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Chapter 2. Fertilizer Management for Vegetable Production in Florida[1]

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Best Management Practices

With the passage of the Federal Clean Water Act (FCWA) in 1972, all states were required to assess the negative impacts of agricultural fertilizer additions on surface and ground water quality. Upon identification of the impaired water bodies, Florida has established specific numeric criteria for the waterbodies and set limits in the supplied nutrients as per the Basin Management Action Plan, whenever excess of nutrients is attributed to agricultural sources. For vegetable production regions, water quality indicators are concentrations of nitrates, phosphates, and total dissolved solids. Best Management Practices (BMPs) are specific cultural practices aimed at reducing the load of specific nutrients entering the ground and surface water while sustaining profitable yields. BMPs are intended to be economically sound, cost effective, and environmentally friendly based on scientific evidence. It is important to recognize that BMPs do not aim at becoming an obstacle to vegetable production. Instead, they should be considered as a means of promoting horticultural and environmental sustainability. The BMPs that will apply to vegetable production in Florida are described in *Water Quality/Quantity Best Management Practices for Florida Vegetable and Agronomic Crops*, produced by the Florida Department of Agriculture and Consumer Services (FDACS). This manual was developed through a cooperative effort between state agencies, water management districts, and commodity groups, and under the scientific leadership of the University of Florida Institute of Food and Agricultural Sciences (UF/IFAS). The manual was adopted by reference in 2006 and by rule in Florida Statutes (5M-8 Florida Administrative Code) and was revised in 2015 (https://www.fdacs.gov/content/download/77230/file/vegAgCropBMP-loRes.pdf). Vegetable growers may contact their local UF/IFAS Extension agent for one-on-one consultation on (1) the benefits from joining the BMP program, (2) how to join it, (3) how to select the BMPs that apply to their operation, and (4) how to meet the requirements.

The vegetable BMP program has adopted the current UF/IFAS nutrient recommendations (“UF/IFAS Standardized Nutrient Recommendations for Vegetable Crop Production in Florida,” https://edis.ifas.ufl.edu/cv002), including irrigation management (see the new BMP manual on “Optimum Fertilizer Management”). At the field level, adequate fertilizer rates should be selected together with proper irrigation-scheduling techniques, and crop nutritional

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status monitoring tools (leaf analysis, petiole sap testing) may also be employed as appropriate. In the BMP manual, adequate fertilizer rates may be achieved by combinations of UF/IFAS-recommended basal rates and supplemental nitrogen (N) allowances to be added in case of leaching rainfall, when planting during cooler seasons, when tissue analysis shows any nutrient deficiency, or when the harvesting season is prolonged.

Soils

Vegetables are grown in various soil types throughout the state. These soil types include sandy and sandy loam soils, muck soils, and calcareous marl soils. Vegetables are produced predominantly on sandy soils throughout the Florida peninsula and on sandy and sandy loams in the Panhandle. Sandy soils have some advantages, such as ease of tillage, production of the earliest vegetable crops, and timely production operations, but also disadvantages, including the potential risk for leaching mobile nutrients such as nitrogen, potassium, and even phosphorus after heavy rains or excessive irrigation. For more information on soils, refer to "Agricultural Soils of Florida" (https://edis.ifas.ufl.edu/ss655). Therefore, sandy soils must be managed carefully regarding nutrient programs and irrigation scheduling. For more information, see "Soil and Fertilizer Management for Vegetable Production in Florida" (https://edis.ifas.ufl.edu/cv101).

Soil Preparation

A well-prepared planting bed is important for uniform stand establishment of vegetable crops. Previous crop residues and weeds should be plowed down well in advance of crop establishment. A six-to-eight-week period between plowing down of green cover crops and crop establishment is recommended to allow the decomposition of the residues. Freshly incorporated plant material promotes severe incidence of damping-off organisms, such as *Pythium* spp. and *Rhizoctonia* spp. Turning under plant residue well in advance of cropping, reduces proliferation of damping-off disease organisms. Land should be kept disked, if necessary, to avoid new weed emergence prior to cropping.

In the Panhandle area, chisel plowing may assist in breaking down subsurface hardpan in fields. For more information about soil preparation for commercial vegetable production, see "Soil Preparation and Liming for Vegetable Gardens" (https://edis.ifas.ufl.edu/vh024).

Liming

Current UF/IFAS recommendations call for maintaining soil pH between 6.0 and 6.5 (Table 1); further discussion is in "*Soil pH Range for Optimum Commercial Vegetable Production*" (https://edis.ifas.ufl.edu/hs1207). If soil pH is too low, liming is needed to adjust the pH to the target range. A frequent problem in Florida has been overliming, which results in high soil pH that ties up micronutrients and phosphorus, thus limiting nutrient uptake by plants. Overliming can also reduce the accuracy of a soil test to estimate the need for supplemental fertilizer application based on the Crop Nutrient Requirement (CNR) approach. For more information about liming, see "Liming of Agronomic Crops" (https://edis.ifas.ufl.edu/aa128). Liming does not only adjust soil pH but also supplies plants with calcium and magnesium when dolomite (i.e., calcium magnesium carbonate) is used.

Irrigation water from wells within limestone aquifers serves as an additional liming material. The combination of liming and the use of alkaline irrigation water has resulted in soil pH above 7.0 in many sandy soils in Florida. To determine the liming effect via irrigation, a water sample must be analyzed for total bicarbonates and carbonates annually, and the results should be converted to pounds of calcium carbonate per acre. Liming (Table 2), fertilization (Table 3), and irrigation management are closely related to each other. To maximize the overall production potential, soil and water tests are essential in any nutrient management program. Elevated soil pH can be adjusted to the recommended range after identifying the reason(s) for the increases. More information on soil pH reduction can be found in "Lowering Soil pH to Optimize Nutrient Management and Crop Production" (https://edis.ifas.ufl.edu/ss651).

