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Soil Management and Fertilization

Traditionally, the best soils and high rates of fertility have been accorded vegetable crops in order to achieve top quality and optimum yields. Vegetables, for the most part, have relatively limited root systems and are fast-growing. They therefore require high levels of soil fertility maintained throughout most of their growth. Vegetable growers must depend on chemical fertilizers and organic materials along with crop rotation to supply the nutrients essential to their crops.

Quality in vegetables depends primarily on tender, succulent growth. The best quality of leafy vegetables results when growth is rapid and continuous, which requires soils with a continuous supply of available nutrients and moisture. Crops such as peas and cauliflower must develop quickly while weather conditions are favorable. Most seed- and fruit-producing vegetables cease growing at the time of fruit set, and subsequent yields are dependent upon the amount of growth before fruiting. Nutrient stress at critical stages of crop development can interrupt growth, causing irreparable damage to both crop yield and quality.

VEGETABLE SOILS

The best soils for growing vegetables are well drained, fairly deep, and relatively high (3 to 5%) in organic matter. They have good physical condition, or structure, with ample nutrient- and water-holding capacity. Vegetable soils should be uniform and free of compacted layers that can reduce root penetration and restrict gas exchange and water infiltration. Proper fertilization, drainage, pH control, and cultivation practices are essential for all soils used for vegetable production.

Selecting Soils

For certain situations, some types of soils may be better than others. In general, sandy loams and silt loams are preferred for most vegetable production. They possess most, if not all, of the above characteristics, and through proper soil management can maintain their high levels of production.

When earliness is of more importance than total yield, sandy soils and light sandy loams are best. These soils are well drained and aerated, drying out and warming up rapidly in the spring. They can be worked soon after a rain or irrigation without danger of soil compaction. This last factor is an important advantage for fresh market farmers who irrigate right up to harvest to keep vegetables fresh and turgid. However, sandy soils are usually low in nutrient and moisture retention and require irrigation and extra fertility practices to produce commercial yields.

Loams and silt loams are preferred when large yields are more important than earliness and moisture is likely to become limited. These soils have good water retention and are relatively free from leaching. They have high base exchange capacities and will absorb and hold large quantities of nutrients. Consequently, phosphorus and potassium can usually be applied sufficiently before planting to supply the crop during its full development.

Clays and heavy soils are not usually well adapted for intensive vegetable production because of poor aeration and consequent poor nutrient liberation and root growth. They may, however, be used advantageously for late crops started during warm, dry weather. If worked when wet, these soils will compact severely.

Well-drained muck soils are used for many leafy vegetables and for some root and bulb crops. The muck forms a very fine seedbed for excellent germination and emergence for small-seeded vegetables. These and other organic soils provide good moisture-holding capacity and can supply a relatively large amount of nitrogen for annual crop growth. However, muck soils tend to warm up slowly in the spring and are not conducive for most early plantings. These soils are very light and subject to wind erosion any time they are fallow. A good drainage system is important to remove water from the soil in the spring and after a heavy rain. To deal with some of these disadvantages, several cultural practices have been widely adapted to muck soils; these include the use of raised beds, fall cover crops, and subirrigation to control the water table.

Topography and Drainage

Soils with only a slight grade will generally have good air and water drainage, making them desirable for growing vegetables. When soils of moderate to steep grades are used, measures should be adopted to conserve soil and moisture. These include no-till planting, terracing, contour cultivation, and strip cropping.

Flat land may have no erosion problem, but it can have drainage and leaching problems. If the subsoil is loose and permits ready drainage, no provision for drainage need be made; but, if the subsoil is tight, and water tends to stand on the land, a drainage system pays big dividends. Properly installed tile is best because it permits free use of the land, although open ditch drainage is better than none. Care must be taken to prevent overdrainage because excessive leaching and lack of moisture may result.

Leaching is greatest during periods when the land is not in use, especially in the winter. During these periods, some sort of cover crop may be used to absorb nutrients as they are liberated and to hold them for use by the next crop.

Southern and southeastern exposures are preferred for early spring and fall crops. A sunny slope dries and warms earlier in the spring than a northern exposure.

