30	30
Kohlrabi	30	20	240	40	40
Leek	30	20	240	40	40
Lettuce, Boston, bibb	30	20	220	40	60
Lettuce, leaf	30	20	220	40	60
Lettuce, head	30	20	220	40	60
Lettuce, romaine	30	20	220	40	60
Market garden	30	20	300	60	40
Muskmelon	30	20			
Onion, dry bulb	30	20	300	60	40
Onion, green	30	20	300	60	40
Pak choi	30	20	240	40	40
Parsley	30	20	220	40	40
Parsnip	30	20	220	40	30
Peas	30	20			
Pepper, bell	30	20			
Pepper, banana	30	20			
Pepper, hot	30	20			
Potato	30	20	180	60	160
Pumpkin	30	20	200	40	30
Radish	30	20	200	40	30
Rhubarb	30	20			
Rutabagas	30	20	240	40	40
Spinach	30	20	300	60	40
Squash, hard	30	20	200	40	30
Squash, summer	30	20	200	40	30
Sweet corn	30	20	200	40	30
Sweet potato	30	20			
Swiss chard	30	20	300	60	40
Tomato, fresh market	30	20			
Tomato, processing	30	20			
Turnip	30	20	200	40	30
Watermelon	30	20			
Zucchini	30	20	200	40	30

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

are related more to environmental factors that influence calcium uptake and movement within the plant than to low calcium levels in the soil. A large proportion of calcium taken up by vegetable plants is carried to the roots in water as it moves to the roots. Maintaining adequate soil moisture is important for adequate calcium uptake. Dry soil conditions result in less calcium movement to the roots and less uptake. Calcium deficiency is frequently preceded by a period of moisture stress. Maintaining a very high soil potassium level can also contribute to calcium-related disorders. Having all of the nitrogen supplied to the roots in the ammonium form contributes to calcium-related disorders, but this situation rarely occurs in a natural soil system because ammonium is readily converted to the nitrate form. Hence, the form of nitrogen used has minimal effect on calcium uptake by vegetables in field soils.

Magnesium Management

Magnesium (Mg) deficiency is most likely to occur in acid sandy soils (sandy loams, loamy sands and sands) with a subsoil as coarse as or coarser than the surface soil. These soils are most common in the southwestern and western areas of Michigan. Use dolomitic limestone (contains calcium and magnesium) on low-magnesium acid soils to neutralize soil acidity rather than using calcitic lime or marl (these contain primarily calcium), which may induce a magnesium deficiency. Applying high rates of potassium fertilizer may also induce a magnesium deficiency.

Cauliflower, celery, muskmelon, potatoes, peas and sweet corn are the vegetable crops most sensitive to marginal magnesium levels.

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

Sulfur Management

Plants take up sulfur (S) in similar amounts as phosphorus. The primary sources of plant-available sulfur are soil organic matter (animal manures or plant residues) and atmospheric deposition. Significant reductions in S from atmospheric deposition have increased the potential for sulfur deficiency, but many areas in southern Michigan still receive more than 10 pounds of sulfur per acre per year from deposition. Crops growing in sandy soils low in organic matter are the most likely to show sulfur deficiency. Studies in the past with sulfur-responsive crops grown on potentially sulfur-deficient sites in Michigan have not shown crops to benefit from supplemental sulfur application. Many soils have an accumulation of sulfur in the subsoil that the crops access once the roots reach that depth, especially where there is an increase in clay content in the subsoil. New studies are needed to reevaluate the need for sulfur by other crops grown in Michigan soils. A recent study with spinach grown on sandy soil shows it to be a good indicator crop.

Micronutrient Recommendations

Micronutrient recommendations are based on soil test, soil pH and crop responsiveness. The responsiveness of selected vegetable crops is given in Table 12. Equations used to calculate the recommended amounts to apply are given at the beginning of each section, except for boron.

Boron Management:

Boron recommendations are based on crop response, not on soil tests. A boron soil test (hot-water soluble) can provide a general guide to whether the status is low (<0.7 ppm), marginal or adequate (>1.0 ppm). Boron occurs in the soil primarily as a water-soluble anion that is subject to leaching, so the available boron status may change over time, especially in sandy soils. Boron readily leaches out of sandy soils over the winter and early spring months, when precipitation exceeds evapotranspiration. Some leaching may also occur in fine-textured soils, but to a lesser degree. For responsive crops such as broccoli, cauliflower, celery, table beets, turnips and rutabagas, boron deficiency may occur when soil moisture is marginal even though the soil contains adequate boron. Applying 2 pounds of boron per acre per year is recommended for these responsive crops grown on sandy soils (CEC <8.0 me/100 grams soil). On fine-textured soils, boron application is usually not as beneficial. On organic soils, applying 3 pounds of boron is suggested for responsive crops. Needed boron may be applied in the broadcast fertilizer or included in the starter fertilizer. Applying boron to the foliage can be effective in alleviating a boron deficiency or meeting crop needs. Apply 0.3 pound of boron per acre. Spraying more than 0.5 pound of boron per acre in one application may cause foliar burn. Never apply boron, soil or foliar, to sensitive crops such as beans, cucumbers and peas.

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

Mineral soils: Mn rec. = [(6.2 x pH) – (0.35 x ST)] – 36

Organic soils: Mn rec. = [(8.38 x pH) – (0.31 x ST)] – 46

where Mn recommendation is lb Mn/A (band application only)
ST is soil test value in ppm Mn

Manganese availability decreases markedly as soil pH increases. In mineral soils, the critical soil test value is 6 ppm at pH 6.3 and 12 ppm at pH 6.7. In organic soils, the critical soil test value is 4 ppm at pH 5.8 and 16 ppm at pH 6.2. Liming acid soils may induce a manganese deficiency. Manganese deficiency is most likely to occur on organic soils with a pH above 5.8 and dark-colored mineral soils in lake-bed and glacial outwash areas with a pH above 6.5. Recommended rates of manganese are for band application because manganese is readily bound into unavailable forms when mixed (broadcast and incorporated) with the soil. Flooding and fumigation temporarily increase manganese availability, but it readily decreases once the soil dries and microbial populations are reestablished. Manganese sulfate has proven to be the most suitable carrier for soil application, though granulated finely

Table 12. Micronutrient responsiveness levels for selected vegetable crops.