Bedding

Fields prone to flooding, those using seepage irrigation, or those with shallow soil profiles should utilize raised beds for cropping. Beds range from 3–8 inches in height, and the tallest ones are preferred where the risk of flooding is high. Taller beds facilitate faster drainage, which can help reduce weed growth in furrows. Raised beds, especially when covered with black plastic mulch, promote early-season soil warming, leading to increased early crop production during cool seasons. Mulching requires a smooth, well-pressed bed for efficient heat transfer from black mulch to the soil. Adequate soil moisture is essential for forming a suitable bed using a bed press. Depending on the planting date and the sensitivity of the crop to heat stress, growers may consider using white or reflective plastic mulch instead of black mulch.

Fertilization

Commercial vegetable production requires intensive nutrient management for optimal production. Effective implementation of **4R** nutrient stewardship principles—**Right Source, Right Rate, Right Place,** and **Right Time**—when applying nutrients to a crop is shown to enhance nutrient efficiencies and minimize nutrient loss to the environment. More information about the 4Rs is available in "What is 4R Nutrient Stewardship?" (https://edis.ifas.ufl.edu/hs1264) and "The Four Rs of Fertilizer Management" (https://edis.ifas.ufl.edu/ss624). For tomato production, more information is available in "Implementing the Four Rs (4Rs) in Nutrient Stewardship for Tomato Production" (https://edis.ifas.ufl.edu/hs1269).

Right Rate

Soil Testing

Soil testing is the #1 BMP for nutrient management. There are 17 elements essential to plant growth (Table 4). The crop nutrient requirement (CNR) for a particular nutrient is defined as the total amount in pound per acre (lb/A) of that element needed by the crop to produce optimum profitable yield. The CNR can be satisfied from many sources, including soil, water, air, organic matter, or fertilizer.

The CNR for a crop has been determined from field calibrations and validation. The CNR is equivalent to the nutrient rate above which no significant increase in yield is expected. The CNR values derived from such experiments consider factors such as the source, solubility, and availability in the soils. It is important to remember that nutrients are supplied to the crop from both the soil and the fertilizers. Supplemental nutrients should be applied only when a properly calibrated soil test indicates a yield or quality response. Mehlich-3 is the standard soil extractant in Florida for all acid-mineral soils and calcareous soils of Miami-Dade County. For mineral soils with a pH of 7.4, currently the ABDTPA procedure is used. For vegetable production on muck soils, phosphorus is extracted using water, while potassium, calcium, and magnesium are extracted with acetic acid. More information about Mehlich-3 is available in "Extraction of Soil Nutrients Using Mehlich-3 Reagent for Acid-Mineral Soils of Florida" (https://edis.ifas.ufl.edu/ss620).

Nitrogen recommendations are based on research data and not on a soil test. A standard soil test provides soil pH, lime requirement (if needed), P, K, Ca, Mg, S, Cu, Mn, and Zn in mg/kg (ppm), and the recommendations are generated based on the interpretation specifically for the extractant used. More information about soil testing can be found in "Developing a Soil Test Extractant: The Correlation and Calibration Processes" (https://edis.ifas.ufl.edu/ss622) and "Soil Testing for Plant-Available Nutrients—What Is It and Why Do We Use It?" (https://edis.ifas.ufl.edu/ss621).

Plant Tissue Analysis

Analysis of plant tissues (e.g., leaves or petioles) for nutrient concentrations provides an efficient tool for monitoring nutrient status of a crop during the growing season. There are two main approaches to plant tissue testing: standard laboratory analysis and the plant sap testing procedures. Standard laboratory analysis involves analyzing the most recently matured leaf of the plant for a series of nutrients. The resulting analyses are compared against published recommended values for the same crop. Laboratory results that fall outside the adequate range for a particular nutrient may indicate either a deficiency or toxicity (especially in the case of micronutrients). The most recently matured leaf serves well for routine crop monitoring and diagnostic procedures for most nutrients. However, for immobile nutrients such as Ca, B, Zn, Fe, Mn, Cu, and Mo, younger leaves are preferred.

The second approach involves using plant sap quick-test kits that have been calibrated for N and K in several vegetables in Florida. These testing kits analyze fresh leaf petiole sap for N and K. Quick tests can be a valuable tool for on-the-spot monitoring of plant nutrient status. Diagnostic information for leaf and petiole sap testing can be found in "Plant Tissue Analysis and Interpretation for Vegetable Crops in Florida" (https://edis.ifas.ufl.edu/ep081) and "Petiole Sap Testing for Vegetable Crops" (https://edis.ifas.ufl.edu/cv004). However, the standard plant tissue test at a laboratory is the primary tool for ground-truthing results to overcome inadequacies in field calibration of these alternate tools.

Understanding the "Per Acre" Rate of Fertilizer Recommendations

Most public (including Extension) and private soil testing laboratories express fertilizer rates as an amount per real-estate (gross) acre. The "per acre" expression in the context of crop fertilization often leads to confusion. Farming systems have different bed center spacing, different numbers of rows per bed, and different configuration of roads and irrigation/drainage ditches. These differences vary the amount of cropped area per gross acre for each system and must be considered when calculating fertilizer needs.

