Soil Test Interpretations and Recommendation Guide Commercial Fruits, Vegetables and Turf

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Introduction

This bulletin presents nutrient management information for commercial fruit and vegetable growers, and an explanation of fertilizer recommendations that accompany soil test results that are analyzed by the University of Missouri Soil and Plant Testing Laboratory. On the last two pages of this bulletin are copies of the Soil Sample Information Form for Commercial Fruits, Vegetable and Turf (MP 727) used by the Soil Testing Laboratory. Those growers who wish to have soils analyzed for commercial fruits, vegetables and turf should submit samples with these forms. The forms can be obtained from County Extension Offices or the Soil Testing Laboratories in Columbia or Portageville. Proper submission of samples of the requested information will result in a better fertilizer recommendation and interpretation of the soil test results.

The nutrition of fruits and vegetables is a very important aspect of their production. Adequate nutrition is required not only for optimum yield, but also for optimum quality. In general, production practices that lead to the greatest yield are associated with the best quality. Proper fertilization for many fruit crops requires a balance between vegetative and fruit growth. Proper fertilization also promotes uniform crop growth and maturity, which are important at harvest.

With the exception of carbon, hydrogen and oxygen, plant nutrients are primarily supplied to plants by the soil. Fertilizers, manure and amendments are often applied to soils to supplement nutrients supplied by the soil. Responsible nutrient management considers first a soil's ability to supply plants with essential nutrients. Soil testing is a nutrient management strategy grounded in research that measures essential plant nutrients in the soil and relates the amounts to crop needs. Fertilizer and amendment recommendations are based on soil tests, soil type, crop yield, crop age (for some perennial crops) and past crop management. By eliminating the guesswork of providing nutrients, the efficiency of supplying nutrients to crops can be increased. Thus growers may benefit from lesser costs and better yields. Also lesser amounts of nutrients are less likely to contribute to non-point source pollution such as phosphorus contamination of surface water or nitrates leaching into groundwater.

Soil Sampling

Collecting a soil sample is a very important part of soil testing. The soil sample must be representative of the area or field to be sampled. Otherwise, interpretations and recommendations based on the results could be misleading, inaccurate and potentially counterproductive. Errors in collecting a representative sample may be made in choosing the area to sample or in the collection of the sample itself.

Individual samples should be taken from areas that will be managed the same and have similar properties which could affect soil test values. Topography, slope, soil texture, drainage, topsoil color, previous fertilizer, lime and manure applications, and cropping history all are factors to consider when selecting an area to sample. A soil survey map may be helpful for determining areas with similar soil properties. Twenty acres may be represented by one sample for uniform or level fields, but for non-uniform areas one sample should represent only 5 acres. When specific crops are grown on small acreages, an even smaller area may be sampled.

Because soils are inherently variable in their distribution of plant nutrients, an individual soil sample should be a composite of several subsamples. Thus the composite sample becomes an "average" of the soil in the area to be represented. Each composite sample should consist of 15-30 subsamples. The more variable the soil, the more subsamples should be collected. Avoid sampling near dead furrows, old fence rows, previous locations of manure or brush piles or any other unusual area. Sample at least 300 feet from crushed limestone or gravel roads, as the road dust can affect soil pH. The collection of subsamples should be mixed, and cores or chunks of soil broken apart. From this mixed soil, a pint of soil should be sent to the Soil Testing Laboratory, preferably in a soil sample bag or box. Soil boxes are available from either of the University of Missouri Soil Testing Laboratories in Columbia or Portageville, or from county extension centers.

The proper depth for collecting soil samples is 6-8 inches for annual crops and 3-4 inches for turf. For established trees or perennial crops, collect soil to a 6 inch depth. At establishment it is preferable to take another sample at 6 to 12 inches for perennial crops, provided there exists the means to fertilize the deeper volume of soil. A soil tube, soil auger or a spade are all appropriate tools for collecting samples. To avoid contamination of the sample, a clean plastic pail is a preferred container into which to collect the sample.

Soil samples may be taken any time of the year, although if results are to be compared across years, it is best to collect the samples at the same time of the year. When obtaining soil test information for specific nutrients, differing sampling frequencies may be necessary. These will be covered more completely later in the bulletin.

Soil Testing

Once soil samples arrive at a soil testing laboratory, soil testing procedures are used to determine nutrient amounts in the soil that may be available to crops. Most soil tests are only an **index** of the total amount of nutrients available to a crop. Through research the index are correlated to crop response in the field. Soil test values within a range are grouped (given ratings) according to the probability of crop response to supplemental fertilizer or amendment applications. Table 1 shows an example of the ratings that might be used to describe the probability of a response to fertilizer.

Table 1. General relationship between soil test rating, crop yield and the probability of response to fertilizer.

Soil Test Rating	Average relative yield without fertilizer (%)	Probability of response to fertilizer	Fertilizer Recommendation
Very low	<50	greater than 90%	Large applications for soil building purposes
Low	50 - 75	75 - 90	Annual applications to maximize crop response and increase soil fertility
Medium	75 100	30 - 75	Annual applications to maximize yields
High	100	less than 30%	Small annual applications to maintain soil level. Amounts may be doubled and applied in alternate years.
Very high	100	unlikely	None until level drops back into the high range.

Several soil test nutrient values are reported in lb/acre. Unfortunately, this sometimes results in the incorrect interpretation that soil test values can be directly related to recommended amounts of fertilizer in lb/acre. For example it would be incorrect to conclude that a soil with a soil test value of 10 lb P/acre would require 35 lb P/acre to bring the soil "up to test" to a high rating of 45 lb P/acre.

A listing of the soil test procedures used by the Soil Testing Laboratories is provided below. The first eight listed are provided with a regular soil test analysis.

1. Soil pH_s (1:1 solution:soil suspension). Solution is 0.01M $CaCl_2$
2. Lime requirement (Neutralizable Acidity) Uses the Woodruff Buffer Solution
3. Organic Matter (%) Loss on ignition
4. Extractable Phosphorus (Bray-1 P)
5. Exchangeable Potassium (Ammonium Acetate (NH_4OAc) extraction)
6. Exchangeable Calcium (NH_4OAc extraction)
7. Exchangeable Magnesium (NH_4OAc extraction)
8. Cation Exchange Capacity (estimated from Exchangeable K, Ca, Mg, and Neutralizable Acidity)
9. Extractable Zinc (DPTA extraction)
10. Extractable Sulfur (calcium phosphate in acetic acid extraction)
11. Extractable iron, manganese and copper (DPTA extraction)
12. Exchangeable Sodium (NH_4OAc extraction)
13. Hot water extractable Boron (0.1% $CaCl_2 \cdot H_20$)
14. Nitrate-nitrogen and Ammonium-nitrogen (2 M KCl extraction)
15. Soluble salts (electrical conductivity in a 1:1 soil:water saturation extraction)
16. Particle size analysis (Hydrometer method)

Basis for Recommendations

Field studies correlate the fertilizer nutrient amounts required by crops to the level of nutrients measured by soil test. When field data are insufficient or a soil test does not reliably measure a nutrient for crop availability, fertilizer recommendations are based on the total amount of a nutrient needed by a crop and an estimated supply by the soil. Because different nutrients vary in the types of reactions with the soil, strategies vary to provide efficient and economical recommendations. For example, a nutrient like nitrogen tends not to accumulate in the soil in plant available forms. Whereas, other nutrients can be accumulated through several growing seasons that remain in plant available forms.

Phosphorus and potassium are both nutrients that are used in large amounts by crops and tend to be held well by the soil. This allows them to be reliably increased in the soil. Thus recommendations are based on supplying the current year's crop needs (maintenance) and future crop need (buildup). A maintenance amount is that amount of the nutrient removed by the crop in a single season. A buildup amount is the amount of nutrient needed to gradually increase the soil test value through several growing seasons. An eight year nutrient buildup period provides an economical amortization of fertilizer costs and results in efficient fertilizer use by minimizing rapid fixation of a large amount of a nutrient with the soil.