PREPARING THE SOIL

Whether from transplants or from seeding directly in the field, successful stand establishment requires a planting bed with soil in good tilth (physical condition). The soil should be free of trash, clods, and any other debris that can interfere with seed germination and plant root growth. The soil surface should be loose and open, with a minimum of crusting (a form of soil compaction) after a rain or irrigation. Tilling excessively or overworking the soil to form a fine seedbed can damage the structure of the soil's upper portion, causing it to quickly dry out.

Breaking

Land should be loosened 6 to 8 inches for vegetables. If the soil has never been plowed more than 6 inches, care should be taken to bring up only about an inch of subsoil at a time, especially if the subsoil is fine-textured. Growers sometimes use deep plowing (at least 12 inches) to aid in disease control. By deep plowing, they hope to put fungus-causing spores, such as sclerotinia in lettuce, beyond the reach of tillage tools and the plant root system.

Fall plowing has advantages in regions of winter freezing, but in the South its value is questionable because of leaching and erosion of sloping soils, which do not freeze much in the winter. However, if level loamy soils are plowed deeply, and especially if a covering of coarse organic matter is turned under, the losses from leaching and erosion will generally not be great and probably will be more than offset by the following advantages: (1) improved physical conditions, resulting from alternate wetting and drying and light freezing; (2) reduction in insects, because of exposure to the weather; (3) rotting of organic materials in contact with the soil, thereby increasing the humus and liberating nutrients; and (4) relieving the pressure of spring work by making it possible to work the soil earlier in the spring.

Spring plowing should not be done too far in advance of planting unless heavy cover crops are turned under. Special care must be used to avoid working the soil when it is too wet. If the soil crumbles readily after being pressed in the hand, it is dry enough to plow; but if it retains its form, the land is too wet for breaking.

Finishing

Vegetables with small seeds require a fine seedbed free of trash for even seeding and uniform germination. Plowed land must be disced well, usually in both directions, before planting. A harrow and float are commonly used to follow the discings for final seedbed preparation. A wide variety of harrows are used; the most popular types are spike-tooth and spring-tooth harrows. Cultipackers and rollers also break up clods and smooth the surface for planting. If vegetables are planted on raised beds, power bedders or a set of disc tillers followed by a bed shaper are used to make the beds.

ORGANIC MATTER

Through good management, most vegetable soils can maintain their high level of productivity. Many low-producing and marginal soils may be improved by sound management practices that involve a combination of tillage, cultural practices, cropping systems, and soil treatments. Central to any soil management program is the maintenance of soil organic matter through the use of manures, sod, and cover crops.

Organic matter constitutes the active or "living" component of the soil, affecting physical and chemical properties. It consists of plant and animal residues in various stages of decomposition and acts as a storehouse for nitrogen, sulfur, and phosphorus. Organic matter increases the cation exchange capacity of the soil and serves as a buffer for chemical reactions.

Organic matter functions as a granulator of soil particles, promoting better soil structure. It increases the porosity of heavy soils, which, in turn, increases water absorption and lessens water runoff, leaching, and erosion. The increased porosity also causes greater aeration, which favors the right kind of bacteria for nutrient liberation and direct chemical oxidation processes. On the other hand, organic matter will help keep sandy soils from becoming too porous. The dark color imparted by organic matter increases heat absorption, aiding the soil to warm up quickly, provided that the amount of water present is not excessive.

However, the use of fresh organic matter too close to the planting time of vegetables may cause problems including (1) burning from rapid decomposition, (2) formation of excessively aerated layers and pockets, which interfere with water movement, (3) locking up of available nitrogen by decomposition bacteria, (4) mechanical interference to plowing and cultivation, and (5) formation of toxic organic compounds, under certain anaerobic and non-colloidal conditions. If air and moisture are favorable and sufficient time is allowed, these difficulties are usually overcome. The addition of lime, if needed, and nitrate will aid in cases of nitrogen deficiency.

Soils differ considerably in their organic matter content. In the semiarid climate of the West, soil organic matter content is quite low, usually less than 1 percent. In eastern regions, and in areas of higher rainfall, vegetation is more abundant, and organic matter levels in soils may range upwards to 10 to 15 percent, although 3 to 5 percent is more common.