To standardize fertilizer recommendations for a crop across varying systems, UF/IFAS and the UF/IFAS Extension Soil Testing Laboratory (ESTL) use the Linear Bed Foot (LBF) system. LBF is defined as the linear distance of 1 foot measured along a bed, and the total number of LBF in a particular system is the cropped area expressed as the LBF per acre .

To determine fertilizer application rates with the LBF system, a grower must know the "typical bed configuration" for the crop. This is based on traditional configuration of the crop and is the configuration that was used for significant nutrient rate research. Table 5 illustrates the typical bed configuration for several vegetable crops and the associated LBF per acre. To calculate the LBF of an alternative configuration, use the following formulas

Step 1:

Alternative #1 LBF per acre = 43,560 square feet per acre/ Alternative bed spacing (ft)

Step 2:

Alternative #2 LBF per acre = Alternative #1 LBF per acre × Alternative plant rows per bed/Typical plant rows per bed

To calculate the fertilizer application rate for an alternative configuration, use either of the following formulas, depending on fertilizer application methods used:

Alternative fertilizer rate = Lab fertilizer rate × Alternative #2 LBF per acre/Typical LBF per acre

LBF rate = Alternative fertilizer rate/Alternative #2 LBF per acre

A thorough discussion of the LBF system and examples of calculations for various scenarios can be found in "Calculating Recommended Fertilizer Rates for Vegetables Grown in Raised-Bed, Mulched Cultural Systems" (https://edis.ifas.ufl.edu/publication/ss516). Note that this EDIS document illustrates the LBF concept for various configurations on a per 100 LBF basis.

Right Source

N, P, and K Sources

Nitrogen is the most limiting nutrient in agriculture. The amount of nitrogen required by vegetable plants must be applied in each growing season, as residual N is lost to the environment through several pathways. Nitrogen requirements vary among crops (Table 6) and are not dependent on soil test results. All other nutrients must be supplied based on soil test results (as described above) to comply with the BMP guidelines. The interpretations of Mehlich-3 (low, medium, and high) are shown in Table 7. UF/IFAS standardized nutrient recommendations based on Mehlich-3 testing include P_2O_5 and K_2O (Table 8) and nutrient management using fertigation (Table 9). More information on Mehlich-3 can be found in "Extraction of Soil Nutrients Using Mehlich-3 Reagent for Acid-Mineral Soils of Florida" (https://edis.ifas.ufl.edu/ss620). Nutrient recommendations listed in Tables 8–11 were derived from field rate studies that evaluated a wide range of nutrient applications across various soil pH levels. Factors such as crop plant development, crop yield, and vegetable quality were taken into account to *determine* the optimum nutrient levels for UF/IFAS recommendations.

Nitrogen can be supplied in various forms, including nitrate, ammoniacal (e.g., ammonium sulfate), and formable ammoniacal (such as urea). Because the mineralization rate of conversion is reduced in cold, fumigated, or strongly acidic soils, it is recommended that under such conditions 25%–50% of the N be supplied from nitrate sources. This ratio is not critical for unfumigated or warm soils.

Phosphorus (P) can be supplied from several sources, such as diammonium phosphate (DAP), monoammonium phosphate (MAP), or monopotassium phosphate, based on the soil pH and other factors. Initial soil reaction pH with DAP is about 8.5, which favors ammonia production and volatilization. This produced ammonia causes seedling injury and inhibits root growth. Adequate separation of seed and DAP is needed to eliminate any seedling damage. DAP should not be used on calcareous or high-pH soils. MAP's reaction pH is 3.5, so it does not have the above problems and is better suited for acidic and lower-pH soils.

Potassium (K) can also be supplied from several sources, including potassium chloride (muriate of potash—60%), potassium sulfate (sulfate of potash—50%), potassium nitrate, and potassium-magnesium sulfate. If adhering to amounts of K fertilizer recommended by soil tests, there should be no concern about the K source or its relative salt index. However, when applying chloride-containing sources, crop sensitivities must be considered.

Ca, Mg, and S Sources

The secondary nutrients calcium (Ca), magnesium (Mg), and sulfur (S) are sufficient in Florida soils. Calcium is ubiquitous in Florida soils due to their genesis from limestone base. Depending on the location, Ca tends to occur remarkably close to or on the surface and typically within the root zone. Therefore, Ca levels are not typically assessed in soil tests. Additionally, irrigation water generally contains dissolved Ca; thus, maintaining optimum moisture levels in the soil via irrigation will ensure adequate supply of Ca to the roots. Calcium is not easily mobile within plants; therefore, foliar sprays of Ca are unlikely to correct deficiencies effectively. It is difficult to provide enough foliar-applied Ca at the growing point of the plant on a timely basis.

Magnesium deficiency may be a problem for vegetable production; however, when the Mehlich-3 soil-test index for Mg is below 20 ppm, then an application of 35 lb Mg/A will satisfy the crop Mg requirement. If lime is also needed, Mg can be added using dolomite as the liming material. If no lime is needed, the Mg requirement can be fulfilled through magnesium sulfate or Sul-Po-Mag. Blending of the Mg source with other fertilizer(s) that are applied to the soil is an excellent way of ensuring uniform supplement of soil Mg.

Although S deficiencies are not common in Florida soils, sulfur deficiency may occur in sandy soils that are low in organic matter. If a Mehlich-3 soil test determines that the S level is <6 mg/kg, or ppm, then S deficiency may be developed that can be corrected by using S-containing fertilizers, such as magnesium sulfate, ammonium sulfate, potassium sulfate, or potassium-magnesium sulfate. Using one of these materials in the fertilizer blends at levels sufficient to supply 20 lb S/A or higher which should prevent S deficiencies.