When soil test values are low, phosphorus and potassium recommendations include both maintenance and buildup amounts. As values approach high levels, the recommended amount is increasingly based on maintenance. At very high levels, the soil is considered to contain an excessive nutrient amount, and a gradual decline in the soil nutrient level is desired. So not even a maintenance amount is recommended. Otherwise without an expected increase in yield, additional fertilization would increase the potential for environmental pollution. In addition to being environmentally hazardous and economically wasteful, excessive fertilization can lead to legislated fertilizer management or a ban of agricultural production altogether in specific areas.

Fertilizer nutrient recommendations provided in this publication are not varied by yield goal, but rather are varied by nutrient soil test values. Recommended amounts of fertilizer are decreased by increasing amounts of the nutrient measured in a soil test. Higher yields are not to be expected by greater fertilization, but by better management. Such management changes may include row width, water supply, plant population, etc. When improved management results in greater yields, then greater amounts of phosphorus and potassium may be applied to replace the greater amounts of nutrients removed by the harvested portion of the crop.

Fertilizers

All commercially sold fertilizers report the percent of primary nutrients (nitrogen, phosphorus and potassium) that are contained within the fertilizer. These three nutrient percentages are referred to as the fertilizer grade. It is shown on the label of the fertilizer and is guaranteed by the manufacturer. Nitrogen is expressed on an elemental basis (N), while phosphorus and potassium are reported on an oxide basis, P_2O_5 and K_2O. This method of reporting should not be confused with the chemical forms in which the nutrients are present in the fertilizer. For instance a commonly used fertilizer, diammonium phosphate, has a grade of 18-46-0. The fertilizer has 18% nitrogen and 46% phosphorus (as P_2O_5). However, the nitrogen in this fertilizer is in the ammonium form (NH_4^+) and the phosphorus is in the phosphate form ($HP0_4^{-2}$). To accommodate fertilizer grades, fertilizer recommendations are also based on amounts of N, P_2O_5 and K_2O per area (usually per acre or per 1000 ft^2).

For each primary nutrient, many different fertilizer sources are available. Some fertilizers are sold as complete fertilizers, i.e., they contain all three primary nutrients. Single nutrient fertilizers are also widely available. Urea (46-0-0) and potassium chloride (0-0-60) are examples of single nutrient fertilizers for nitrogen and potassium, respectively. Complete fertilizers are often a blend of single nutrient fertilizers. Many different fertilizer sources exist. Aside from fertilizer grade, each has different properties which influence their management and the situations in which they are best used.

Soil pH

Soil pH is a measurement of a soil's reaction, i.e., its acidity or alkalinity. Most Missouri soils have a pH less than 7.0 and thus have varying degrees of acidity. Alkaline soils (those with a pH greater than 7.0) are typically not native to Missouri, but usually result from or repeated lime applications or circumstances of location (e.g. lime dust from roads). As an important chemical property, a soil's acidity level affects nutrient availability, the activity of soil microbes and the growth of plants

The University of Missouri Soil Testing Laboratory measures soil acidity in a very dilute salt solution, and it is reported as a salt pH (pH_s). Commercial laboratories typically measure soil pH in water. Although both methods accurately measure soil acidity, salt pH is usually 0.5 pH unit less than pH measured in water.

The acidity measured in either water or a dilute salt solution is a measure of the soil's active acidity. On soils that are strong to very strongly acid, a much larger reserve acidity exists. A laboratory procedure different from pH measures this acidity, which is called neutralizable acidity (NA). From this value lime recommendations are determined. As with pH, commercial laboratories typically use a different laboratory measurement to determine reserve acidity. Their measurement of reserve acidity is reported as a buffer pH. While both measurements are proper methods of reserve acidity, there is not a good means for comparing the two. The method used for calculating a lime recommendation from a value of neutralizable acidity cannot be used with a buffer pH value.

Fruit and Vegetable and Turf pH_s Preferences and Limestone Recommendations

Horticulture crops vary in preferable soil pH_s. Most prefer a pH_s between 5.5 and 6.5. Where the pH_s is much greater or lesser than the preferred range, some corrective measure is recommended. Table 2 shows preferred pH_s ranges, and the pH_s values at which an amendment should be applied to correct the pH_s.

Some crops benefit from either high or low pH_s. Blueberries prefer acidic soil and on most Missouri soils, lowering the pH_s is necessary for economical blueberry production. Other crops grow better at high or low pH_s in response to disease suppression. Scab (*Streptomyces scabies*) is a soil inhabiting fungus of potatoes that is suppressed by low pH_s (< 4.7). The optimum pH_s range for scab resistant potatoes is 5.1 – 5.7. When potatoes are grown in rotation with other crops that do not prefer a low pH_s, lime should be applied after the potato harvest and before planting the rotation crop. Alternatively, the soil fungus that causes Clubroot of cole crops is increasingly suppressed as pH_s becomes greater than 6.5. Yet the preferred pH_s range is no more than 6.5-7.0, as crop growth is decreased for other reasons at greater pH_s.

Table 2. Preferred pH_s ranges and recommended correction.

	Preferable pH_s range	High pH correction	Low pH correction
Most fruits and vegetables	5.5-6.5	pH_s > 7.0, apply sulfur	pH_s < 5.5, apply limestone
Blueberries Potatoes	4.3 - 5.0	pH_s > 5.5, apply sulfur	pH_s < 3.5, apply limestone
Asparagus Beets Cabbage	5.5 - 7.5	pH_s > 7.5, apply sulfur	pH_s < 5.5, apply limestone
Turf	5.5 - 7.2	pH_s > 7.2, apply sulfur	pH_s < 5.5, apply limestone

Soil test reports provide a rating of the measured pH_s (Table 3). Soils with a pH_s rating of very low to low have a definite need for limestone. The low pH_s is likely limiting yield potential. A medium pH_s indicates that soil acidity is near a yield limiting point, and limestone may be needed in coming seasons, as the soil acidifies naturally or through the application of manure and/or ammonium based fertilizers. A high pH_s rating indicates that the soil acidity is optimum for crop growth. A very high rating indicates that the pH_s is above the preferred range, and nutrient availability may be reduced. A very high pH_s may also be an indicator of other soil problems that could be limiting to growth such as salinity or excessive sodium.

Table 3. pH_s rating for Vegetables, Turf and Fruit Crops

	Vegetables, Fruits, Turf	Blueberries, Potatoes
Rating	pH range	
Very low	< 4.5	< 3.5
Low	4.5 – 5.3	3.5 – 4.3
Medium	5.3 – 6.0	4.3 – 5.0
High	6.0 – 7.5	5.0 – 6.0
Very high	> 7.5	> 6.0

Guidelines for increasing pH_s.

Recommendations for increasing pH_s are based upon a single application of lime with the objective of increasing the pH_s to the optimum range, 6.1 – 6.5, to a depth of six inches. Limestone is recommended by amounts of lb ENM/acre. Effective neutalizable material (ENM) is used as a means for standardizing limestone. Limestone originating from different quarries can vary in effectiveness because of purity and particle size. Both of these variables are used to calculate an ENM value for limestone. Purity is defined by the calcium carbonate equivalent. It represents how much acidity is neutralized by a given amount of limestone. Fineness of grind or particle size affects how rapidly and thoroughly limestone reacts with soil. Small or finely ground particles react with a larger soil volume and thus neutralize acidity in a lesser amount of time than larger particles. All limestone sold in Missouri must have an ENM rating. Although limestone is the most commonly applied amendment to increase soil pH, any liming material can be used with ENM recommendations.

The equation used to calculate ENM is given below:

$$ENM = 400 * \left[N.Acid - \frac{N.Acid}{41.425 - 10.3078 pH_s + 0.629 * pH_s^2} \right]$$

Suppose a recommendation suggests a need of 1500 ENM (lb/ton), and limestone available at the local quarry has an ENM rating of 500 (lb/ton). The proper amount of limestone to apply would be three tons/acre. For a more complete discussion of ENM see UMC Ext. Pub. G09107, "Missouri Limestone Quality-What is ENM."