Crop	Boron	Copper	Manganese	Zinc
Asparagus, crowns	L	L	L	L
Asparagus, new planting	L	L	L	L
Asparagus, established	L	L	L	L
Beans, snap	L	L	H	H
Beets, red	H	H	M	M
Broccoli	H	M	M	L
Brussels sprouts	M	M	M	L
Cabbage, Chinese	M	M	M	L
Cabbage, fresh market	M	M	M	L
Cabbage, processing	M	M	M	L
Carrots, fresh market	H	M	M	L
Carrots, processing	H	M	M	L
Cauliflower	H	M	M	L
Celeriac	H	M	M	L
Celery, fresh market	H	M	M	L
Celery, processing	H	M	M	L
Cucumbers	L	M	H	M
Dill	L	L	M	M
Eggplant	M	M	M	M
Endive	M	H	H	M
Escarole	M	H	H	M
Garlic	L	M	H	M
Ginseng	L	L	M	M
Greens, leafy	M	H	H	M
Horseradish	M	L	M	L
Kohlrabi	M	M	M	L
Leek	L	H	H	H
Lettuce, Boston, bibb	M	H	H	M
Lettuce, leaf	M	H	H	M
Lettuce, head	M	H	H	M
Lettuce, romaine	M	H	H	M
Market garden	M	M	H	M
Muskmelon	M	M	H	M
Onion, dry bulb	L	H	H	H
Onion, green	L	H	H	H
Pak choi	M	M	M	L
Parsley	M	M	H	M
Parsnip	H	M	M	L
Peas	L	L	H	L
Pepper, bell	L	L	M	L
Pepper, banana	L	L	M	L
Pepper, hot	L	L	M	L
Potato	M	L	H	M
Pumpkin	M	L	H	M
Radish	M	M	H	M
Rhubarb	L	L	M	M
Rutabagas	H	M	M	M
Spinach	M	H	H	H
Squash, hard	L	L	H	M
Squash, summer	L	L	H	M
Sweet corn	M	M	H	H
Sweet potato	L	M	H	M
Swiss chard	M	M	M	M
Tomato, fresh market	H	M	M	M
Tomato, processing	H	M	M	M
Turnip	H	M	M	M
Watermelon	M	L	M	M
Zucchini	M	L	M	M

ground manganous oxide-sulfate mixtures (granusols) and some chelates are also acceptable sources on mineral soils. Manganese chelates are not recommended for application in organic soils. Once in the soil the chelate binds with iron and increases its availability, which reduces the uptake of manganese. It is difficult to build up the available manganese status of soils. Therefore, if a manganese deficiency occurs in a field one year, it will likely reoccur each year, especially when sensitive crops are grown.

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, muskmelon, onions, potatoes, radishes, spinach, parsley and table beets. Manganese deficiency in these crops can be alleviated by spraying the crop foliage with 1 to 2 pounds of manganese per acre. Under severe conditions and when lower rates are used, multiple applications may be necessary. If symptoms persist or appear on the new foliage 10 days after application, make another application.

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

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

Michigan soils with a pH below 6.5 generally contain adequate zinc to meet the needs of vegetable crops. At pH 6.6, the critical soil test value is 2 ppm; at pH 7.0, it is 7 ppm. Zinc deficiency is most likely to occur on the alkaline mineral soils of the lake-bed regions of eastern Michigan and on near neutral to alkaline organic soils. Deficiencies are also likely to occur on spoil-bank areas and areas where drainage tile was trenched into calcareous subsoil. High rates of phosphorus may enhance the occurrence of a zinc deficiency when the available soil zinc status is marginal. Sweet corn, onions, leeks and spinach are the vegetables most sensitive to low levels of available zinc. Band application of the recommended zinc rate is preferred, but broadcast application of 10 pounds or more per acre is effective in meeting the need of the crop and building up the soil level. Annual band applications will gradually build up available zinc levels and eliminate the need for further applications. Zinc sulfate, granulated finely ground zinc oxide-sulfate mixtures and chelates are good sources of zinc for soil application. Chelates are actually more effective than the inorganic salts in improving the zinc availability for a given growing season. The recommended rate for zinc chelates is one-fifth the rate calculated above for the inorganic salts. A foliar spray of 0.5 lb zinc per acre is effective in preventing or alleviating a zinc deficiency.

Copper Management:
Copper (Cu) recommendation for organic soils is based on the 1 *N* HCl soil test.

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

The mineral soils of Michigan generally contain adequate amounts of copper. Soil test values greater than 0.5 ppm (1 *N* HCl extractable) indicate adequate copper availability. Acid sandy soils that have been heavily cropped are the most likely of the mineral soils to show a copper deficiency. Organic soils are naturally low in available copper, and many vegetable crops will respond to copper application when grown on these soils. Once applied to the soil, copper remains available. Therefore, copper levels may have been improved by past applications to the soil or by copper fungicide sprays in fields that have been in production for a long time. The 1 *N* HCl soil test is a good indicator of copper availability in organic soils. No further copper is needed for most vegetable crops once a total of 20 pounds of copper per acre have been applied to an organic soil or the soil test exceeds 20 ppm. The exception is lettuce, which responds up to a soil test of 30 ppm. Lettuce, onions, spinach and table beets are the vegetable crops most sensitive to low soil copper. When grown on high organic matter sandy soils, these crops may benefit from the application of 2 to 4 pounds of copper per acre. Copper sulfate and copper oxide are both effective sources of copper applied broadcast or in a band. Copper chelates are also good sources of copper and may actually be slightly more effective than the inorganic salts.

Molybdenum Management:
Plants require very small amounts of molybdenum. Cauliflower, lettuce, spinach, cabbage and onions are

the vegetable crops most likely to benefit from molybdenum application. The need for supplemental molybdenum is most acute in mineral soils with a pH below 5.5, in organic soils with a pH below 5.0 and in soils with a high available iron content. Liming acid soils is the best way to improve molybdenum availability and prevent a deficiency.

Foliar application is the most effective way to supply molybdenum to plants. Spray 2 ounces of sodium molybdate per acre. Using more than 20 gallons of water per acre provides better coverage than using lesser amounts. Using a non-ionic surfactant helps wet the leaves and enhances the absorption of molybdenum by the leaves. For sensitive crops such as cauliflower, apply every 2 weeks. Treating the seed is an option for improving the molybdenum status of developing seedlings. Use 0.5 ounce of sodium molybdate for the amount of seed to plant 1 acre. For sensitive crops, even with seed treatment one or more foliar applications may be necessary if the crop is grown in a fairly acid soil, pH 5.5 or lower.