Micronutrient Sources

It has been common in Florida vegetable production to routinely apply a micronutrient package. This practice is justified because these nutrients are inexpensive and because their application seems to provide "insurance" for high yields. In addition, there has been little research data and a lack of soil-test calibrations to guide judicious application of micronutrient fertilizers. Confounding the problem has been the vegetable industry's use of micronutrient-containing pesticides for disease control.

Copper (Cu), manganese (Mn), and zinc (Zn) from pesticides have tended to accumulate in the soil. This situation has forced some vegetable producers to overlime in an effort to reduce availability and avoid micronutrient toxicities. Table 11 provides guidelines for the above micronutrients on sufficient levels, toxicities, and soil pH dependencies. It is unlikely that micronutrient fertilizers will be needed on old vegetable land, especially where micronutrients have been applied regularly via recommended pesticides. A standard soil-test report includes micronutrients also.

Manures and Composts

Waste organic products, including animal manures and composted organic matter, contain nutrients that can be recovered by crops. These materials, when applied to the soil, are gradually decomposed, releasing nutrients to be utilized by vegetable crops. These materials must comply with food safety requirements, such as those of the Produce Safety Alliance (PSA). The key to proper use of organic materials as fertilizers comes in the knowledge of the nutrient content and the decomposition rate of the material. Growers interested in using organic materials as fertilizer sources should have conducted an analysis of the material composition in order to determine the rate of application. Sludge is not permitted for land application in vegetable production. Decomposition rates of organic materials are rapid in warm, sandy soils in Florida. Residual nutrient levels in soils beyond the crop season are limited. Usually, application rates of organic wastes are determined largely by the N content, which will result in inadvertent P applications too. Excessive rates of organic waste materials can contribute to groundwater or surface water pollution; therefore, it is important to understand the nutrient content and the decomposition rate of the organic waste material and the P-holding capacity of the soil. For more information about using manure for vegetable production, see "Using Composted Poultry Manure (Litter) in Mulched Vegetable Production" (https://edis.ifas.ufl.edu/ss506) and "Introduction to Organic Crop Production" (https://edis.ifas.ufl.edu/cv118).

As a soil amendment, compost improves soil's physical, chemical, and biological properties, thus making it more productive. To eliminate or minimize human and plant pathogens, nematodes, and weed seeds, the composting temperature must be kept in a range from 131°F–170°F for three days in an in-vessel or static aerated pile. The majority of nitrogen in compost is in organic form. Thus, before being mineralized, compost N is not as readily bioavailable as synthetic N fertilizers. Compost N mineralization rate varies with feedstock, soil characteristics, and composting conditions. Compost N fertilizer releases only 5%–30% bioavailable N to crops in the first year. Contrarily, compost P and K are as bioavailable as chemical fertilizers. Composting converts raw organic materials to humus-stable forms and hence minimizes possible adverse impacts on the environment.

Right Place

Fertilizer Placement

Fertilizer rate and placement must be considered together. Banding low amounts of fertilizer too close to plants can result in the same or greater amount of damage as broadcasting excessive amounts of fertilizer on the field. Because P is immobile in soils, it should be banded alongside the plant rows. Micronutrients can be broadcast with the P and incorporated in the bed area. In calcareous soils, micronutrients, such as Fe, Mn, and B, should be banded or foliar applied. Because N and K are easily prone to leaching in sandy soils, they must be managed properly to maximize crop uptake. Both N and K should be supplied in split applications in unmulched production systems to minimize losses below the root zone. Hence, one-third to one-half of the N and K may be applied to the soil at planting or shortly thereafter. The remaining fertilizer can be applied in one or two applications during the early part of the growing season. Split applications also will help reduce the potential for fertilizer burn, which is defined as leaf scorch resulting from overfertilization. In mulched beds with fertigation, both N and K should be applied in 10–14 equal split installments for efficient uptake by plant roots and minimized leaching.

When using plastic mulch, fertilizer placement options depend on the type of irrigation system (seepage or drip) and on whether drip tubing or the liquid fertilizer injection wheels are to be used. With seepage irrigation, all P and micronutrients should be incorporated in the soil during bed preparation. Apply 10%–20% (but not more) of N and K with P and other pre-plant fertilizers for soil incorporation. The remaining N and K could be placed in narrow bands on the bed shoulders, the number of which depends on the crop and number of rows per bed. These bands should be placed in shallow (2-to-2½-inch-deep) grooves. This placement requires that adequate bed moisture be maintained so that capillarity is not broken. Otherwise, fertilizer nutrients will not move to the root zone. Excess moisture can result in fertilizer leaching. Fertilizer and water management programs are linked. Maximum fertilizer efficiency is achieved only with close attention to water management. When supplemental side-dressing of mulched crops is needed, applications of liquid fertilizer can be made through the mulch with a liquid fertilizer injection wheel. This implement is mounted on a tool bar and, using 30–40 psi, injects fertilizer through a hole pierced in the mulch.

When beds are not covered with plastic mulch, split applications are recommended to avoid the risk of nutrient leaching or salinity damage. Split applications can also minimize P fixation in acidic soils containing high levels of aluminum and iron or in alkaline soils containing high levels of calcium and magnesium.