Because it is undesirable to increase pH_s for blueberries and potatoes to the pH_s targeted in the above equation, an ENM of 500 is recommended when the pH_s is less than 3.5. Soil sample again in a year to determine if the limestone application increased pH_s to the desired range.

Guidelines for Lowering pH_s.

Acidifying soils (lowering pH) for better crop growth is likely to be economical for acid loving blueberries. Blueberries require acid soils for growth and respond well to amendments that decrease pH. For other crops, higher than desired pH may not sufficiently reduce growth to warrant the cost of applying acidifying amendments to large acreages. Few soils in Missouri have excessively high pH for horticultural crops.

Recommendations for lowering pH_s are based on the application of finely ground elemental sulfur. Application rates to decrease the pH_s by one pH_s unit in the surface six inches are shown in Table 4. Rates vary by the soil's cation exchange capacity (CEC), which can be related to soil texture. Sulfur's effect on soil pH_s is slow and typically takes several months to react with the soil. It should be incorporated and for perennial plants applied a year before planting.

Table 4. Soil texture and CEC effects on sulfur recommendation to lower pH_s.

Soil Texture	CEC	Ground Sulfur*
	(meq/100 g)	(lb/acre)
Sand, Sandy loam	< 10	350
Silt loam, Loam	10 - 18	600
Clay loam, Clay	> 18	1000

*Amount necessary to reduce the soil pH_s by one unit.

Other materials can be used to lower soil pH_s. or maintain a low soil pH_s. Iron sulfate reacts faster than elemental sulfur (within 3 to 4 weeks), yet it requires 4 to 5 times more material. Single applications should not exceed 2 tons/acre. Greater amounts will cause salt injury. Ammonium sulfate and urea when used as nitrogen sources will maintain low soil pH_s. Although higher rates could decrease pH_s, they are not recommended because of salt injury.

Soluble Salts

Soluble salts refer to electrolyte compounds in the soil that dissolve in the soil water. Soluble salt level is also referred to as the salinity level. At high levels soluble salts can reduce water uptake in the plant, restrict root growth, cause root tip burn and in general reduce plant growth and fruit or vegetable yield. Soluble salts compete with plants for soil water. Plant symptoms of excessive salts are similar to those from water stress. Seed germination and seedling growth are the most sensitive growth stages to high salinity levels. Plant species and cultivars vary in their sensitivity to soil salts.

The soil test to measure soluble salts is electrical conductivity. It is determined from a saturated paste extract and is reported in units of mmhos/cm. The sensitivity of plants to soluble salt levels is shown in Table 5. The salt tolerances of specific horticultural crops is given in Table 6.

Most Missouri soils are sufficiently leached by precipitation such that very low salinity levels exist. Human activities are usually the cause of high salinity levels in Missouri. Over fertilization, fertilizer spills or placing fertilizer too close to roots can create soluble salt problems for plants.

Table 5. Soluble salt levels and relative plant sensitivity.

Electrical Conductivity	Salinity Level	Effect on plant growth
mmhos/cm		
0 to 2	non-saline	none
2.1 to 4	very slightly saline	sensitive plants are inhibited
4.1 to 8	moderately saline	many plants are inhibited
8.1 to 16	strongly saline	most cultivated plants inhibited
> 16	very strongly saline	few plants are tolerant

Table 6. Salt tolerances of horticultural crops.

Non-tolerant	Slightly tolerant	Moderately tolerant	Tolerant
0 to 2 mmhos	2 to 4 mmhos	4 to 8mmhos	8 to 16mmhos
Blueberry	Apple	Beet	Asparagus
Carrot	Cabbage	Broccoli	
Beans	Cucumber	Musk Melon	
Onion	Grape	Spinach	
Pea	Lettuce	Squash	
Radish	Peach	Tomato	
Raspberry	Pear		
Strawberry	Pepper		
	Plum		
	Potato		
	Sweet Corn		
	Sweet Potato		

Primary Nutrients

Nitrogen, phosphorus and potassium are referred to as primary nutrients because plants use these nutrients in greater amounts than other nutrients. Soils typically contain these nutrients in amounts sufficient to supply many years of crops. However, the annual supply of these nutrients may be deficient for optimum plant growth.

Nitrogen Recommendations

Nitrogen is the nutrient most often limiting for crop growth. Soils generally contain large amounts of nitrogen in soil organic matter, which releases it to plant available forms. However, the release rate is usually too slow to adequately supply a growing crop. Within crops' rooting zone, these forms are ephemeral because of plant uptake and soil reactions. Consequently, a reliable soil test for determining nitrogen availability has not been developed.

Nitrogen supply to crops is estimated from variables that directly and indirectly affect nitrogen release from organic matter. Soil organic matter content and CEC are two variables measured in the soil test that are used for calculating available nitrogen. If a legume crop has preceded the crop to be grown, the nitrogen recommendation is reduced by an amount called the nitrogen credit. Another variable is an individual crop's requirement for nitrogen. Crops vary in the amount of nitrogen needed to produce a marketable product and also in their ability to obtain nitrogen from the soil.

Fruit Crops

Nitrogen recommendations for fruit crops vary only by organic matter content and whether plantings are new or established (Table 7). Less nitrogen is recommended for high organic matter soils as they mineralize more nitrogen than soils with lower organic matter levels. Newly planted fruit trees require little nitrogen, as at this time roots must become established. Excess nitrogen at this time encourages top growth at the expense of root growth. In Table 7 the Newly Established category for fruit trees refers to young non-fruiting trees. At this growth stage higher nitrogen rates encourage rapid shoot growth. Once established and trees mature to become fruit bearing, a decreased nitrogen rate for fruit crops maintains a balance between vegetative growth and fruit development. Under fertilizing crops decreases yield and quality, while over-fertilization can result in poor fruit color, delayed maturity and irregular ripening, decreased winter-hardiness and increased disposition for disease.

Table 7. Nitrogen recommendations for fruit crops.

	Organic Matter Level/Rating			
	< 2.5 %	2.5–4.5%	> 4.5 %	
	Low	Medium	High	Application Time
Newly Established	------------- lb/acre		------------	
Apples/Pears	60	45	30	½ at planting, ½ sidedress in June
Grapes	60	45	30	½ at planting, ½ sidedress in June
Blueberries	40	30	20	Sidedress when 2nd flush of growth starts
Brambles†	60	50	40	½ at planting, ½ sidedress in June
Stone Fruits‡	60	45	30	½ at planting, ½ sidedress in June
Strawberries	80	70	60	½ at planting, ½ sidedress in August
Established				
Apples	30	20	10	Sidedress in spring
Grapes	30	20	10	Sidedress in spring
Pears	30	20	10	Sidedress in spring
Brambles	60	50	40	Sidedress in spring
Stone Fruits	60	40	20	Sidedress in spring
Strawberries	80	70	60	Topdress after renovation
Age				
Blueberries 1-2 year		60		
3 year		80		Sidedress in spring
4 year		100		

† Raspberries, Blackberries, Gooseberries,
‡ Peaches, Plums, Apricots, Cherries, Nectarines

Vegetable Crops

The calculation of nitrogen recommendations for vegetable crops is diagrammed below.

Recommended nitrogen (lb/acre) = Maximum N amount (Table 8) – Organic Matter Adjustment (Table 9) – Legume Credit (Table 10)

The first part of the equation determines the maximum amount of nitrogen needed by a crop (Table 8). This amount is based on a yield goal, which is listed beside the required nitrogen amount. The other two parts of the equation reduce the amount of nitrogen recommended. The Organic Matter Adjustment is an estimate of the amount of nitrogen released from organic matter during a growing season. It is dependent on CEC and the percent organic matter in the soil (Table 9). Greater amounts of nitrogen are released from soils which have greater organic matter levels and CEC. The Legume Credit estimates the amount of nitrogen that is supplied from the breakdown of a legume crop residue from the previous year (Table 10).

Table 8. Nitrogen needs for vegetable crops and application methods.