In most mineral soils used for vegetable production, organic matter breaks down quickly from oxidation as a result of intensive cultivation and frequent irrigation. The other major loss of organic matter from soils is crop removal. Growers try to maintain soil organic matter levels by the use of green-manure crops, sod rotations, cover crops, animal manures, and mulches and composts. Unfortunately, in most cultivated soils, any long-term increase in soil organic matter would be highly unlikely. Soils such as peats and mucks are inherently high in organic material and generally do not require special practices to maintain their organic matter content.

Maintaining Organic Matter with Green-Manure and Cover Crops

Green-manure crops are grown during the same season as a cash crop and are plowed under before they mature. At this stage, plants contain the highest amount of nitrogen plus adequate moisture for rapid decay. Green vegetation incorporated into the soil rots much more quickly than dry material. When vegetation is allowed to dry out before it is turned under, nutrients are transformed to less available forms. Long exposure to oxidation in the weather may result in some loss of nitrogen. Common green-manure crops are sweet clover, soybeans, sudan grass, and a mixture of peas and oats.

Perhaps the best system for maintaining soil organic matter levels is a rotation that includes the extended use of a legume or grass sod. Leaving the soil undisturbed for an extended period under a sod will minimize organic matter oxidation and may cause some accumulation from root disintegration. Including grasses and legumes in a rotation once every three years not only helps maintain organic matter but also promotes good structure and friability of the soil.

Although green manures and sod rotations are probably the cheapest and most effective ways to maintain organic matter and secure nitrogen, they are not always feasible. Production and marketing decisions, land availability, and financial conditions may dictate when or what rotations to use. For a grower located on a limited area of land, it may be economically prohibitive to take the land out of production for any extended period by growing sod or green-manure crops.

When rotations and green-manure crops are not feasible, fall-seeded cover crops may be used. The cover crops are planted after harvest and are turned under in the early spring, in time so as not to interfere with planting. Seeding cover crops in the fall is a common practice on sandy soils that are subject to blowing. Generally, grasses are used as cover crops because they are easily started and form a nonerosive surface that quickly prevents leaching. Rye is almost universally used as a winter cover by farmers, but there is some question as to its value for the southern vegetable growers, because it is difficult to kill and hinders early gardening. In many cases in the southern states, vegetables are grown in the late fall and early spring, and cool-season crops are grown during January and February so rye would be of little value. Oats make a good cover if sown in the fall, but this crop is subject to winter injury.

Various methods are employed in the planting of cover crops. A seed drill has the advantage of planting at uniform depth and rate and saves unnecessary operations. The hand-broadcast method is uncertain and requires more seed for satisfactory coverage.

Maintaining Organic Matter with Animal Manures

If animal manure can be secured cheaply, it is one of the best materials for maintaining the organic content of the soil as well as a good source of nitrogen. Usually, it is advantageous to use fresh manure in the fall and well-rotted manure in the spring. Fresh and straw manures may cause damage if used too near planting time.

Decomposed manure that has been well cared for is valuable because it has no burning effects and can be applied just ahead of the crop. It offers less mechanical interference to plant roots and equipment and generally produces more uniform action throughout the soil mass than fresh manure. If excessive leaching has been stopped, it will have a high percentage of total nutrients and usually contains more phosphorus in relation to nitrogen than fresh manure, thus furnishing a more balanced nutrient supply. The decomposition process destroys or reduces weed seed germination.

If applied far enough in advance of the crop, fresh and straw manures have several important advantages over rotted manure: (1) fewer nutrients are lost through decomposition and leaching, (2) more bacteria are added to the soil, (3) more energy is provided for bacteria, resulting in a much greater liberation of nutrients through solvent action, and (4) buffer effects are greater.

The rate of manure application varies greatly with the land, the crop, the cost of manure, and the kind of manure. Often 30 to 40 tons, especially of the straw mix of cow manure, are not excessive. Many experiment stations have shown that light applications supplemented by commercial fertilizers, especially phosphate, are more economical than manure alone. Chicken manure should be put on very lightly and far enough from the plants to avoid burning. Broadcasting of manure is best, except in the case of widely spaced hills of cucurbits or melons.

