lower nitrogen availability following the composting process. For more information on manure management and calculating rates to apply for vegetable and fruit crops refer to: http://www.extension.umn.edu/distribution/horticulture/M1192.html.

Sewage Sludge (Biosolids)

Although sewage sludge from municipal treatment plants can supply nutrients for crop growth, there is concern about elevated metal content and enteric diseases in some types of sewage sludge. While preventing metals from entering the sewer system and use of certain processing techniques can minimize these problems, use of sewage sludge for fertilizing fruit and vegetable crops is questionable. Sewage sludge is best used to provide nutrients (primarily nitrogen and phosphorus) for ornamental landscape plants and crops not directly used for human consumption.

Using Green Manures/Cover Crops

Crops that are incorporated into the soil while still green are referred to as green manures. Cover crops are similar to green manures, but are usually grown to protect soil from erosion during the non-growing season. Because topsoil is higher in organic matter and nutrient content than subsoil, controlling erosion is an important method of conserving soil nutrients. Green manures and cover crops are both used to supply nitrogen and increase soil organic matter. Legumes such as clover and alfalfa can fix between 100 and 200 lbs of nitrogen per acre in one year. The use of grasses such as rye or oats without a legume will not increase the nitrogen content of the soil. These crops are used for increasing soil organic matter content. They can also scavenge residual nitrogen from the previous crop and keep it from being lost by leaching. A mixture of both grasses and legumes can be used to obtain the advantages of each. Improved soil tilth from added organic matter improves root growth, which increases the capacity of a crop to take up available soil nutrients. The decision to plant a green manure should take into account the cost of cultural practices (planting, cultivation) and seed, as well as the lost opportunity cost if the green manure is grown instead of a cash crop.

Some green manure crops accumulate high levels of phosphorus and are thought to increase phosphorus availability to subsequent crops by returning it to the soil in organic form. For example, buckwheat and oilseed radish may solubilize phosphorus from relatively insoluble minerals like rock phosphate through the action of organic acids secreted by their roots. The benefit of these phosphorus accumulating crops will depend on the following crop and to what extent recycling of organic phosphorus increases phosphorus availability to them compared to inorganic soil phosphorus. There is little research information on phosphorus response of different crops following green manures like buckwheat and oilseed radish. More information on nutrient cycling and maintaining soil fertilization can be found at the following website: http://www.extension.umn.edu/distribution/horticulture/M1193.html.

Fertigation

Fertigation refers to the application of water soluble fertilizer through the irrigation water. Nutrients in a concentrated solution are injected in the irrigation water using an appropriate injection device. Providing nutrients through the irrigation system enables more flexibility in a fertilizer program. Several types of irrigation systems are available for use in crop production. For any system used, approved backflow control valves and interlock devices are necessary to prevent accidental contamination of the water source due to irrigation system failure or shutdown. Contact the Minnesota Department of Agriculture (http://www.mda.state.mn.us/) for Minnesota state regulations regarding application of fertilizer through irrigation systems. The type of system selected will depend on the crop being grown and resources available.

Overhead irrigation

Center pivot and solid set overhead irrigation systems provide the most uniform distribution of water. Center pivot systems are especially well suited for large acreage crops such as sweet corn and potatoes, while solid set systems are used for the smaller acreage. In most cases, nitrogen is the primary nutrient applied with an overhead irrigation system. Nitrogen solutions in the form of urea-ammonium nitrate (28-32% N) are the most common and economical sources to use. Generally, 20-40 lb N/A per application can be applied through the system to supplement crop needs. Other elements such as phosphorus, potassium, and micronutrients are more efficiently used if incorporated in the soil at or before planting.

For solid set systems a batch load of fertilizer is injected. That is, the area being irrigated is calculated and the amount of fertilizer required for that given area is then determined. In making these calculations with fertilizer solutions, the density or pounds of solution per gallon needs to be known. The density is usually provided on the fertilizer label or can be obtained from the fertilizer dealer. For solid set systems, the injection rate does not need to be precisely controlled. For center pivot systems, the movement of the system in acres per hour needs to be taken into account. For calibration of center pivot systems, refer to the manufacturer's irrigator operating manual. The timing of application should be based on crop demand and can be determined using tissue analyses. For potatoes, the demand for nitrogen is generally greatest between initial tuber growth and tuber enlargement (5 to 10 weeks after planting). For sweet corn, the demand for nitrogen is greatest between the 12-leaf stage and tasseling.

Drip Irrigation

Drip or trickle irrigation is a type of irrigation where water is supplied under low pressures directly to or near the plant's root zone. Water is carried through plastic tubing and emitted through small openings. Drip irrigation is often used in combination with plastic mulch. Advantages of using drip irrigation are better control of foliar diseases and more efficient water and fertilizer use. Water savings with drip irrigation can amount to as much as 50 percent compared with an overhead sprinkler system. This method of irrigation is particularly suited for high value crops such as tomatoes, peppers, blueberries, raspberries, strawberries, apples, vine crops, and cole crops.