Foliar Nutrient Applications

Spraying nutrients on the foliage of vegetable plants can be an effective way to meet their micronutrient needs, especially when a fertilizer program or the growth stage of the crop does not allow the soil application of needed micronutrients. Recommended rates for foliar application of inorganic carriers of the secondary and micronutrients are given in Table 13. Chelate carriers should be used at their labeled rates because applying too much may cause leaf injury. Many liquid chelate carriers contain around 6 percent of the indicated element. Applying 1 gallon of material will supply about 0.5 pound of the indicated element per acre. Some fungicides contain sufficient amounts of copper, manganese and/or zinc to partially or completely meet the need for these micronutrients. Spraying calcium and magnesium on the foliage can benefit crops that are sensitive to reduced uptake of these elements under certain environmental or soil conditions (see the sections on calcium and magnesium). With a good soil fertility program, spraying nitrogen, phosphorus and potassium on the foliage does not improve crop quality and yield. The amounts of these nutrients that can be supplied, without injury, are small relative to the total vegetable crop need. However, foliar application of 4 to 5 pounds of nitrogen per acre can help vegetable crops through stress periods, especially saturated soil conditions, when poor aeration may limit root activity and nutrient uptake.

Table 13. Recommended rates of selected nutrients for application to the foliage of vegetable crops.

Nutrient	Pounds of element per acre	Common source[1]	% element in source
Calcium	1 – 2	calcium nitrate	19
Magnesium	1 – 2	magnesium sulfate	10
Boron	0.1 – 0.3	soluble sodium borate	20
		boric acid	17
Copper	0.5 – 1.0	basic copper sulfate	13 – 35
Manganese	1.0 – 2.0	manganese sulfate	24 – 28
Molybdenum	0.06 – 0.1	sodium molybdate	39
Zinc	0.3 – 0.7	zinc sulfate	36

[1]Chelate carriers commonly contain around 6 percent of the indicated element. Use according to the label.

Plant Tissue Analysis

Analysis of appropriate plant parts for their nutrient concentration can provide information about the nutritional status of the crop. This can be helpful in diagnosing in-season plant growth problems or in adjusting the long-term soil nutrient management plan. Plants are the best indicator of whether they can take up adequate quantities of the essential nutrients. A low level of an essential nutrient in the plant does not always mean that the amount available in the soil is insufficient, however. Other conditions, such as compacted soil or poor drainage, may limit root growth and nutrient uptake by plants. Table 14 provides information about the critical levels in the youngest mature leaves of selected vegetable crops.

Suggested Nutrient Management Practices for the Primary Vegetable Crops Grown in Michigan

Soil test to determine lime and nutrient requirements!

A good nutrient management program is based on soil test information and is coupled with other good management practices, such as using crop rotation, cover crops, raised beds, plastic mulch, irrigation and reduced tillage. Most vegetable crops require relatively high levels of fertility for good quality and yields. Amounts of nutrients recommended will meet the needs of the growing vegetable crop and gradually build up low soil levels of phosphorus and potassium

Table 14. General guidelines for sufficient nutrient levels in sampled plant tissue of some vegetable crops.[1, 2]

Vegetable	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
	percent						ppm				
Asparagus	2.5	.25	1.5	0.6	.25		40	5	40	25	20
Beans, snap	5.0	.35	2.3	1.5	.30		20	7	50	50	20
Broccoli	3.2	.30	2.0	1.0	.25	.30	30	5	70	25	35
Cabbage	3.6	.33	3.0	1.1	.40	.30	25	5	30	25	20
Carrot	2.1	.20	2.8	1.4	.30		30	5	50	60	25
Cauliflower	3.3	.33	2.6	2.0	.27		30	4	30	25	20
Celery	1.6	.30	7.5	2.2	.25		25	5	30	10	25
Cucumber	4.5	.34	3.9	1.4	.30	.40	25	4	30	50	25
Lettuce	3.8	.45	6.0	1.5	.36		25	7	50	25	25
Muskmelon	4.5	.30	4.0	2.3	.35	.25	25	7	50	50	20
Onions	4.5	.30	3.5	1.5	.25	.50	25	15	60	50	25
Peas	4.0	.30	2.0	1.2	.30		25	7	50	30	25
Peppers	4.0	.35	4.0	1.0	.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]Adapted from Plant Analysis Handbook by Jones, Wolf and Mills, Micro-Macro Publishing Inc.

[2]Guidelines are for the youngest mature leaves, except celery, in which they are for the youngest mature petiole. 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.

over a 4-year period. Once an optimum level of available nutrients is attained, apply amounts of phosphorus and potassium equal to crop removal for maintenance. Supplemental nutrients may be applied for vegetable crops in a combination of methods: broadcast before or after primary tillage, placed in bands near the seed or transplants, sidedressed or topdressed, in irrigation water and/or foliar application.

Cover crops can effectively cycle and improve the availability of nutrients. On sandy soils, establish cover crops after crop harvest to take up residual nitrogen and soluble potassium to prevent leaching loss, and to prevent wind erosion. It is usually not necessary to fertilize cover crops. Leguminous cover crops, such as clover, can fix nitrogen that will become available for the following crop.

Many warm-season vegetable crops will grow on organic soils, but they are not recommended for commercial production because of the potential of late spring frosts and early fall frosts. The release of large amounts of nitrogen from organic soils may also stimulate vegetative growth of some crops and delay fruit set.

Key nutrient management points for specific vegetable crops are presented in the following sections. Total nitrogen recommendations are based on Table 4. Recommended amounts of phosphorus and potassium are based on a soil test and are the sum of the amount required to build up low soil levels (Tables 7, 8, 9 and 10) and a maintenance amount (crop removal, Table 3). When the soil test is sufficiently high, no nutrients are recommended. If soil test information is not available, apply maintenance amounts (crop removal). The amounts of N, P_2O_5 and K_2O removed in each ton of harvested produce are listed at the beginning of each section below and also in Table 3.

Asparagus (crown production):
Adjust the soil pH to 6.8 or above before seeding. Before seeding, incorporate 50 pounds of nitrogen per acre and the recommended amounts of phosphorus and potassium. When the asparagus plants are about 6 inches tall, sidedress with 50 pounds of nitrogen per acre.

Asparagus (new planting):
The year before planting, sample and test the soil. Apply lime, if necessary, to raise the soil pH to 6.8 or above. In the spring before setting the crowns, broadcast and incorporate 50 pounds of nitrogen per acre and the recommended amounts of phosphate (P_2O_5) and potash (K_20) to build the available levels up to the optimum range (tables 15 and 16). It is also important to get adequate phosphorus below the crowns. Apply 30 pounds of P_2O_5 per acre in the furrows before setting the crowns. After the new fern growth is 6 inches tall, sidedress with 50 pounds of nitrogen per acre.