In many cases, animal manures are rather expensive and difficult to secure, especially for a market gardener who keeps no livestock. However, with tractors replacing animals on the farm, more crop residues are available for maintaining soil organic matter.

CONSERVATION TILLAGE—"NO-TILL"

Conservation tillage systems, such as "no-till" culture, have become accepted practices in the production of corn, soybeans, and other nonirrigated agronomic crops. Vegetables traditionally have required more intensive management, and conservation tillage methods are not used to any great extent. Depending on the crop, a grower may use as many as six different tillage operations in a growing season.

There are, however, certain situations where conservation tillage may be used. No-till systems offer the advantages of moisture conservation and erosion control, making it possible to grow vegetables on sloping, highly erodible soils. The mulch, or plant residue, that is left on the surface acts as a barrier, protecting the soil against the impact of rain drops. The surface mulch also reduces moisture evaporation and helps retain moisture under drought conditions. Reducing tillage trips across the field protects the soil structure from breakdown and compaction under heavy equipment use.

When vegetables are grown under no-till culture, the seed is planted in previously undisturbed soil by means of a heavy special planter equipped to plant through a surface residue in firm soil. Proper planting is critical to ensure uniformity of emergence and yield, and seeding depth must be carefully adjusted according to the surface mulch and soil moisture content. Fertilizers and pesticides must be applied to the soil surface or in the narrow, tilled area of the row. Without cultivation, weed control is dependent on herbicides. This is critical if no-till culture is to be successful. Weeds growing at planting are killed with a contact herbicide. Annual summer weeds are controlled with herbicide combinations.

Early spring plantings generally do not lend themselves to no-till systems because cool soil temperatures and wet conditions that occur with this type of culture slow germination and increase the incidence of seedling diseases. The potential for insect and disease problems is greater with no-till than with conventional systems because no-till culture gives pests a stable environment for development. Previous crop residues can hinder mechanical harvesting of vegetables.

SOIL REACTION (pH)

The soil reaction, or pH, is a measure of the acidity or alkalinity of a soil. The pH scale ranges from 1 to 14; a pH value of 7.0 is neutral, values below 7.0 are acid, and those above 7.0 are alkaline.

Most vegetable crops on mineral soils grow best in a pH range of 5.5 to 7.0 (Figure 6.1). However, if the proper amounts and ratios of nutrients for the crop are maintained, and other elements, such as aluminum, are not present in high concentrations, the optimum pH growth range can be expanded to 5.0 to 8.0. On muck soils, or highly organic soils, a pH of 5.0 to 6.0 is best. Sometimes potatoes may be grown in a soil with a pH of about 5.0 to avoid serious damage from scab disease. Cabbage may also be grown in soil with a pH slightly above 7.0 to reduce incidence of club root.