Right Time

Supplemental Fertilizer Applications and BMPs

In practice, supplemental fertilizer applications, when growing conditions require doing so, allow vegetable growers to stay within BMP guidelines while numerically applying fertilizer rates higher than the standard UF/IFAS-recommended rates. Conditions that may require supplemental fertilizer applications are leaching to excessive rainfall, cooler planting seasons, and extended harvest periods. Applying additional fertilizer under the following four circumstances is part of the current UF/IFAS fertilizer recommendations and thus BMPs: (1) If grown on bare ground with seepage irrigation, a 30 lb/A of N and/or 20 lb/A of K_2O supplemental application is allowed after a leaching rain, defined as when it rains at least 3 inches in 3 days or 4 inches in 7 days; (2) potatoes planted in cooler seasons may receive a supplemental application of 25 lb/A P_2O_5; (3) if nutrient levels in the leaf or in the petiole fall below the sufficiency ranges, the supplemental amount allowed for bare-ground production is 30 lb/A of N and/or 20 lb/A of K_2O, and for drip-irrigated crops, 1.5 to 2.0 lb/A per day for N and/or K_2O for one week; or (4) for economic reasons, the harvest period has to be longer than the typical harvest period. When the results of tissue analysis or petiole testing are below the sufficiency ranges, a supplemental 30 lb/A of N and/or 20 lb/A of K_2O may be made for each additional harvest for bare-ground production. For drip-irrigated crops, the supplemental fertilizer application is 1.5–2.0 lb/A per day for N and/or K_2O until the next harvest.

Fertigation

Common irrigation systems used for fertigation include drip, sprinkler, and pivot systems. Advantages of fertigation over conventional fertilizing methods are (1) more efficient delivery of nutrients, (2) more precise localized application, (3) more flexible control of application rate and timing, and (4) lower application cost. Liquid and water-soluble fertilizers are more commonly used for fertigation than dry fertilizers. The most common liquid N fertilizers for fertigation are ammonium nitrate (20-0-0), calcium ammonium nitrate (17-0-0), and urea ammonium nitrate (32-0-0). Complete fertilizers (e.g., 8-8-8 and 4-10-10) are also commonly used. For commercial vegetable production in south Florida, a formula of 4-0-8 or 3-0-10 is the most common in fertigation. To develop a more precise fertilizer application strategy, growers can request a custom blend at a local fertilizer dealer based on soil test results and crop nutrient requirements. For more information, consult *Fertigation Nutrient Sources and Application Considerations for Citrus* (https://doi.org/10.32473/edis-ch185-2002).

The basic components for a fertigation system include a fertilizer tank, an injector, a filter, a pressure regulator, a pressure gauge, and a backflow prevention device. All components must be resistant to corrosion. In most situations, N and K are the nutrients injected through the irrigation tube. Split applications of N and K through the irrigation system offer a means to capture management potential and reduce leaching losses. Other nutrients, such as P, are usually applied to the soil rather than by injection. This is because chemical precipitation can occur with these nutrients and the high calcium carbonate content of our irrigation water in Florida.

Nutrient management through irrigation tubes involves precise scheduling of N and K applications. Application rates are determined by crop growth and resulting nutrient demand. Demand early in the season is small, and thus rates of application are small, usually in the order of ½ lb to ¾ lb of N or K_2O per acre per day. As the crop grows, nutrient demand increases rapidly, so that for some vegetable crops such as tomato the demand might be as high as 2 lb of N or K_2O per day. Schedules of N and K application have been developed for most vegetables produced with drip irrigation in Florida (Table 8).

Irrigation water with high and alkaline pH can be acidified using injections of sulfuric acid, phosphoric acid, N-Phuric (Sulamic acid), hydrochloric acid, urea-sulfate, and so forth.

Foliar Fertilization

Foliar fertilization should be used as the last resort for correcting a nutrient deficiency (Table 12). The plant leaf is structured so that it naturally resists to fertilizer infiltration. Foliar fertilization is most appropriate for micronutrients but not appropriate for macronutrients, such as N, P, and K. In certain situations, temporary deficiencies of Mn, Fe, Cu, or Zn can be corrected by foliar application. For example, micronutrients should be foliar applied in the following situations: (1) In winter when soils are cool, and roots cannot extract adequate micronutrients; and (2) in high-pH soils (marl and Rockdale soils) that immobilize broadcast micronutrients. There is a fine line between adequate and toxic amounts of micronutrients. Indiscriminate application of micronutrients may reduce plant growth and yields because of the toxicity. The micronutrients can accumulate in the soil and may cause yield and economic losses in vegetable production. If you are not sure if your crop requires micronutrients or how much you should apply, contact your local UF/IFAS Extension agent.

The 5th R, Right Irrigation

Fertilization and irrigation go hand in hand, with fertilizers included in irrigation schedules and systems. Water is the solvent of all nutrients and the carrier of every pollutant. Keeping moisture and fertilizer primarily in the root zone by managing irrigation inputs and drainage minimizes nutrient-related impacts. Irrigating more than the soil's water-holding capacity leads to increased runoff or leaching and may result in greater production costs or smaller marketable yields. Similarly, insufficient water supply to crops can reduce nutrient bioavailability for vegetable production. Please read "Implementing the Five Rs of Nutrient Stewardship for Fertigation in Florida's Vegetable Production," for more information at https://edis.ifas.ufl.edu/publication/HS1386.