Crop	Yield Goal	Maximum Required N.*	Suggested application times
	cwt/acre	lb N/acre	
Asparagus (New)	-		½ at planting, 2/3 sidedress during cultivation
Asparagus (Est.)	40	80	Topdress before cutting starts or after harvest
Beans/Peas	80	30	Broadcast
Beets	200	100	½ at planting, ½ sidedress 3-5 wks after planting
Broccoli	120	180	1/3 at planting,1/3 sidedress 2 wks after 1/3 sidedress 5 wks after planting
Brussels Sprout	175	140	1/3 at planting,1/3 sidedress 2 wks after 1/3 sidedress 5 wks after planting
Cabbage	400	180	1/3 at planting,1/3 sidedress 2 wks after 1/3 sidedress 5 wks after planting
Carrots	400	120	½ at planting, ½ sidedress when plants are established
Cauliflower	150	180	½ at planting, ½ sidedress when plants are established
Cucumbers	250	100	½ at planting, ½ sidedress when vines begin to run
Lettuce	300	120	½ at planting, ½ sidedress 3-5 wks after planting
Melons	200	100	½ at planting, ½ sidedress when vines begin to run
Onions, dry	500	130	¼ banded at planting, ¾ sidedress 4-5 wks after emergence
Onions, green	150	80	¼ at planting, ½ sidedress 4-5 wks after emergence, ¼ sidedress 4 wks before harvest
Peppers	200	140	½ at planting, ½ sidedress when fruit appear
Potatoes		180	1/5 at planting, 2/5 at emergence, 2.5 at hilling
Pumpkins/Squash	400	70	½ at planting, ½ sidedress when vines begin to run
Radishes	70	60	At planting
Spinach	150	100	½ at planting, ½ sidedress 4-5 weeks after planting
Sweet corn	180	140	1/5 in starter, 2/5 at 4-6 leaf stage, 2/5 at 10-12 leaf stage
Sweet potatoes		60	1/5 at planting, 2/5 at emergence, 2/5 at hilling
Tomatoes	270	130	¼ at planting, ¼ 2 wks after planting, ¼ 4 wks after planting, ¼ 6 wks after planting

*Maximum amount to apply

Plant available nitrogen primarily exists in two forms, ammonium and nitrate. Whether derived from manufactured fertilizer, organic fertilizer, soil organic matter, manure or legume crop residue, nitrogen is eventually converted into ammonium and then nitrate by soil microbes. In the nitrate form, nitrogen may be "lost" from a crop's rooting zone through volatilization or leaching. Both processes can drastically reduce fertilizer efficiency and deprive a crop of adequate nitrogen for optimum growth and yield. Application time of nitrogen fertilizer then becomes important. By coinciding the conversion of nitrate to ammonium with active crop growth, more of the applied nitrogen is available to crops.

Table 9. Organic matter adjustment by CEC and percent soil organic matter.

CEC	Soil Organic Matter	Organic Matter Adjustment
meq/100 g	(%)	(lb/acre)
≤ 10	≤ 0.5	10
≤ 10	0.5 – 1.5	20*OM*
≤ 10	≥ 1.5	30
10 - 18	≤ 2.0	20
10 - 18	2.0 – 4.0	10*OM
10 - 18	≥ 4.0	40
> 18	≤ 2.0	10
> 18	2.0 – 5.0	5.0*OM
> 18	≥ 5.0	25

*OM – percent organic mater

Table 10. Nitrogen credit for previous legume crop.

Crop	Nitrogen Credit (lb/acre)
Alfalfa (good stand)	50
Alfalfa (poor stand)	40
Birdsfoot Trefoil	40
Grass-Legume Hay	40
Grass-Legume Pasture	40
Red Clover	40
Beans/Peas	30

The suggested application times and methods in Table 8 are intended to optimize availability to the crop during the growing season to produce the best quality product. Because nitrogen has such a profound effect on plant growth, ripening, and fruit development, specific application times can greatly affect crop development, for the benefit of the crop (e.g. greater yield or better color) or also to the detriment of the crop value (e.g. splitting of fruit or rank vegetative growth).

Phosphorus Recommendations

Phosphorus exists in the soil as rather insoluble compounds with iron and aluminum at low pH and with calcium at high pH. Upon contact with the soil, phosphorus fertilizer is rapidly converted into these compounds. Plants take up phosphorus in the form of the orthophosphate anion ($H_2PO_4^-$). Soil phosphorus compounds supply the soil solution with orthophosphate in relatively small amounts. The Bray-1 P soil test provides an estimate of phosphorus released from soil compounds that are available to plants. The Bray-2 P soil test is a variation of the Bray-1 P test. It is best used when a field has a history of rock phosphate fertilization.

The insoluble nature of soil phosphorus compounds limits movement of phosphorus in the soil to very short distances, usually less than an inch from the point of application. Consequently for best fertilizer effectiveness, phosphorus fertilizer should be incorporated into the surface soil or banded near the crop rather than topdressed. Banding all or a portion of phosphorus fertilizer near the seed or vegetable transplants is most beneficial in the spring when soils are cool. In such conditions, a readily available supply of phosphorus enhances root growth and uptake of phosphorus.

Soil test phosphorus ratings are the same for both fruit crops and vegetable crops (Table 11).

Table 11. Phosphorus ratings by soil test phosphorus

Soil Test Rating	Soil Test Phosphorus
	lb P_2O_5/acre
Very low	< 20
Low	20 – 40
Medium	40 – 80
High	80 – 200
Very High	> 200

Fruit Crops

Phosphorus fertilizer recommendations for fruit crops are given in Table 12. Recommended amounts for blueberries and brambles are 25 lb P_2O_5/acre less than for the other fruit crops. New plantings receive a 25 percent greater recommendation than established plantings. When the calculated recommendation is less than 20 lb P_20_5/acre but greater than zero, the recommendation is rounded up to 20 lb P_20_5/acre.

Table 12. Phosphorus recommendations for fruit crops.

Crop	Recommendation equation	Maximum amount
		P_2O_5 (lb/acre)
New Plantings	P_2O_5=Established Rec.*1.25	-
Established		
Blueberries	P_2O_5=95 - 1.25*PTest	75
Brambles†	P_2O_5=95 - 1.25*PTest	75
Apples/Pears	P_2O_5=120 - 1.25*PTest	100
Grapes	P_2O_5=120 - 1.25*PTest	100
Stone Fruits‡	P_2O_5=120 - 1.25*PTest	100
Strawberries	P_2O_5=120 - 1.25*PTest	100

† Raspberries, Blackberries, Gooseberries,
‡ Peaches, Plums, Apricots, Cherries, Nectarines

Vegetable Crops

Ratings for soil test phosphorus for vegetables are the same as that of fruit crops. Recommendations for fertilizer phosphorus are based on four equations, which are provided in Table 13. These recommendations provide for a buildup when soil tests are low, maintain nutrient levels when soil tests are medium to high and allow for gradual drawdown when soil tests are very high.

Table 13. Phosphorus recommendations for vegetable crops.