Asparagus (established):
Crop removal in lb/ton: *N = 13.4 P_2O_5 = 4.0 K_2O = 10.0*

Annual nitrogen applications are best split between pre- and postharvest. The total amount should not exceed 80 pounds per acre. Every 2 to 3 years, soil sample and test, primarily to monitor the soil pH and available potassium, calcium and magnesium levels. Broadcast amounts of lime necessary to maintain the soil pH above 6.5. Use dolomitic lime if the magnesium level is less than 50 ppm. Every second year, broadcast 60 pounds of K_20 per acre or the amount recommended by a soil test. Applying phosphorus after establishment is usually not beneficial unless the level was not built up before setting the crowns.

Table 15. Phosphorus recommendations for two asparagus yields.

Soil test	Yield (tons/A) 1	2
ppm	- - - lb P_2O_5/A - - -	
15	154	158
25	104	108
35	54	58
45-80	4	8
90	0	0

Numbers highlighted are maintenance amounts.

Table 16. Potassium recommendations for two asparagus yields.

Soil test	1 ton/A					2 tons/A			
	4	8	12	16	CEC	4	8	12	16
ppm	- - - - - - - - lb K_2O/A - - - - - - -					- - - - - - - - lb K_2O/A - - - - - - - - -			
40	64	87	124	145		74	97	134	155
80	16	31	50	73		26	41	60	83
85	10	24	42	64		20	34	52	74
95	10	10	26	46		20	20	36	56
105	10	10	10	28		20	20	20	38
115	10	10	10	10		20	20	20	20
125	5	10	10	10		10	20	20	20
135	0	5	10	10		0	10	20	20

Numbers highlighted are maintenance amounts.

Beans, Snap:

Crop removal in lb/ton: *N = 24.0* *P_2O_5 = 2.4* *K_2O = 11.0*

Most of the required potassium is best broadcast and incorporated before planting. Placing fertilizer in a band 2 inches to the side and 2 inches below the seed can improve early growth. The placed fertilizer may include 30 pounds of nitrogen, all the required phosphate (P_2O_5) and up to 40 pounds of potash (K_2O) per acre. When planting time fertilizer is not used, broadcast the required phosphate and potassium (tables 17 and 18) and 30 pounds of nitrogen per acre. When beans are growing in soil with a pH near or above 6.5, manganese deficiency may occur. Include 2

Table 17. Phosphorus recommendations for three snap bean yields.

Soil test	Yield (tons/A)		
	2	4	6
ppm	- - - - - lb P_2O_5/A - - - - -		
15	155	160	164
25	105	110	120
35	55	60	70
45-80	5	10	14
90	0	0	0

Numbers highlighted are maintenance amounts.

Table 18. Potassium recommendations for two snap bean yields.

Soil test	2 tons/A					6 tons/A			
	4	8	12	16	CEC	4	8	12	16
ppm	- - - - - - - - lb K_2O/A- - - - - - -					- - - - - - - - lb K_2O/A- - - - - - -			
40	76	99	126	157		120	143	170	201
80	28	43	62	85		72	87	106	129
85	22	36	54	76		66	80	98	120
95	22	22	38	58		66	66	82	102
105	22	22	22	40		66	66	66	84
115	22	22	22	22		66	66	66	66
125	11	22	22	22		33	66	66	66
135	0	11	22	22		0	33	66	66

Numbers highlighted are maintenance amounts.

pounds of manganese per acre in the planting time fertilizer or spray the foliage with 1 to 2 pounds of manganese per acre when the bean plants approach 6 inches tall.

Beets (red, table):

Crop removal in lb/ton: $N = 3.5$ $P_2O_5 = 2.2$ $K_2O = 7.8$

Before planting, broadcast needed potassium. At seeding, fertilizer placed 2 inches to the side and 2 inches below the seed can supply 30 pounds of nitrogen, all the phosphate and up to 40 pounds of potash (K_2O) per acre. If no planting time fertilizer is used, broadcast and incorporate 40 pounds of nitrogen per acre and all the required phosphorus and potassium, and 2 to 3 pounds of boron per acre. After the plants are well established, topdress with 50 pounds of nitrogen per acre when grown on mineral soils. On organic soils, no additional nitrogen should be necessary.

Broccoli, Cabbage, Brussels Sprouts, Cauliflower:

Crop removal in lb/ton: $N = 7.0$ $P_2O_5 = 1.6$ $K_2O = 6.8$ *cabbage*

Broadcast and incorporate 50 to 60 pounds of nitrogen per acre plus the required amounts of phosphorus and potassium (Tables 19 and 20), and enough boron to supply 3 pounds per acre. Using a nitrogen-phosphorus starter solution when setting the plants improves early growth. A suitable starter solution can be made by mixing into each 100 gallons of water ¾ to 1 quart of 28 percent liquid nitrogen (UAN) and 2 to 3 quarts of liquid 10-34-0 fertilizer. For cauliflower, include 1 to 2 ounces of sodium molybdate. Three to 4 weeks after transplanting and again about 3 weeks later, topdress with 40 pounds of nitrogen per acre. For cabbage, a single sidedress of 60 to 80 pounds of *N* per acre 4 weeks after transplanting works well. On organic soils, only one topdress nitrogen application is necessary for each of these crops. For some varieties of cauliflower, spraying 2 ounces of sodium molybdate per acre every 2 weeks is essential for good development of the wrapper leaves.

Table 20. Potassium recommendations for two cabbage yields.

Soil test	20 tons/A					30 tons/A			
	4	8	12	16	CEC	4	8	12	16
ppm	- - -	lb K_2O/A	- - -			- -	lb K_2O/A	- - -	
40	190	213	240	271		258	281	300	300
80	142	157	176	199		210	225	244	267
85	136	150	168	190		204	218	236	258
95	136	136	152	172		204	204	220	240
105	136	136	136	154		204	204	204	222
115	136	136	136	136		204	204	204	204
125	68	136	136	136		102	204	204	204
135	0	68	136	136		0	102	204	204

Numbers highlighted are maintenance amounts.

Carrots, Horseradish and Parsnips:

Crop removal in lb/ton: $N = 3.4$ $P_2O_5 = 1.8$ $K_2O = 6.8$ *carrot*

Broadcast and incorporate 40 to 50 pounds of nitrogen per acre and the required amounts of phosphorus (tables 21 and 22) and potassium (tables 23 and 24). Mix boron into the broadcast fertilizer to supply 2 pounds of boron per acre for carrots and parsnips, and 1 pound of boron per acre for horseradish. If boron is not applied to the soil, spray the foliage once or twice with 0.3 pound of boron per acre before and after root enlargement begins. On organic soils, include 3 to 4 pounds of copper per acre if the soil test is low. On mineral soils, topdress 40 pounds of nitrogen per acre about every 4 weeks or as needed according to a soil nitrate test or a petiole sap nitrate test. On deep muck soils, a total of 60 pounds of nitrogen per acre is

Table 19. Phosphorus recommendations for three cabbage yields.