Table 1. A general guideline to crop tolerance of mineral soil acidity.[1]

Slightly Tolerant (pH 6.8–6.0)		**Moderately Tolerant (pH 6.8–5.5)**		**Very Tolerant (pH 6.8–5.0)**
Beet	Leek	Bean, lima	Mustard	Endive
Broccoli	Lettuce	Bean, snap	Pea	Potato
Cabbage	Muskmelon	Brussels sprouts	Pepper	Shallot
Cauliflower	Okra	Carrot	Pumpkin	Sweet potato
Celery	Onion	Collard	Radish	Watermelon
Chard	Spinach	Corn	Squash	
		Cucumber	Strawberry	
		Eggplant	Tomato	
		Kale	Turnip	

[1] From Donald N. Maynard and George Hochmuth, *Knott's Handbook for Vegetable Growers*, 5th edition (2007). Reprinted by permission of John Wiley & Sons, Inc.

Table 2. Liming materials.

Material	**Formula**	**Amount of Material to Be Used to Equal 1 Ton of Calcium Carbonate[1]**	**Neutralizing Value[2] (%)**
Calcium carbonate, calcite, Hi-Cal lime	$CaCO_3$	2,000 lb	100
Calcium-magnesium carbonate, dolomite	$CaCO_3$, $MgCO_3$	1,850 lb	109
Calcium oxide, burnt lime	CaO	1,100 lb	179
Calcium hydroxide, hydrated lime	$Ca(OH)_2$	1,500 lb	136
Calcium silicate, slag	$CaSiO_3$	2,350 lb	86
Magnesium carbonate	$MgCO_3$	1,680 lb	119

[1] Calculate as (2000×100)/neutralizing value (%).

[2] The higher the neutralizing value, the greater the amount of acidity that is neutralized per unit weight of material.

Table 3. Effect of some fertilizer materials on soil pH.

Fertilizer Material	**Approximate Calcium Carbonate Equivalent (lb)[1]**
Ammonium nitrate	–1200
Ammonium sulfate	–2200
Anhydrous ammonia	–3000
Diammonium phosphate	–1250 to –1550
Nitrogen solutions	–759 to –1800
Normal (ordinary) superphosphate	0
Potassium chloride	0
Potassium nitrate	+520
Potassium sulfate	0
Potassium-magnesium sulfate	0
Sodium-potassium nitrate	+550
Triple (concentrated) superphosphate	0
Urea	–1700

[1] A minus sign indicates the number of pounds of calcium carbonate needed to neutralize the acid formed when one ton of fertilizer is added to the soil. A positive sign means that applying the fertilizer can increase soil pH as much as the number of pounds of calcium carbonate is applied.

Table 4. Nutrient elements required by plants.

	Nutrient	Deficiency Symptoms	Occurrence
Macronutrients	Nitrogen (N)	Stems thin, erect, hard. Leaves small, yellow; on some crops (tomatoes), undersides are reddish. Lower leaves affected first.	On sandy soils especially after heavy rain or after overirrigation. Also on organic soils during cool growing seasons.
	Phosphorus (P)	Stems thin and shortened. Leaves develop purple color. Older leaves affected first. Plants stunted and maturity delayed.	On acidic soils or very basic soils. Also when soils are cool and wet.
	Potassium (K)	Older leaves develop gray or tan areas on leaf margins. Eventually a scorch appears on the entire margin.	On sandy soils following leaching rains or overirrigation.
Secondary nutrients	Calcium (Ca)	Growing-point growth restricted on shoots and roots. Specific deficiencies include blossom-end rot of tomato, pepper, and watermelon, brown heart of escarole, celery blackheart, and cauliflower or cabbage tip burn.	On strongly acidic soils, or during severe droughts.
	Magnesium (Mg)	Initially older leaves show yellowing between veins, followed by yellowing of young leaves. Older leaves soon fall.	On strongly acidic soils, or on leached sandy soils.
	Sulfur (S)	General yellowing of younger leaves and growth.	On very sandy soils, low in organic matter, especially following continued use of sulfur-free fertilizers and especially in areas that receive little atmospheric sulfur.
Micronutrients	Boron (B)	Growing tips die and leaves are distorted. Specific diseases caused by boron deficiency include brown curd and hollow stem of cauliflower, cracked stem of celery, blackheart of beet, and internal browning of turnip.	On soils with pH above 6.8 or on sandy, leached soils, or on crops with very high demand such as cole crops.
	Copper (Cu)	Yellowing of young leaves, stunting of plants. Onion bulbs are soft with thin, pale scales.	On organic soils or occasionally new mineral soils.
	Chlorine (Cl)	Deficiencies are rare.	Usually only under laboratory conditions.
	Iron (Fe)	Distinct yellow or white areas between veins on youngest leaves.	On soils with pH above 6.8.
	Manganese (Mn)	Yellow mottled areas between veins on youngest leaves, not as intense as iron deficiency.	On soils with pH above 6.4.
	Molybdenum (Mo)	Pale, distorted, narrow leaves with some interveinal yellowing of older leaves, e.g., whiptail disease of cauliflower. Rare.	On very acidic soils.
	Nickel (Ni)	Deficiencies are rare. This EDIS article has more at https://edis.ifas.ufl.edu/publication/HS1191.	Usually only under laboratory conditions.
	Zinc (Zn)	Small reddish spots on cotyledon leaves of beans; light areas (white bud) of corn leaves.	

Table 5. Typical bed spacing and number of rows per bed for some vegetable crops.