Crop	Yield Goal	Soil Test Phosphorus in lb P_2O_5/acre: 10	30	50	70	90	110	130	150	170	190	Equation
	ton/acre	Phosphorus recommendation, lb P_2O_5/acre										
Asparagus (Est.)	2	140	110	90	60	40	10	0	0	0	0	P_2O_5 = 150 – 1.25*PTest
Asparagus (New)	-	215	190	165	140	115	90	65	40	20*	0	P_2O_5 = 225 – 1.25*PTest
Beans, Lima	2	140	110	90	60	40	10	0	0	0	0	P_2O_5 = 150 – 1.25*PTest
Beans, Snap	4	140	110	90	60	40	10	0	0	0	0	P_2O_5 = 150 – 1.25*PTest
Beets	13	215	190	165	140	115	90	65	40	20*	0	P_2O_5 = 225 – 1.25*PTest
Broccoli	4	215	190	165	140	115	90	65	40	20*	0	P_2O_5 = 225 – 1.25*PTest
Brussels Sprout	5	215	190	165	140	115	90	65	40	20*	0	P_2O_5 = 225 – 1.25*PTest
Cabbage	20	215	190	165	140	115	90	65	40	20*	0	P_2O_5 = 225 – 1.25*PTest
Cantaloupes	9	215	190	165	140	115	90	65	40	20*	0	P_2O_5 = 225 – 1.25*PTest
Carrots	15	175	150	125	100	75	50	25	0	0	0	P_2O_5 = 188 – 1.25*PTest
Cauliflower	8	215	190	165	140	115	90	65	40	20*	0	P_2O_5 = 225 – 1.25*PTest
Cucumbers	15	215	190	165	140	115	90	65	40	20*	0	P_2O_5 = 225 – 1.25*PTest
Lettuce	20	175	150	125	100	75	50	25	0	0	0	P_2O_5 = 188 – 1.25*PTest
Onions, dry	20	250	225	200	175	150	125	100	75	50	25	P_2O_5 = 263 – 1.25*PTest
Onions, green	8	215	190	165	140	115	90	65	40	20*	0	P_2O_5 = 225 – 1.25*PTest
Peas	3	140	110	90	60	40	10	0	0	0	0	P_2O_5 = 150 – 1.25*PTest
Peppers	10	215	190	165	140	115	90	65	40	20*	0	P_2O_5 = 225 – 1.25*PTest
Potatoes		250	225	200	175	150	125	100	75	50	25	P_2O_5 = 263 – 1.25*PTest
Pumpkins	20	175	150	125	100	75	50	25	0	0	0	P_2O_5 = 188 – 1.25*PTest
Radishes	4	175	150	125	100	75	50	25	0	0	0	P_2O_5 = 188 – 1.25*PTest
Spinach	6	175	150	125	100	75	50	25	0	0	0	P_2O_5 = 188 – 1.25*PTest
Squash	15	175	150	125	100	75	50	25	0	0	0	P_2O_5 = 188 – 1.25*PTest
Sweet corn	10	175	150	125	100	75	50	25	0	0	0	P_2O_5 = 188 – 1.25*PTest
Sweet potatoes	10	175	150	125	100	75	50	25	0	0	0	P_2O_5 = 188 – 1.25*PTest
Tomatoes	30	250	225	200	175	150	125	100	75	50	25	P_2O_5 = 263 – 1.25*PTest
Watermelons	11	215	190	165	140	115	90	65	40	20*	0	P_2O_5 = 225 – 1.25*PTest

*When the calculated recommendation is less than 20 lb P_2O_5/acre, the recommendation is rounded up to 20 lb P_2O_5/acre.

Potassium Recommendations

Available potassium exists in the soil as the K^+ ion. Because potassium attaches to clay minerals in the soil, movement and supply of potassium in the soil is dependent on soil texture. In soils with loam, silt loam or heavier textures, potassium movement is greatly restricted. Thus potassium fertilizer can be applied to buildup soil potassium levels. Also incorporation is preferred to topdressing. On sandy soils with lesser amounts of clay, potassium moves more freely such that it can actually leach from the root zone. Fall application of potassium on these soils is not recommended, since the potassium may leach from the root zone during the winter months.

Potassium chloride, which contains 60 percent K_20, is the cheapest and most common potassium fertilizer. Potassium, like phosphorus, can be beneficial when banded near the seed at planting. Due to the potential for salt injury, potassium should not be applied directly with the seed, but rather 2-3 inches from the seed. On low potassium testing soils, the bulk (at least half) of recommended potassium should be applied broadcast and the rest in a band. No more than 50 lb K_20 should be applied as a banded starter near the seed.

Potassium ratings are the same for fruit and vegetable crops (Table 14).

Table 14. Potassium ratings by soil test potassium level

Soil Test Rating	Soil Test Potassium
	lb P_2O_5/acre
Very low	< 65
Low	65 – 110
Medium	110 – 220
High	220 – 330
Very High	> 330

Fruit Crops

Potassium fertilizer recommendations for established fruit crops are generated using three different equations (Table 15). For some crops a set value is used at the higher soil test potassium levels. However the range of soil test potassium at which recommendations change are not consistent across crops. So the crops are grouped below according to their potassium recommendations. For all crops fertilizer recommendation for new plantings 1.25 times the established recommendation.

Table 15. Potassium recommendations for fruit crops.

Crop	Recommendation equations	Recommended Potassium (lb K_2O/acre)			
	Soil Test Potassium Ranges (lb K_2O)	# 230	> 230		
Blueberries	K_2O=230 - 1.0*Ktest – 150 lb K_20 maximum	Use Equation	0		
	Soil Test Potassium Ranges (lb K_2O)	<180	180-220	220-260	>260
Brambles†	K_2O=210 - 1.0*KTest – 100 lb K_20 maximum	Use Equation	30	20	0
	Soil Test Potassium Ranges (lb K_2O)		< 200	220-330	>330
Other Fruits‡	K_2O=250 - 1.0*KTest – 200 lb K_20 maximum		Use Equation	30	0

† Raspberries, Blackberries, Gooseberries
‡ Apples, Pears, Grapes, Strawberries, Peaches, Plums, Apricots, Cherries, Nectarines

Vegetable Crops

Potassium recommendations for vegetable crops are varied according to soil texture. For sands and loamy sands, recommendations are given in Table 16. For all heavier textured soils, recommendations are given in Table 17. Within both recommendation tables, four equations are used for individual vegetable crops. Similar to phosphorus, the recommended amounts provide for a buildup with low soil test values plus a maintenance amount and only maintenance amounts at high soil test levels

Table 16. Potassium recommendations for vegetable crops on soils with CEC less than.

		Soil Test Potassium Level ($lb\ K_2O/acre$)												
Crop	Yield Goal	50	75	100	125	150	175	200	225	250	275	300	325	Equation
	ton/acre	Potassium recommendation, lb K_2O/acre												
Asparagus (Est.)	2	205	185	160	140	115	95	70	50	25	20*	0	0	K_2O = 250 – 0.9*KTest
Asparagus (New)	-	230	210	185	165	140	120	95	75	50	30	20*	0	K_2O = 275 – 0.9*KTest
Beans, Lima	2	205	185	160	140	115	95	70	50	25	20*	0	0	K_2O = 250 – 0.9*KTest
Beans, Snap	4	205	185	160	140	115	95	70	50	25	20*	0	0	K_2O = 250 – 0.9*KTest
Beets	13	280	160	135	215	190	170	145	125	100	80	55	35	K_2O = 325 – 0.9*KTest
Broccoli	4	330	310	285	265	240	220	195	175	150	130	105	85	K_2O = 375 – 0.9*KTest
Brussels Sprouts	5	330	310	285	265	240	220	195	175	150	130	105	85	K_2O = 375 – 0.9*KTest
Cabbage	20	280	160	135	215	190	170	145	125	100	80	55	35	K_2O = 325 – 0.9*KTest
Cantaloupes	9	280	160	135	215	190	170	145	125	100	80	55	35	K_2O = 325 – 0.9*KTest
Carrots	15	230	210	185	165	140	120	95	75	50	30	20*	0	K_2O = 275 – 0.9*KTest
Cauliflower	8	330	310	285	265	240	220	195	175	150	130	105	85	K_2O = 375 – 0.9*KTest
Cucumbers	15	280	160	135	215	190	170	145	125	100	80	55	35	K_2O = 325 – 0.9*KTest
Lettuce	20	230	210	185	165	140	120	95	75	50	30	20*	0	K_2O = 275 – 0.9*KTest
Onions, dry	20	280	160	135	215	190	170	145	125	100	80	55	35	K_2O = 325 – 0.9*KTest
Onions, green	8	230	210	185	165	140	120	95	75	50	30	20*	0	K_2O = 275 – 0.9*KTest
Peas	3	205	185	160	140	115	95	70	50	25	20*	0	0	K_2O = 250 – 0.9*KTest
Peppers	10	280	160	135	215	190	170	145	125	100	80	55	35	K_2O = 325 – 0.9*KTest
Potatoes		330	310	285	265	240	220	195	175	150	130	105	85	K_2O = 375 – 0.9*KTest
Pumpkins	20	230	210	185	165	140	120	95	75	50	30	20*	0	K_2O = 275 – 0.9*KTest
Radishes	4	205	185	160	140	115	95	70	50	25	20*	0	0	K_2O = 250 – 0.9*KTest
Spinach	10	280	160	135	215	190	170	145	125	100	80	55	35	K_2O = 325 – 0.9*KTest
Squash	15	230	210	185	165	140	120	95	75	50	30	20*	0	K_2O = 275 – 0.9*KTest
Sweet corn	10	230	210	185	165	140	120	95	75	50	30	20*	0	K_2O = 275 – 0.9*KTest
Sweet potatoes		280	160	135	215	190	170	145	125	100	80	55	35	K_2O = 325 – 0.9*KTest
Tomatoes	30	330	310	285	265	240	220	195	175	150	130	105	85	K_2O = 375 – 0.9*KTest
Watermelons	11	280	160	135	215	190	170	145	125	100	80	55	35	K_2O = 325 – 0.9*KTest

*When the calculated recommendation is less than 20 lb K_2O/acre, the recommendation is rounded up to 20 lb K_2O/acre.