Soil test	Yield (tons/A) 20	25	30
ppm	- - - -	lb P_2O_5/A	- - - -
15	157	165	173
25	107	115	123
35	57	65	73
40-70	32	40	48
80	0	0	0

Numbers highlighted are maintenance amounts.

Table 21. Phosphorus recommendations for three carrot yields (mineral soil).

Soil test	Yield (tons/A) 20	25	30
ppm	- - - -	lb P_2O_5/A	- - - -
15	136	145	172
25	86	95	122
35-60	36	45	72
70	0	0	0

Numbers highlighted are maintenance amounts.

Table 22. Phosphorus recommendations for three carrot yields (organic soil).

Soil test	Yield (tons/A) 20	25	30
ppm	- - - - lb P_2O_5/A	- - -	
40	156	165	192
80	76	85	112
100-115	36	45	72
130	0	0	0

Numbers highlighted are maintenance amounts.

Table 23. Potassium recommendations for two carrot yields (mineral soil).

Soil test	20 tons/A				CEC	30 tons/A			
	4	8	1	16		4	8	12	16
ppm	- - lb K_2O/A - -					- - lb K_2O/A - -			
40	190	213	240	271		258	281	300	300
80	142	157	176	199		210	225	244	267
85	136	150	168	190		204	218	236	258
95	136	136	152	172		204	204	220	240
105	136	136	136	154		204	204	204	222
115	136	136	136	136		204	204	204	204
125	68	136	136	136		102	204	204	204
135	0	68	136	136		0	102	204	204

Numbers highlighted are maintenance amounts.

Table 24. Potassium recommendations for three carrot yields (organic soil).

Soil test	Yield (tons/A) 20	25	30
ppm	- - - - lb P_2O_5/A	- - - -	
100	300	300	300
150	241	275	300
200	166	200	234
220-260	136	170	204
280	68	85	102
300	0	0	0

Numbers highlighted are maintenance amounts.

sufficient. On shallow or marginal mucks, 80 to 100 pounds of nitrogen per acre is required. On sandy mineral soils, as much as 140 pounds of nitrogen per acre may be needed. Where the soil pH is above 6.5, one or two foliar sprays of manganese at 1 pound per acre may benefit the health and growth of the leaves, especially on organic soils.

Celery, Celeriac:

Crop removal in lb/ton: N = 5.0 P_2O_5 =2.0 K_2O = 11.6 celery

For early plantings (when the average soil temperature at 4 inches is below 55 degrees F), banding fertilizer near the transplant row can improve early growth. Apply 40 pounds of N, up to 100 pounds of P_2O_5 and up to 40 pounds of K_2O per acre. When band fertilizer is applied, broadcast phosphorus and potassium needed in excess of what is applied in the band fertilizer. When no band-placed fertilizer is used, broadcast and incorporate 40 pounds of nitrogen per acre plus the recommended amounts of phosphorus and potassium before transplanting (tables 25 and 26). Include 3 to 4 pounds of boron per acre in either the broadcast or band fertilizer.

Spray the foliage periodically with 1 to 2 pounds of manganese and 1 to 2 pounds of magnesium per acre. Sidedress two to three times during the season with 40 to 50 pounds of nitrogen per acre. The number of applications depends on the season, drainage, and type of muck or soil. Plant color, petiole tissue nitrate concentration or a soil nitrate test can help determine when additional nitrogen is required. The highest rate of nitrogen uptake in celery occurs from 6 weeks after transplanting to harvest.

Table 25. Phosphorus recommendations for three celery yields (organic soil).

Soil test	Yield (tons/A) 25	30	35
ppm	- - - - lb P_2O_5/A	- - - -	
40	210	220	230
80	130	140	150
120-140	50	60	70
130	0	0	0

Numbers highlighted are maintenance amounts.

Table 26. Potassium recommendations for three celery yields (organic soil).

Soil test	Yield (tons/A) 25	30	35
ppm	- - - - lb P_2O_5/A - - - -		
100	455	500	500
150	380	438	492
200	305	363	417
210-260	290	348	402
310	217	261	301
360	145	174	201
410	72	87	100
460	0	0	0

Numbers highlighted are maintenance amounts.

Table 27. Phosphorus recommendations for three cucumber yields.

Soil test	Yield (tons/A) 6	10	14
ppm	- - - - lb P_2O_5/A - - - -		
15	157	162	167
25	107	112	117
35	57	62	67
45-80	7	12	17
90	0	0	0

Numbers highlighted are maintenance amounts.

Table 28. Potassium recommendations for two cucumber yields.

Soil	6 tons/A					14 tons/A			
test	4	8	12	16	CEC	4	8	12	16
ppm	- - lb K_2O/A - -					- - lb K_2O/A - -			
40	76	99	126	157		104	127	154	185
80	28	43	62	85		56	71	90	113
85	22	36	54	76		50	64	82	104
95	22	22	38	58		50	50	66	86
105	22	22	22	40		50	50	50	68
115	22	22	22	22		50	50	50	50
125	11	22	22	22		25	50	50	50
135	0	11	22	22		0	25	50	50

Numbers highlighted are maintenance amounts.

Celery is susceptible to calcium deficiency (blackheart), especially when soil moisture stress (either too little or too much) or heat stress occurs. If these conditions are expected, use preventive calcium sprays. Spray 15 pounds of calcium nitrate or 10 pounds of calcium chloride per acre.

Cucumbers:

Crop removal in lb/ton: N = 2.0 P_2O_5 *= 1.2* K_2O *= 3.6*

Recommended amounts of phosphorus and potassium are given in tables 27 and 28. Broadcast phosphorus and potassium required in excess of what is applied in the starter fertilizer. For slicing and hand-picked pickling cucumbers, band a starter fertilizer 2 inches to the side and 2 inches below the seed depth. The starter fertilizer should supply 30 pounds of nitrogen, up to 100 pounds of phosphate (P_2O_5) and up to 40 pounds of potassium (K_2O) per acre. When the soil pH is above 6.5, include 2 pounds of manganese per acre in the starter fertilizer and/or spray the foliage at tip-over with 1 pound of manganese per acre. Just before tip-over, topdress with 30 to 40 of pounds nitrogen per acre. Nitrogen can also be applied through the irrigation system at 10 to 15 pounds per acre per application. For hand-picked cucumbers, a second topdress nitrogen application may be needed to maintain the vines and fruit production.