Vegetable crop	**Typical bed spacing (ft)**[1]	**No. of LBF per acre**	**Number of rows of plants on a bed**	**Vegetable crop**	**Typical bed spacing (ft)**[1]	**No. of LBF per acre**	**Number of rows of plants on a bed**
Bean: Snap, Lima	2.5	17424	1	Muskmelon	5	8712	1
Broccoli	6	7260	2	Okra	6	7260	2
Brussels sprouts	6	7260	2	Onion	6	7260	4
Cabbage	6	7260	2	Pea	2.5	17424	1
Carrot	1	43560	3	Pepper	6	7260	2
Cauliflower	6	7260	2	Potato	3.5	12446	1
Celery	4	10890	2	Radish	6	7260	6
Collards	6	7260	2	Spinach	6	7260	4
Cucumber	6	7260	2	Squash, summer	6	7260	2
Eggplant	6	7260	1	Squash, winter	6	7260	2
Greens: Mustard, Turnip	6	7260	4	Strawberry	4	10890	2
Herbs: Parsley, Cilantro	6	7260	4	Sweet Corn	3	14520	1
Kale	6	7260	2	Tomato	6	7260	1
Lettuce	4	10890	2	Watermelon	8	5445	1

[1] The bed spacing is measured from the center of one bed to the center of the adjacent bed.

Table 6. Target pH and nitrogen (N) fertilization recommendations for selected vegetable crops in mineral soils of Florida.

Crops	**Target pH**	**N (lb/Acre)**
Tomato, pepper, potato, celery, sweet corn, crisphead lettuce, endive, escarole, romaine lettuce, and eggplant	6.0 (potato) and 6.5	200
Snapbean, lima bean, and pole bean	6.5	100
Broccoli, cauliflower, brussels sprouts, cabbage, collards, Chinese cabbage, carrots, and strawberry	6.5	175
Radish and spinach	6.5	90
Cucumber, squash, pumpkin, muskmelon, leaf lettuce, sweet bulb onion, and watermelon	6.0 (watermelon) and 6.5	150
Southern pea, snow pea, English pea, and sweet potato	6.5	60
Kale, turnip, mustard, parsley, okra, bunching onion, leek, and beet	6.5	120

Table 7. Soil test interpretation for Mehlich-3 extractions for vegetable crops in Florida.

Nutrient	**Mehlich-3 Interpretations**		
	Low	**Medium**	**High**
	(parts per million soil)		
P	=25	26–45	>45
K	=35	36–60	>60
Mg[1]	=20	21–40	>40

[1] Up to 35 lb/A may be needed when soil test results are medium or lower.

Table 8. Phosphorus (P, expressed as P_2O_5) and potassium (K, expressed as K_2O) fertigation recommendations for selected vegetable crops in mineral soils for Florida based on low, medium, and high soil-test index using the Mehlich-3 soil extractant method. (For details, refer to EDIS document "UF/IFAS Standardized Nutrient Recommendations for Vegetable Crop Production in Florida.")

	P_2O_5			**K_2O**		
	Low	**Medium**	**High**	**Low**	**Medium**	**High**
	(lb/A/crop season)			**(lb/A/crop season)**		
Celery	150–200	100	0	150–250	100	0
Eggplant	130–160	100	0	130–160	100	0
Broccoli, cauliflower, brussels sprouts, cabbage, collards, Chinese cabbage, carrots, kale, turnip, mustard, parsley, okra, muskmelon, leaf lettuce, sweet bulb onion, watermelon, pepper, sweet corn, crisphead lettuce, endive, escarole, strawberry, and romaine lettuce	120–150	100	0	120–150	100	0
Tomato	120–150	100	0	125–150	100	0
Cucumber, squash, pumpkin, snapbean, lima bean, pole bean, beet, radish, spinach, and sweet potato	100–120	80	0	100–120	80	0
Bunching onion and leek	100–120	100	0	100–120	100	0
Potato[1]	120	100	0	150	--	--
Southern pea, snow pea, and English pea	80	80	0	80	60	0

[1] Potatoes planted in cool soils might respond to up to 25 lb P_2O_5 applied as starter fertilizer in the furrow with the seed pieces. See also Footnote 253 in Table 4 in "*UF/IFAS Standardized Nutrient Recommendations for Vegetable Crop Production in Florida*" (https://edis.ifas.ufl.edu/cv002). On October 25, the UF/IFAS Plant Nutrient Oversight Committee (PNOC) announced its memorandum: "The P fertilizer application rate for potato may be determined independent of a preplant soil test of P. Therefore, P fertilizer may be applied up to the maximum UF/IFAS recommended rate for potato of 120 lb/acre P_2O_5 regardless of the soil test P value. It will remain in effect throughout the 2022–2023 commercial potato growing season."

Table 9. Fertigation[1] and supplemental fertilizer[1] recommendations for selected vegetable crops grown on mineral soils testing low in potassium (K_2O) based on the *Mehlich-3 soil extraction method*.

	Preplant[2] (lb/A)	**Injection rate[3] (lb/A/day)**					**Low Plant Content[4,5]**	**Extended Season[4,6] (lb/A/day)**
Eggplant								
Wk after transplanting[7]		1–2	3–4	5–10	11–13			
N	0–70	1.5	2.0	2.5	2.0		1.5–2.0	1.5–2.0
K_2O	0–55	1.0	1.5	2.5	1.5		1.5–2.0	1.5–2.0
Okra								
Wk after transplanting		1–2	3–4	5–12	13			
N	0–40	1.0	1.5	2.0	1.5		1.5–2.0	1.5–2.0
K_2O	0–50	1.0	1.5	2.0	1.5		1.5–2.0	1.5–2.0
Pepper								
Wk after transplanting		1–2	3–4	5–11	12	13		
N	0–70	1.5	2.0	2.5	2.0	1.5	1.5–2.0	1.5–2.0
K_2O	0–70	1.5	2.0	2.5	2.0	1.5	1.5–2.0	1.5–2.0
Tomato[8]								
Wk after transplanting		1-2	3–4	5–11	12	13		
N	0–70	1.5	2.0	2.5	2.0	1.5	1.5–2.0	1.5–2.0
K_2O	0–70	1.5	2.0	2.5	2.0	1.5	1.5–2.0	1.5–2.0

[1] A=7,260 linear ft/A (6-ft bed spacing); for soils testing "low" in Mehlich-3 potassium (K_2O), seeds and transplants may benefit from applications of a starter solution at a rate no greater than 10–15 lb/A for N and P_2O_5 and applied through the plant hole or near the seeds.