Table 17. Potassium recommendations for vegetable crops on with CEC greater than.

Crop	Yield Goal	Soil Test Potassium Level ($lb\ K_2O/acre$) 50	75	100	125	150	175	200	225	250	275	300	325	Equation
	ton/acre	Potassium recommendation, lb K_2O/acre												
Asparagus (Est.)	2	200	175	150	125	100	75	50	25	0	0	0	0	K_2O = 250 – 1.0*KTest
Asparagus (New)	-	225	200	175	150	125	100	75	50	25	0	0	0	K_2O = 275 – 1.0*KTest
Beans, Lima	2	200	175	150	125	100	75	50	25	0	0	0	0	K_2O = 250 – 1.0*KTest
Beans, Snap	4	200	175	150	125	100	75	50	25	0	0	0	0	K_2O = 250 – 1.0*KTest
Beets	13	275	250	225	200	175	150	125	100	75	50	25	0	K_2O = 325 – 1.0*KTest
Broccoli	4	325	300	275	250	225	200	175	150	125	100	75	50	K_2O = 375 – 1.0*KTest
Brussels Sprouts	5	325	300	275	250	225	200	175	150	125	100	75	50	K_2O = 375 – 1.0*KTest
Cabbage	20	275	250	225	200	175	150	125	100	75	50	25	0	K_2O = 325 – 1.0*KTest
Cantaloupes	9	275	250	225	200	175	150	125	100	75	50	25	0	K_2O = 325 – 1.0*KTest
Carrots	15	225	200	175	150	125	100	75	50	25	0	0	0	K_2O = 275 – 1.0*KTest
Cauliflower	8	325	300	275	250	225	200	175	150	125	100	75	50	K_2O = 375 – 1.0*KTest
Cucumbers	15	275	250	225	200	175	150	125	100	75	50	25	0	K_2O = 325 – 1.0*KTest
Lettuce	20	225	200	175	150	125	100	75	50	25	0	0	0	K_2O = 275 – 1.0*KTest
Onions, dry	20	275	250	225	200	175	150	125	100	75	50	25	0	K_2O = 325 – 1.0*KTest
Onions, green	8	225	200	175	150	125	100	75	50	25	0	0	0	K_2O = 275 – 1.0*KTest
Peas	3	200	175	150	125	100	75	50	25	0	0	0	0	K_2O = 250 – 1.0*KTest
Peppers	10	275	250	225	200	175	150	125	100	75	50	25	0	K_2O = 325 – 1.0*KTest
Potatoes		325	300	275	250	225	200	175	150	125	100	75	50	K_2O = 375 – 1.0*KTest
Pumpkins	20	225	200	175	150	125	100	75	50	25	0	0	0	K_2O = 275 – 1.0*KTest
Radishes	4	200	175	150	125	100	75	50	25	0	0	0	0	K_2O = 250 – 1.0*KTest
Spinach	10	275	250	225	200	175	150	125	100	75	50	25	0	K_2O = 325 – 1.0*KTest
Squash	15	225	200	175	150	125	100	75	50	25	0	0	0	K_2O = 275 – 1.0*KTest
Sweet corn	10	225	200	175	150	125	100	75	50	25	0	0	0	K_2O = 275 – 1.0*KTest
Sweet potatoes		275	250	225	200	175	150	125	100	75	50	25	0	K_2O = 325 – 1.0*KTest
Tomatoes	30	325	300	275	250	225	200	175	150	125	100	75	50	K_2O = 375 – 1.0*KTest
Watermelons	11	275	250	225	200	175	150	125	100	75	50	25	0	K_2O = 325 – 1.0*KTest

Secondary Nutrients

The secondary nutrients – calcium, magnesium, and sulfur - are used by plants at amounts almost similar to some of the primary nutrients, but they are less likely to be in deficient supply to a crop.

Calcium Recommendations for Fruits and Vegetables

Available calcium exists in the soil as the Ca^+ ion. It attaches to clay minerals in the soil, so the amount and supply of calcium is dependent on soil texture. Calcium deficiency in field soils is relatively rare, but it may occur on acid sandy soils. For most crops calcium needs can be met by liming the soil to increase soil pH. However for blueberries and potatoes, the maintenance of a low pH can result in low calcium levels, which may require corrective measrures. For potatoes grown in rotation, a small amount of lime (1000 lb/acre) can be applied during the cropping year out of potatoes to meet calcium needs and yet not adversely affect soil pH for the potatoes.

The calcium rating assigned to a soil is dependent on CEC and soil test calcium (Table 18). With less clay to hold calcium on low CEC, sandy soils, less soil test calcium is necessary to obtain a high calcium rating. No corrective Ca applications are recommended for soils with a high Ca rating.

Table 18. Calcium rating by soil test calcium and the soil CEC.

	Soil CEC		
Rating	< 10	10 - 20	> 20
Low	Ca ≤ 1000	Ca ≤ 3000	Ca ≤ 5000
Medium	1000 ≥ Ca ≥ 1600	3000 ≥ Ca ≥ 5000	5000 ≥ Ca ≥ 8000
High	Ca > 1600	Ca > 5000	Ca > 8000

Gypsum (calcium sulfate) is an amendment that supplies calcium. Yet unlike lime it does not have a large effect on soil pH_s. Thus it can be used to supply calcium for acid loving crops. The pH_s ranges for which gypsum is recommended are given in Table 19.

Table 19. Soil pH_s range for which gypsum is recommended for different crops.

Crop	pH_s range to recommend gypsum
Blueberries, potatoes	4.3 – 5.0
Asparagus, Beets, Cabbage	5.5 – 7.0
All other fruits and vegetables	5.5 – 6.5

The recommended amount of gypsum to supply calcium is dependent on the soil CEC and soil test Ca. The formula to calculate a gypsum recommendation is given below.

$$Gypsum\ (lb/acre) = \left\{ \frac{[(CEC * 300) - CaTest] * 30}{400} \right\} * 43.56$$

Calcium deficiencies can occur with some crops despite the presence of adequate calcium in the soil. These deficiencies are related to physiological disorders and include blossom end rot in tomatoes and peppers, tipburn in lettuce, cabbage or cauliflower, black heart in celery, or bitter pit in apples. In soils in which the soil pH has been corrected to 6.0 or above, soil applied calcium will not correct these disorders. Foliar sprays of calcium chloride at a rate of 5 to 10 lb per acre or calcium nitrate at 10 to 15 lb per acre can help overcome these disorders. Solutions of these calcium sources should be applied at a rate of 100 gallons per acre directly to the crop’s foliage.

Magnesium Recommendations for Fruits and Vegetables

Magnesium is available to plants as the Mg^+ ion. Similar to calcium it is primarily held in the soil by clay particles, Its deficiency typically occurs on acid, low CEC or sandy soils. On soils with marginal magnesium levels, deficiencies can be induced by high application rates of potassium or a heavy application of calcitic limestone.

Soil magnesium ratings are based on the percent magnesium saturation which is calculated using soil test magnesium and CEC (see equation below). Magnesium ratings are given in Table 20.

$$\%\ Magnesium\ Saturation = \frac{MgTest/240}{CEC * 100}$$

Table 20. Magnesium rating by soil test magnesium and the soil CEC.