For mechanically harvested pickling cucumbers with high plant populations, broadcast and incorporate before planting 30 pounds of nitrogen and all the recommended amounts of phosphorus and potassium. Just before tip-over, topdress with 30 pounds of nitrogen. Incorporating all the nitrogen in a slow-release form before planting is effective and eliminates the need to topdress. Cucumbers are responsive to manganese. In soils with a pH above 6.5, spray the foliage with 1 pound of manganese per acre near tip-over.

Lettuce (leaf, romaine, head):

Crop removal in lb/ton: N = 4.8 P_2O_5 *= 2.0* K_2O *= 9.0*

After primary tillage, broadcast and incorporate 40 pounds of nitrogen per acre, the required amounts of phosphorus and potassium, and 0.5 pound of boron per acre. Lettuce is quite responsive to copper. Use a soil test to determine copper need, or broadcast 2 pounds of copper per acre. Where possible, band (2 inches to the side and 2 inches below the depth of the seed) 40 pounds of nitrogen, 40 pounds of P_2O_5, 1 pound of manganese, 0.5 pound of copper and 0.5 pound of boron per acre to improve early growth in cool soils. After thinning or 3 weeks after transplanting, sidedress with 60 pounds of nitrogen per acre.

Muskmelon, Watermelon:

Crop removal in lb/ton: N = 8.4 P_2O_5 = 2.0 K_2O = 11.0 muskmelon

Nearly all melons are grown on plastic mulch. Before laying the plastic, broadcast and incorporate 75 to 90 pounds of nitrogen and all the required phosphorus and potassium. If nitrogen is applied through trickle irrigation, reduce the amount broadcast preplant. Melons are quite responsive to magnesium. When the soil test magnesium value is less than 50 ppm, include 50 pounds of actual magnesium per acre in the broadcast fertilizer, or spray the foliage with 1 to 2 pounds of magnesium per acre just as the plants begin to run. For muskmelons grown on soils with a pH above 6.5, spray the foliage with 1 to 2 pounds of manganese per acre.

Onions (dry bulb, green):

Crop removal in lb/ton: N = 5.0 P_2O_5 = 2.6 K_2O = 4.8 dry bulb

Phosphorus and potassium recommendations are given in tables 29 and 30. Before planting, broadcast and incorporate the required potassium. Placing a starter fertilizer 2 inches directly below the seed improves early growth and plant establishment. Include 40 pounds of nitrogen, 2 pounds of manganese, all the required phosphorus and up to 20 pounds of K_2O per acre. Depending on the soil test, copper and zinc (0.5 to 1 pound per acre) may also need to be included in the starter fertilizer. If starter fertilizer is not used, broadcast and incorporate after primary tillage 50 to 60 pounds of nitrogen, all the required phosphorus and potassium, and the required micronutrients. For dry bulb onions, side- or topdress 90 to 100 pounds of nitrogen per acre in mid-June, or split the amount between early and late June. A soil nitrate test provides a good indicator of how much available nitrogen is in the soil and how much additional nitrogen is needed. For green onions, topdress with 40 to 50 pounds of nitrogen per acre when the onions have about four true leaves. Onions benefit from foliar manganese sprays, especially when the soil pH is above 6.0. Spray with 1 to 2 pounds of manganese per acre when the onions have about four true leaves and then every 2 to 3 weeks for a total of three applications.

Table 29. Phosphorus recommendations for three bulb onion yields (organic soil).

	Yield (tons/A)		
Soil test	20	25	30
ppm	- - - - - - lb P_2O_5/A - - - - -		
40	212	225	238
80	132	145	158
100	92	105	118
120-135	52	65	78
150	0	0	0

Numbers highlighted are maintenance amounts.

Table 30. Potassium recommendations for three onion yields (organic soil).

	Yield (tons/A)		
Soil test	20	25	30
ppm	- - - - - - lb P_2O_5/A - - - - -		
100	300	300	300
150	300	300	300
200	246	270	294
250	171	195	219
300-360	96	120	144
380	48	60	72
400	0	0	0

Numbers highlighted are maintenance amounts.

Peas:

Crop removal in lb/ton: N = 20.0 P_2O_5 = 4.6 K_2O = 10.0

Broadcast and incorporate 30 to 40 pounds of nitrogen per acre plus the required amounts of phosphorus and potassium. If the field has a history of manganese deficiency on other crops, a foliar spray of manganese (1 pound per acre) may be beneficial.

Peppermint, Spearmint:

For row mint, broadcast and incorporate before planting 40 pounds of nitrogen per acre plus the required amounts of phosphorus and potassium. For meadow mint, in early spring before growth begins, drill in or broadcast the recommended amounts of phosphorus and potassium plus 30 to 40 pounds of nitrogen per acre. In early June, topdress with 40 pounds of nitrogen per acre on organic soils and 80 pounds per acre on mineral soils. Use a dry granulated or pelletized form of nitrogen when the foliage is dry to prevent foliage burn. Irrigate in the nitrogen if rain is not likely to occur during the next 5 to 7 days. If the soil pH is above 6.5, spray the foliage with 1 to 2 pounds of manganese per acre, depending on past experience.

Peppers:

Crop removal in lb/ton: N = 4.0 P_2O_5 = 1.4 K_2O = 5.6

Most peppers are grown on raised beds with plastic mulch and trickle irrigation. Before forming beds and laying plastic, broadcast 30 pounds of nitrogen per acre plus recommended amounts of phosphorus and potassium (tables 31 and 32). Incorporation of broadcast fertilizer prior to bedding is optional. Nitrogen and potassium can be effectively added through trickle irrigation. When this is done, reduce the amount of potassium broadcast according to the amount that will be added through the irrigation. Supply the equivalent of about 1 pound of nitrogen and 1 to 1.5 pounds of K_2O per acre per day through the trickle system. For peppers not grown on plastic, topdress with 30 to 40 pounds of nitrogen per acre about 4 weeks after transplanting and again 3 to 4 weeks later.

Table 31. Phosphorus recommendations for three bell pepper yields.

Soil test	Yield (tons/A) 6	9	12
ppm	- - - - -	- lb P_2O_5/A -	- - - - -
15	133	138	142
25	83	138	92
35	33	88	42
45-80	8	13	17
90	0	0	0

Numbers highlighted are maintenance amounts.

Table 32. Potassium recommendations for two pepper yields.