As with overhead irrigation, nitrogen is the primary nutrient applied through the system. Nitrogen solutions are the most economical source of nitrogen to apply; potassium nitrate and ammonium sulfate are soluble and can also be used. Calcium nitrate is also water soluble but may precipitate if injected in high pH water. Drip irrigation, in combination with plastic mulch, allows for precise timing (spoon feeding) of nitrogen. Small amounts can be applied daily (1-2 lb N/A) or weekly (5-10 lb N/A) to meet the growth demands of the crop.

Potassium can also be injected without any precipitation problems, although in most Minnesota soils a broadcast and starter application can meet plant requirements. Phosphorus may precipitate with micronutrients or with calcium and magnesium in the irrigation water, resulting in clogging problems. Some micronutrients such as copper, iron, manganese, and zinc may also precipitate in high pH water. For most situations, phosphorus, and micronutrients, if needed, should be applied before planting. These elements can be injected alone in the drip system without precipitation problems. For phosphorus applications, phosphoric acid should be used. For micronutrients, chelated forms should be used. Clogging problems in drip lines can be corrected by injecting acids into the line to dissolve precipitates. If clogging is caused by bacteria or algae growth, then chlorine should be mixed with water. In all cases, the cause of clogging should be determined before treatment, and injection rates of chlorine or acid should be carefully monitored to avoid damaging the plants.

Calibration of fertilizer injection for drip irrigation is similar to that of a solid set sprinkler system in that a batch type injection is used. The area to be fertilized is first calculated and then the amount of fertilizer needed for that area is determined. In most cases, nutrients should be injected over a 15-20 minute period followed by a 15-20 minute flushing period.

Foliar Fertilization

For all fruit and vegetable crops, the major pathway for mineral nutrient uptake is via the roots. Nutrients applied to the leaves can be absorbed and utilized by the plant; however, for nitrogen, phosphorus, and potassium the quantity absorbed at any one time is small relative to the larger levels required for growth by the plant. Foliar application of these three nutrients cannot be expected to supply the total amount required for crop production.

An appropriate time to consider foliar fertilization would be when a shortage of a nutrient is evident as indicated by tissue analysis or visual symptoms. In these situations, foliar fertilization provides the quickest means to correct the problem. Certain soil conditions, such as high pH, excess moisture, or cool temperatures, may render a nutrient or nutrients unavailable to the plant root. If these conditions exist, the problem may be more effectively corrected by foliar applications compared with soil applications. For the macronutrients, foliar applications are a short-term solution. Refer to the potassium section **(page 15)** for suggestions on using potassium foliar sprays and **page 26** for using magnesium foliar sprays. Some crops have inefficient mechanisms for translocating calcium to fruits of young tissue. See the calcium section **(page 26)** for recommendations on using calcium foliar applications. For micronutrients, two to three applications may be all that are needed to meet crop demands. Even for micronutrients, the application is only effective during the year of application. Recommendations for rates of micronutrient foliar fertilizers to apply are provided in the micronutrient section **(pages 26-29)**.

Routine use of foliar fertilizers without a documented need is not recommended. Furthermore, foliar fertilization should not be used as a substitute for good soil fertility management. Have your soil tested and fertilize according to soil test recommendations.

Selecting a Yield Goal

Higher yielding crops generally require more nutrients than low yielding crops. For most fruit and vegetable crops listed in this bulletin, fertilizer recommendations are based on the yield obtained under optimum field conditions (i.e., water is not limiting and soil drainage is not a problem). If certain management practices such as plastic mulches, drip irrigation, row covers, or high tunnels are used, yield potential may be substantially higher than that reported in this bulletin. In those cases, an increase in fertilizer rates over those recommended may be warranted.

For the major processing crops (peas, sweet corn, snap beans, lima beans, and potatoes) where larger acreage is planted and soil conditions and water availability may not be as favorable as for the higher value fruit and vegetable crops, yield may vary as a function of the area in which the crop is grown as well as management practices. Selecting a realistic yield goal for these crops will improve fertilizer use efficiency. Reasonable yield goals are usually set at 15-20 percent higher than a grower’s average yield for the past 5 years.

Primary Macronutrients

Nitrogen, phosphorus, and potassium are often referred to as the primary macronutrients because of the general probability of plants being deficient in these nutrients and the large quantities taken up from the soil relative to other essential nutrients.

Nitrogen

Of all the essential nutrients, nitrogen is the one most often limiting for crop growth. Many soils contain large amounts of nitrogen, but most of the nitrogen is tied up in the organic fraction and only slowly released. For most nonlegume crops, some nitrogen fertilizer is required for adequate yields. Nitrogen is available to the plant in two forms—ammonium (NH_4^+) and nitrate (NO_3^-). In most soils, ammonium is quickly converted to the nitrate form, a process called nitrification. This nitrate form is not tightly held on soil particles and is soluble in water. Consequently, nitrogen management is important both from a production and environmental standpoint. On sandy soils, nitrogen applied early in the season can be easily leached out of the root zone with heavy rainfall or excess irrigation. Nitrogen deficiency may result, as well as an increased potential for nitrate contamination of the groundwater. On irrigated sandy soils, nitrogen should be split applied—a small portion at planting and the remainder during the growing season after the