Rating	% Magnesium Saturation
Very low	< 2
Low	2 – 5
Medium	5 – 10
High	10 – 32.5
Very high	32.5 – 55
Extremely high	55

Magnesium recommendations are based on soil test magnesium and CEC and are calculated using the equation below.

$$Mg(lb/acre) = \frac{CEC * (240 - MgTest)}{20}$$

If CEC is less than 6, assume 6, or if greater than 20 assume 20.

Magnesium can be supplied from dolomitic limestone, which can also correct low soil pH that may be coincident with low soil magnesium levels. Other sources of magnesium include potassium magnesium sulfate (trade names of K-Mag or Sul-Po-Mag; 11% magnesium), magnesium sulfate (Epsom salts, 10% magnesium) and magnesium oxides.

Sulfur Recommendations for Fruits and Vegetables

Plant available sulfur exists in the soil as the sulfate ion (SO_4^{2-}). Similar to nitrate-nitrogen, it is susceptible to leaching. Sulfur is supplied to crops by the breakdown of organic matter and by atmospheric deposition of sulfur, which primarily originates from the burning of coal. Sulfur deficiencies are usually found on sandy, low organic matter soils, i.e., soils on which sulfur supply is likely to be small and on which sulfur has a greater potential to leach beyond the root zone. Soil test sulfur ratings are given in Table 21. Fertilizer sulfur is recommended (30 lb/acre) only for soils that test low.

Table 21. Sulfur rating by soil test value.

Sulfur Rating	Sulfur Soil Test Value
	(ppm)
Low	≤ 6
Medium	6 – 12
High	>12

Micronutrients

Micronutrients are used by crops in only small amounts. Yet when micronutrients are deficient, yield reductions can be as severe as those incurred by deficiencies of the primary nutrients. Micronutrients discussed here include: boron, copper, iron, manganese and zinc. Most soils typically supply micronutrients in sufficient amounts for crop needs. However, some soils have a greater proclivity for micronutrient deficiencies. Crops also vary in their demand for micronutrients and their response to applied micronutrients when deficiencies exist (Table 22).

Table 22. Relative response of fruit and vegetable crops to applied micronutrients when soil conditions favor a deficiency.

Crop	Boron	Copper	Iron	Manganese	Zinc
Apples	high	medium	-	high	high
Asparagus	low	low	medium	low	low
Beans, Snap	low	low	high	high	high
Beets	high	high	high	high	medium
Blueberries	low	medium	high	low	-
Broccoli	high	medium	high	medium	-
Cabbage	medium	medium	medium	medium	medium
Carrots	medium	high	-	medium	low
Cauliflower	high	medium	high	medium	-
Cucumbers	low	medium	-	high	-
Grapes	medium	low	high	high	medium
Lettuce	medium	high	-	high	medium
Onions, dry	low	high	-	high	high
Peaches	medium	medium	-	high	high
Pears	medium	medium	-	-	medium
Peas	low	low	-	high	low
Peppers	low	low	-	medium	-
Potatoes	low	low	-	high	medium
Radishes	medium	medium	-	high	-
Raspberries	medium	-	high	high	-
Spinach	medium	high	high	high	-
Strawberries	medium	medium	high	high	-
Sweet corn	low	medium	medium	medium	high
Tomatoes	high	medium	-	medium	-

Because micronutrients are required in such small amounts, they can be combined with primary nutrient fertilizers and applied in the same fertilizer application. For dry fertilizers the micronutrients may be incorporated at the time of granulation or impregneated onto the surface of granules. With liquid fertilizers, micronutrients are well suited to be added to suspension fertilizers or to ammonium polyphosphate (10-34-0).

Boron Recommendations

Boron is available to plants as H_3BO_3. It is mobile in the soil and is subject to leaching, especially on sandy soils. It also does not accumulate in the soil, so boron responsive crops may need annual applications. Boron availability may be reduced on neutral to alkaline soils. A deficiency should be identified by soil test or plant analysis before a boron fertilizer application is made, because excessive boron is very toxic to plants. Soil test ratings for boron are given in Table 23.

Table 23. Boron rating by soil test value.

Boron Rating	Boron Soil Test Value (ppm)
Low	≤ 0.4
Medium	0.4 – 0.9
High	> 0.9

Even when deficient, boron recommendations are small. Boron recommendations are given for fruit crops in Table 24 and for vegetable crops in Table 25. Fertilizer sources of boron include Borax (11% B), Boric acid (17% B) and Solubor (28% B).

Table 24. Boron recommendations for fruit crops.

	Soil Boron Rating		
Crop	Low	Medium	High
	lb Boron/acre recommended		
Apples/Pears	2	1	0
Blueberries	1	0	0
Brambles	2	1	0
Grapes	2	1	0
Stone Fruits	2	1	0
Strawberries	2	1	0

Table 25. Boron recommendations for vegetable crops.

Crop	Soil Boron Rating Low	Medium	High
		lb Boron/acre recommended	
Asparagus (Est.)	1	0	0
Asparagus (New)	1	0	0
Beans, Snap	0	0	0
Beets	4	2	0
Broccoli	4	2	0
Brussels Sprouts	4	2	0
Cabbage	2	1	0
Cantaloupes	1	0	0
Carrots	2	1	0
Cauliflower	4	2	0
Cucumbers	0	0	0
Lettuce	1	0	0
Onion, dry	2	1	0
Onions, green	1	0	0
Peas	0	0	0
Potatoes	1	0	0
Pumpkins	1	0	0
Radishes	2	1	0
Spinach	2	1	0
Squash	1	0	0
Sweet corn	1	0	0
Sweet potatoes	1	0	0
Tomatoes	2	1	0
Watermelons	1	0	0

Copper Recommendations

The copper ion Cu^{+2} readily binds with organic matter in the soil. Copper may be available to plants as the Cu^{+2} ion or as a chelated ion with organic matter. Deficiencies are most likely to occur on organic soils, rather than the mineral soils of Missouri. No fertilizer recommendations are given for copper, but a soil test rating is given in Table 26.

Table 26. Copper rating by soil test value.

Copper Rating	Copper Soil Test Value (ppm)
Low	≤ 0.2
High	> 0.2

Manganese Recommendations

Manganese exists in the soil as various oxides and hydroxides, but is available to plants in the Mn^{+2} form. This form represents only a small fraction of the total amount of manganese in the soil. Soil pH, organic matter levels and aeration all affect manganese availability. Neutral to alkaline soil pH and high organic matter levels decrease manganese availability. Alternatively, very acid soils may have manganese toxicity.

As indicated in Table 22, fruit and vegetable crops are most responsive to manganese deficiency. Soil test ratings for manganese are given in Table 27. If a manganese deficiency occurs, apply 1-2 pounds of manganese per acre. Fertilizer sources of manganese include manganese sulfate (27% Mn) and manganese chelate (12% Mn).

Table 27. Manganese rating by soil test value.

Manganese Rating	Manganese Soil Test Value
Low	≤ 1.0 (ppm)
High	> 1.0 (ppm)

Iron Recommendations

Iron is an abundant element in the soil; however, it exists in relatively small amounts in a plant available form, Fe^{+2}. Iron deficiency symptoms (an interveinal chlorosis) on plants occurs frequently on high pH_s soils ($pH_s > 7.2$) in which soil iron is unavailable to plant roots. Because of the chemical reactions associated with soil iron, soil application of iron, particularly inorganic fertilizer salts, is ineffective. Soil application of iron chelates can be economically effective for some vegetable crops. Deficiencies are best treated by a foliar application of an iron fertilizer solution at a rate of 0.5 to 3.0 lb/acre. Application of farmyard manure can provide a long term correction to iron deficiency by keeping iron in an available chelate form. Ratings of soil iron are given in Table 28.

Table 28. Iron rating by soil test value.