Soil test	6 tons/A, CEC 4	8	12	16	14 tons/A, CEC 4	8	12	16
ppm	- -	lb K_2O/A	- -		- - -	lb K_2O/A	- - -	
40	88	111	138	169	121	144	171	202
80	40	55	74	97	73	88	107	140
85	34	48	66	88	67	81	99	121
95	34	34	50	80	67	67	83	103
105	34	34	34	52	67	67	67	85
115	34	34	34	34	67	67	67	67
125	17	34	34	34	34	67	67	67
135	0	17	34	34	0	34	67	67

Numbers highlighted are maintenance amounts.

Potatoes:

Crop removal in lb/ton:N = 6.6 P_2O_5 = 2.6 K_2O = 12.6

Recommended nitrogen can be calculated as follows:

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

For Russet Burbank, Snowden and other late-maturing varieties, increase the nitrogen recommendation by 40 pounds of nitrogen per acre. Phosphorus and potassium recommendations are given in tables 33 and 34. Apply up to 60 pounds of nitrogen, all of the phosphorus and up to 100 pounds of potash (K_2O) per acre in starter bands 2 inches to the side and level with or slightly below the seed pieces. Placing bands on both sides of the seed pieces is more effective than banding on just one side. Before planting, broadcast and incorporate potash in excess of the amount applied in the fertilizer bands. Fall application of potassium on sandy and organic soils is not recommended because of the potential for leaching loss. Incorporating a legume cover crop or animal manure can significantly reduce the amount of supplemental nitrogen needed. Nitrogen broadcast before planting has an increased risk of loss by leaching. Nitrogen applied after planting is generally used more efficiently than nitrogen applied preplant. It is best to supply needed nitrogen through a combination of applications at planting time and hilling and through irrigation. (For more information on nutrient management of potatoes, see MSU Extension bulletin E-2779.) After harvest, establish a cover crop to take up any residual nitrogen and to protect against wind erosion.

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

Table 33. Phosphorus recommendations for selected potato yields.

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

Numbers highlighted are maintenance amounts.

Table 34. Potassium recommendations for selected potato yields.

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

Numbers highlighted are maintenance amounts.

Pumpkin, Squash, Zucchini:

Crop removal in lb/ton: N =4.0 P_2O_5 = 1.2 K_2O = 6.8 pumpkin

Before planting, broadcast and incorporate 40 pounds of nitrogen per acre plus all the required phosphorus and potassium (tables 35 and 36). At the time of plant tip-over topdress with 40 pounds of nitrogen per acre. Where the soil pH is above 6.5, include 0.5 to 1 pound of manganese per acre in any foliar sprays.

Table 35. Phosphorus recommendations for selected three pumpkin yields.

Soil test	Yield (tons/A) 15	20	25
ppm	- - - - - - lb P_2O_5/A -	- - - -	
15	168	174	186
25	118	124	136
35	68	74	86
45-80	18	24	36
90	0	0	0

For squash increase the amount by 1 lb/ton.
Numbers highlighted are maintenance amounts.

Table 36. Potassium recommendations for two pumpkin yields.

Soil test	15 tons/A				25 tons/A			
CEC	4	8	12	16	4	8	12	16
ppm	- - lb K_2O/A - -				- - lb K_2O/A - - -			
40	156	179	206	237	224	247	274	300
80	108	123	142	165	176	191	210	243
85	102	116	134	156	170	184	202	224
95	102	102	118	138	170	170	186	206
105	102	102	102	120	170	170	170	188
115	102	102	102	102	170	170	170	170
125	51	102	102	102	85	170	170	170
135	0	51	102	102	0	85	170	170

Numbers highlighted are maintenance amounts.

Radishes, Rutabagas, Swiss Chard, Turnips:

Crop removal in lb/ton: N = 3.0 P_2O_5 = 0.8 K_2O = 5.6 radish

Broadcast and incorporate 50 pounds of nitrogen per acre plus recommended amounts of phosphorus and potassium (tables 37 and 38) and 1 pound of boron for radishes and 2 pounds of boron for rutabagas, Swiss chard and turnips. Topdress the rutabagas, Swiss chard and turnips with 30 to 50 pounds nitrogen per acre about 4 weeks after emergence. Radishes are highly responsive to manganese, especially when grown on organic soil. When the pH is above 6.5 on mineral soils and above 6.0 on organic soil, spray the foliage 10 to 15 days after emergence with 1 to 2 pounds of manganese per acre. If boron is not included in the broadcast fertilizer, spray the foliage with 0.3 pound of boron per acre.

Table 37. Phosphorus recommendations for three radish yields (organic soil).

Soil test	Yield (tons/A) 2	4	6
ppm	- - - - - - lb P_2O_5/A	- - - - -	
40	62	63	65
60	22	23	25
70-85	2	3	5
100	0	0	0

Numbers highlighted are maintenance amounts.

Table 38. Potassium recommendations for three radish yields (organic soil).

Soil test	Yield (tons/A) 2	4	6
ppm	- - - - - - lb P_2O_5/A	- - - - -	
100	161	172	183
150	86	97	108
200-240	11	22	33
265	5	11	16
270	0	0	0

Numbers highlighted are maintenance amounts.

Rhubarb:

Crop removal in lb/ton: N = 3.5 P_2O_5 = 0.6 K_2O = 6.9

Before a new planting, broadcast and incorporate 50 pounds of nitrogen per acre plus the recommended amounts of phosphorus and potassium. For established plantings, in early spring before rhubarb emergence, broadcast 50 pounds of nitrogen plus maintenance amounts of phosphorus and potassium based on anticipated yield. Two to 3 weeks after new growth starts, sidedress with 50 pounds of nitrogen per acre.

Sweet Corn:

Crop removal in lb/ton: N = 8.4 P_2O_5 = 2.8 K_2O = 5.6

Phosphorus and potassium recommendations are given in tables 39 and 40. Before planting, broadcast up to 40 pounds of nitrogen per acre and the recommended amount of potassium. At planting, band 30 pounds of nitrogen, all the recommended phosphorus and up to 40 pounds of potassium (K_2O) per acre placed 2 inches to the side and 2 inches below the seed depth. On mineral soils with a pH above 6.5 or organic soils with a pH above 6.0, include 0.5 pound of zinc per acre in the starter fertilizer. On organic soils, include 1 pound of manganese per acre. Sidedress nitrogen when the corn is 6 to 12 inches tall. On mineral soils, the amount to sidedress per acre equals 120 minus the amounts applied preplant and in the planting time starter fertilizer. On organic soils, reduce the sidedress nitrogen amount by 40 pounds per acre under that recommended for mineral soils.

Table 39. Phosphorus recommendations for three sweet corn yields.