[2] Applied using the modified broadcast method (fertilizer is broadcast where the beds will be formed only, and not over the entire field). Preplant fertilizer cannot be applied to double/triple crops because of the plastic mulch; hence, all fertilizer must be injected.

[3] This fertigation schedule is applicable when no N and K_2O are applied preplant. Reduce schedule proportionally to the amount of N and K_2O applied preplant. Fertilizer injections may be done daily or weekly. Inject fertilizer at the end of the irrigation event and allow enough time for proper flushing afterwards.

[4] Plant nutritional status may be determined with tissue analysis or fresh petiole-sap testing, or any other calibrated method. The "low" diagnosis needs to be based on UF/IFAS interpretative thresholds.

[5] Plant nutritional status must be diagnosed every week to repeat supplemental fertilizer application.

[6] Supplemental fertilizer applications are allowed when irrigation is scheduled following a recommended method (see "*Evapotranspiration-Based Irrigation Scheduling for Agriculture*" at https://edis.ifas.ufl.edu/ae457). Supplemental fertilizations are to be applied in addition to base fertilization when appropriate. Supplemental fertilization is not to be applied "in advance" with the preplant fertilizer.

[7] For standard 13-week-long transplanted tomato crop.

[8] Some of the fertilizer may be applied with a fertilizer wheel through the plastic mulch during the tomato crop when only part of the recommended base rate is applied preplant. Rate may be reduced when a controlled-release fertilizer source is used.

Table 10. Fertigation recommendations for strawberry grown on mineral soils testing low in potassium (K_2O) based on the *Mehlich-3 soil extraction method*.

Nutrient	**Injection rate[1] (lb/A/day)**							**Low Plant Content[2]**
	Oct.	**Nov.**	**Dec.**	**Jan.**	**Feb.**	**Mar.**	**Apr.**	
N_3	1.5–2.0	1.0–2.0	1.0–1.5	0.75–1.0	0.5–1.0	0.5–0.75	0.5–0.75	1.5–2.0
K_2O	0.6–0.8	0.6–0.8	0.6–0.8	0.6–0.8	0.6–0.8	0.6–0.8	0.6–0.8	0.6–0.8

[1] Planting date of October 1st and end-of-harvesting date of April 30th. Recommendations are for bare-root transplants with no preplant N or K. The total N rate may increase or decrease, depending on the length of the growing season. Growers may choose to omit N fertilization when sprinkler irrigation is used for the establishment of transplants (typically 10–12 days after transplanting). If preplant N and K are to be applied, growers are encouraged to use controlled-release or slow-release fertilizers to minimize the risk of nutrient leaching or runoff.

[2] Plant nutritional status may be determined with tissue analysis or fresh petiole-sap testing, or any other calibrated method. The "low" diagnosis needs to be based on UF/IFAS interpretative thresholds.

[3] The target total season N rate is 175 lb/A. Plants on high-organic matter soils may require less N, whereas plants on sandy soils, prone to leaching, may require slightly more, but no more than 200 lb/A. Extra seasonal N applications should depend on plant leaf or petiole sap testing, leaching rainfall, or extended-season needs. The optimum N rate also varies among strawberry cultivars. Growers should choose N rates that are appropriate for the particular cultivar and soil within the ranges shown in the table.

Table 11. Soil test guidelines for micronutrients.

	Soil pH (Mineral Soils Only)		
	5.5–5.9	**6.0–6.4**	**6.5–7.0**
	(parts per million)		
Test level below which there may be a crop response to applied copper	0.1–0.3	0.3–0.5	0.5
Test level above which copper toxicity may occur	2.0–3.0	3.0–5.0	5.0
Test level below which there may be a crop response to applied manganese	3.0–5.0	5.0–7.0	7.0–9.0
Test level below which there may be a crop response to applied zinc	0.5	0.5–1.0	1.0–3.0

When soil tests are low or known deficiencies exists, apply per acre 5 lb Mn, 2 lb Zn, 4 lb Fe, 3 lb Cu, and 1.5 lb B (higher rate needed for cole crops).

Table 12. Foliar fertilizer sources and rates for vegetable production in Florida.

Nutrient	Source	Foliar Application (lb Product/A)
Boron	Borax[1] Solubor	2–5 1–1.5
Copper	Copper sulfate	2–5
Iron	Ferrous sulfate[2] Chelated iron	2–3 0.75–1
Manganese	Manganous sulfate	2–4
Molybdenum	Sodium molybdate	0.25–0.50
Zinc	Zinc sulfate Chelated zinc	2–4 0.75–1
Calcium	Calcium chloride Calcium nitrate	5–10 5–10
Magnesium	Magnesium sulfate	10–15

[1] Mention of a trade name does not imply a recommendation over similar materials.

[2] Ferrous sulfate ($FeSO_4$) is rapidly oxidized to ferric sulfate ($Fe_2(SO_4)_3$) in water, rendering the latter form unavailable for most vegetable crops. Therefore, it is advisable to use chelated iron fertilizers instead of ferrous sulfate.