Iron Rating	Iron Soil Test Value (ppm)
Low	≤ 2.1
Medium	2.1 – 4.5
High	> 4.5

Zinc Recommendations

Zinc is available to plants as the ion Zn^{+2}. Zinc deficiencies in Missouri have been noted on sandy or low organic matter soils. Eroded or graded soils that have had the subsoil exposed or alkaline soils may also have zinc deficiencies. Soil application of zinc sulfate can be used to correct a zinc deficiency. These rates are shown in Table 29. If a zinc chelate is used, the amount applied should be reduced to 1/5 that of the inorganic rate. Zinc is relatively non-mobile in the soil, so incorporation or placement in a band is suggested. When banded zinc fertilizer should not come in contact with the seed. A single zinc application may be effective for three to five years. In season deficiencies can be corrected by foliar applications of chelated zinc at a rate of 2 oz of zinc per acre.

Table 29. Zinc rating by soil test value.

Zinc Rating	Zinc Soil Test Value (ppm)	Zinc to apply (lb/acre)
Low	≤ 0.5	10
Medium	0.5 – 1.0	5
High	> 1.0	0

Fertilizer Recommendations For Turf

Soil pH_s

Turf prefers a soil pH_s of 5.5 to 7.2. An acid soil is detrimental to turf growth from several perspectives. First, an acid soil is more likely to be impervious to water. Second, microbial activity is reduced which decreases decay of dead roots and clippings. Consequently, turf becomes root-bound. Third, acid soil can develop toxic amounts of aluminum, iron, and manganese or drastically reduced amounts of available phosphorus. Forth, turf prefers a supply of both ammonium and nitrate, and an acid soil decreases the microbial conversion of ammonium to nitrate.

Lime recommendations are calculated as indicated earlier. For new seedings, lime should be mixed with the surface 6 inches of soil, and precede seeding by several months to allow the lime's reaction with the soil. Do not use more than 100 lb/1000 ft^2 on high cut turf and 50 lb/1000 ft^2 on low cut turf. Burnt lime (CaO or MgO) or hydrated lime ($Ca(OH)_2$ or $Mg(OH)_2$) are not recommended for application directly to turf. These products can burn the turf and stick to the shoes of people walking on the turf.

Nitrogen Recommendations

Turf typically requires fertilizer nitrogen to enhance turf color; promote tillering which thickens turf, and maintain plant vigor. Nitrogen requirements for turf vary according to establishment, species, and management. As turf is often stressed through use, weather, and disease, proper nitrogen management helps turf endure stresses and heal damaged areas. Nitrogen rate, source and fertilizer application time are all important management factors.

Establishing Turf

Less nitrogen is needed to establish turf than to maintain it. Recommended fertilizer amounts are intended to supplement nitrogen released by the soil organic matter. Less nitrogen is released as soil organic matter levels decrease, and in lower CEC soils, the rate of release is decreased. Two equations are used for determining nitrogen recommendations: one for soils with a CEC < 11 and another for soils with a CEC > 11.

When the CEC is <11, the following equation applies:

$$Nitrogen(lb/1000\,ft^2 = \left\{\frac{[2+(CEC-6)*0.2]-\%OM}{43.56}\right\}*25$$

When the CEC is >11, the following equation applies:

$$Nitrogen(lb/1000\,ft^2) = \left\{\frac{[3+(CEC-11)*0.1]-\%OM}{43.56}\right\}*25$$

To obtain nitrogen recommendations in lb/acre, multiply either equation by 43.56. When the calculated recommendation is less than 0.5 and greater than 0, then the recommendation will be 0.5 lb/1000 ft^2.

Maintenance Turf Nitrogen Recommendations

Turf is maintained for several different purposes. Nitrogen recommendations for the various management objectives are based not on a prediction of nitrogen supplied by the soil, but rather on the specific nitrogen needs of turf in relation to its management (Table 30). Fertilizer application times and amounts are coordinated primarily to mollify effects of stress incurred through use and season.

Grass species are classified according to the season in which they grow best. Cool season grasses grow well in the spring and fall. They are fertilized to optimize growth during these times and minimize stress during the warm summer months. Fall fertilization is particularly important. Turf fertilized in the fall will stay green later into the fall, build root reserves to overwinter in a healthier condition and begin growth earlier in the spring. Cool season grasses include: bluegrass, fescue, ryegrass and bentgrass. Warm season grasses grow best and are best fertilized during the warm summer months, and include bermudagrass, zoysiagrass and buffalograss.

Table 30. Nitrogen recommendations for turf according to application month, use and grass species.

Turf Use	Grass Species	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.
		-----	-----	-----	-----	lb/1000 ft^2	-----	-----	-----	-----
Athletic Fields	Cool Season			1		1+		1		1
	Warm Season			2		2				
Commercial Sod	Cool Season			1				1+		1
	Warm Season			2		2				
Low maintenance	Cool Season			1				1+		
	Warm Season						1-			
Golf Courses										
Putting Greens	Bentgrass (soil)	½	½	½	½	½	½	½	½	½
	Bentgrass (sand)*	¼ - ½*	¼ - ½*	¼ - ½*	¼ - ½*	¼ - ½*	¼ - ½*	¼ - ½*	½	½
Fairways	Cool Season	½ - 1		½ - 1		½ - 1			½ - 2	
	Warm Season			1	1		1+			
Tees	Cool Season	½ - 1		½ - 1	1	½	½ - 1		½ - 2	
	Warm Season			1	1		1+			

+ designates an application in the early part of the month
- designates an application in the late part of the month
*Applied at biweekly intervals

A variety of nitrogen sources are formulated specifically for turf. They vary in the rate at which nitrogen is released and the potential for burning grass blades when applied. Slow release products are important to avoid over stimulation of the turf. In any one application, half of the nitrogen should be in a slow release form. Table 31 lists some typical nitrogen sources used for turf. Most contain urea or derivatives of urea, which are generically called ureaform. Ureaform is the product resulting from the reaction of urea and formaldehyde in which urea is formed into chains of different length. In general, the longer the chain the slower the release. Release rates are also described by the solubility in water (WIN) or hot water (HWIN).

Table 31. Nitrogen sources typically used for turf.

Nitrogen Source	Percent Total Nitrogen	Percent Ammonium Nitrate	Percent Urea	Percent SRN[†]	Percent WIN[‡]	Percent HWIN[#]	Speed of N release	Burn potential
UAN	28	50	50				Fast	High
Urea	46	100					Release	Burn
Methylol urea	30		50	50			⇩	⇩
Suspended Methylene Urea	18		35	40	25	5		
Methylene urea	41		35	30	36	13		
Methylene urea polymers	38		11	17	72	40	Slow Release	Low Burn

[†] Short chain soluble nitrogen, soluble reacted urea
[‡] Water soluble nitrogen
[#] Hot water soluble nitrogen

Phosphorus Recommendations For Turf

Phosphorus recommendations for establishing turf are calculated using the equation below. Recommended maintenance amounts are half that of establishment.

$$P_2O_5(lb/1000\,ft^2) = \frac{110 * \left(\sqrt{85} - \sqrt{Ptest}\right)}{4 * 43.56}$$

Potassium Recommendations For Turf

Potassium recommendations for establishing turf are varied by soil potassium level and CEC, and are calculated using the equations below. Recommended maintenance amounts are half that of establishment. If the CEC is less than 6, then assume 6, and if greater than 20 then assume 20.

$$K_2O(lb/1000\,ft^2) = \frac{75.5\left(\sqrt{100 + 10 * CEC} - \sqrt{Ktest}\right)}{4 * 43.56}$$

Secondary and Micronutrients

Secondary and micronutrient recommendations for turf are the same as those detailed for fruit and vegetable crops. The one exception is that of boron. For turf boron is rated the same as other horticulture crops. However, no boron recommendation is given for turf.

Soil Sample Information Form

On the following page is a copy of the soil sample information form that is used with the submission of commercial horticultural crops and turf. Proper entry of grower and county information is necessary for correct billing of the soil tests. As many as six soil samples can be submitted per form. With each sample information is requested regarding irrigation, topography, last liming date, soil region and prior crop. This information although not necessary for obtaining a recommendation is useful toward providing a better recommendation. Also requested is the cropping option for which a recommendation is desired. Crop codes are chosen from the gray box above the cropping options box. Crop age applies only when blueberries are chosen as a cropping option.