Soil test	Yield (tons/A) 6	9	12
ppm	- - - - - - lb P_2O_5/A	- - - - -	
15	167	175	184
25	117	125	134
35	67	75	84
45-80	17	25	34
90	0	0	0

Numbers highlighted are maintenance amounts.

Table 40. Potassium recommendations for two sweet corn yields.

Soil test	6 tons/A					12 tons/A			
	CEC 4	8	12	16		CEC 4	8	12	16
ppm	- - lb K_2O/A - -					- - lb K_2O/A - -			
40	87	110	137	168		121	144	171	200
80	39	54	73	96		73	88	107	130
85	34	47	65	87		67	81	99	121
95	34	34	49	59		67	67	83	103
105	34	34	34	51		67	67	67	85
115	34	34	34	34		67	67	67	67
125	17	34	34	34		34	67	67	67
135	0	17	34	34		0	34	67	67

Numbers highlighted are maintenance amounts.

Tomatoes:

Crop removal in lb/ton: $N = 4.0$ $P_2O_5 = 0.8$ $K_2O = 7.0$

For machine-harvested processing tomatoes, broadcast and incorporate 40 pounds of nitrogen per acre plus the amounts of phosphorus and potassium recommended by a soil test (tables 41 and 42) and expected yield. Use a nitrogen-phosphorus starter solution when setting the plants to improve establishment and early growth. A suitable starter solution can be made by mixing into each 100 gallons of water ¾ to 1 quart of 28 percent liquid nitrogen (UAN) and 2 to 3 quarts of liquid 10-34-0 fertilizer. Four to 5 weeks after transplanting or after first fruit set, topdress with 40 to 50 pounds of nitrogen per acre. A total of 80 to 100 pounds of nitrogen is usually adequate, though an additional 25 pounds of nitrogen may be beneficial when high yields are anticipated or adverse weather conditions results in the loss of nitrogen by leaching or denitrification. When tomatoes are grown after soybeans, reduce the amount of nitrogen applied by 30 pounds per acre.

Nearly all fresh market tomatoes are grown on raised beds and plastic mulch with trickle irrigation. Before forming beds and laying plastic, broadcast 30 pounds of nitrogen per acre, the recommended amount of phosphorus and the recommended amount of potassium minus the amount that will be supplied through trickle irrigation. Including 1 pound of boron per acre in the broadcast fertilizer may have some beneficial effect in reducing shoulder checking. Incorporation of broadcast fertilizer prior to bedding is optional. Nitrogen and potassium can be effectively added through trickle irrigation. When this is done, reduce the amount of potassium broadcast according to the amount that will be added through the irrigation. Supply the equivalent of about 1 pound of nitrogen and 1.5 to 2.5 pounds of K_2O per acre per day through the trickle system.

Table 41. Phosphorus recommendations for three tomato yields.

Soil test	Yield (tons/A) 20	25	30
ppm	- - - - - lb P_2O_5/A - - - - -		
15	166	170	174
25	116	120	124
35	66	70	74
45-80	16	20	24
90	0	0	0

Numbers highlighted are maintenance amounts.

Table 42. Potassium recommendations for two tomato yields.

Soil test	6 tons/A					12 tons/A			
	CEC 4	8	12	16		CEC 4	8	12	16
ppm	- - lb K_2O/A - -					- - lb K_2O/A - -			
40	194	217	244	275		264	287	300	300
80	146	161	180	203		216	231	250	300
85	140	154	172	194		210	224	242	264
95	140	140	156	176		210	210	226	246
105	140	140	140	158		210	210	210	228
115	140	140	140	140		210	210	210	210
125	70	140	140	140		105	210	210	210
135	0	70	140	140		0	105	210	210

Numbers highlighted are maintenance amounts.

Market Garden (mixture of crops):
Broadcast and incorporate 50 pounds of nitrogen per acre plus the amounts of phosphorus and potassium recommended by a soil test. When a starter fertilizer is placed 2 inches to the side and 2 inches below the seed depth, it may include 30 pounds of nitrogen, up to 100 pounds of phosphate (P_2O_5) and 40 pounds of potash (K_2O). For cole crops and root crops, include 1 to 2 pounds of boron per acre. Depending on the crop, make one or two sidedress applications of 30 to 40 pounds of nitrogen per acre. Suggested total nitrogen rates are listed in Table 4. More nitrogen generally is needed by leafy green vegetables, tomatoes, peppers, sweet corn and rhubarb than by beans, peas cucumbers, melons, root crops or asparagus. Avoid overuse of nitrogen to minimize nitrate accumulation in vegetables and to minimize the potential of leaching loss. Most vine crops will benefit from foliar application of manganese (1 to 2 pounds per acre) when the soil pH is above 6.5.

Use a nitrogen-phosphorus starter solution when setting vegetable transplants (see tomato section). Starter solutions are most likely to benefit early growth when soils are cool (below 55 degrees F).

Bulletins Cited:

Circular Bulletin 53. 1932. Fertilizer recommendations for 1932. C.E. Millar, G.M. Grantham and P.M. Harmer. Michigan State College Agricultural Experiment Station.

Extension Bulletin E-159. 1946. Fertilizer recommendations for 1946. Michigan State College Extension Service.

Extension Bulletin E-159. 1954. Fertilizer recommendations for Michigan Field Crops. Michigan State College Cooperative Extension Service.

Extension Bulletin E-159. 1963. Fertilizer recommendations for Michigan Field Crops. Michigan State University Cooperative Extension Service.

Extension Bulletin E-471. 1988. Lime for Michigan soils. Michigan State University Cooperative Extension Service.

Extension Bulletin E-486. 1998. Secondary and micronutrients for vegetable and field crops. Michigan State University Extension.

Extension Bulletin E-498. 1998. Sampling soils for fertilizer and lime recommendations. Michigan State University Extension.

Extension Bulletin E-550. 1970. Fertilizer recommendations for vegetable and field crops in Michigan. Michigan State University Cooperative Extension Service.

Extension Bulletin E-1616. 1983. Soil sampling for no-till and conservation tillage crops. Michigan State University Cooperative Extension Service.

Extension Bulletin E-2567. 1995. Tri-state fertilizer recommendations for corn, soybeans, wheat and alfalfa. Michigan State University Extension.

Extension Bulletin E-2779. 2003. Nitrogen management for Michigan potatoes. Michigan State University Extension.

North Central Regional Research Publication No. 221. 1998. J.R. Brown (ed.). Recommended chemical soil test procedures for the North Central Region. Missouri Agricultural Experiment Station.

North Central Multistate Report 348. 2001. Soil sampling for variable rate fertilizer and lime application. Minnesota Agricultural Experiment Station.

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