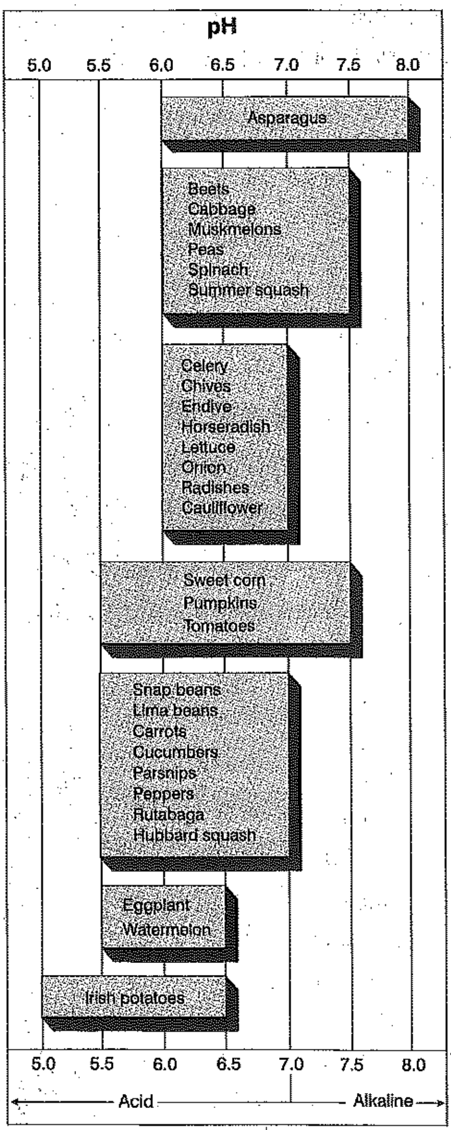

Figure 6.1. Optimum pH ranges for vegetable crops. (Source: Gerber, J. M., and J. M. Swiader. 1982. Liming Vegetable Crops. University of Illinois Coop. Ext. Ser. Hort. Facts VC–18–82)

In eastern growing areas of the United States and in most humid regions, many soils are naturally acid or become acid under present soil management systems. The most common cause of acidity in vegetable soils is the use of chemical fertilizers, specifically, ammonium containing N fertilizers. Bacteria in the soil convert ammonium ions to nitrate ions, releasing hydrogen into the soil solution. Other factors resulting in increased soil acidity are the decomposition of organic matter and calcium removal by crops or leaching.

In western growing areas and in arid climates, the soil pH is usually neutral or alkaline. This results from a lack of significant leaching and the accumulation of basic cations such as calcium, magnesium, potassium, and sodium.

Optimum pH levels are very important for vegetable fertility, because nutrient availability is determined by the level of soil acidity or alkalinity (Figure 6.2). In acid soils, potassium, calcium, and magnesium may be deficient, and the availability and uptake of phosphorus is reduced. Minor elements such as aluminum and manganese are more soluble at low pH and may become toxic. Also, microbial activity in the soil is hindered in acid soils, thus restricting the decomposition of plant residues and the mineralization of organic nitrogen. In alkaline soils with a pH above 7.4, deficiencies of such micronutrients as iron, manganese, zinc, and boron are most likely to occur. At high pH levels (above 9.0), excess sodium can retard the growth of some crops.

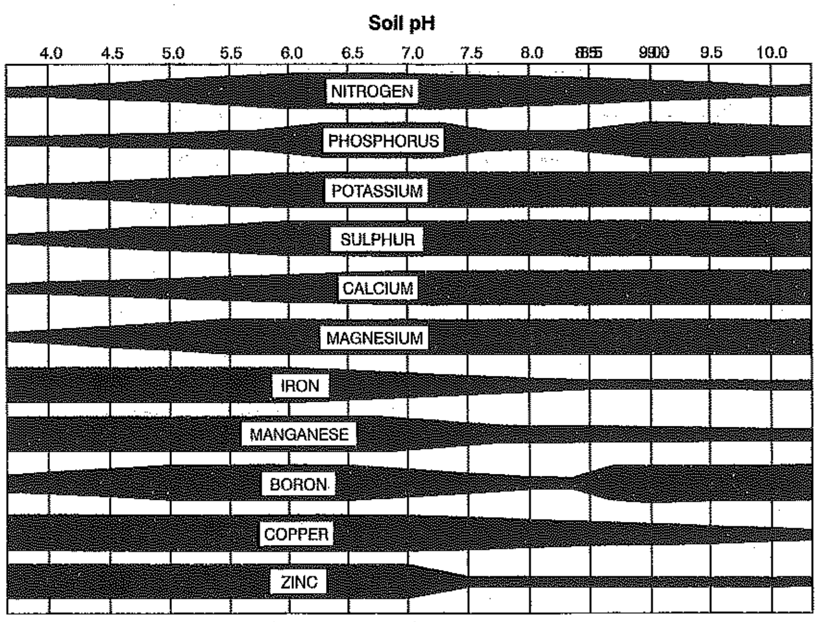

Figure 6.2. The relationship between soil pH and nutrient availability; the wider the band, the greater the availability.

LIMING

Liming neutralizes excess soil acidity and also supplies calcium and magnesium. Soil pH tests indicate the soil acidity but do not show the amount of lime needed to adjust soil pH to a specified value. This is determined by the lime index or buffer pH.

The amount of lime needed to raise the pH a given amount will vary, depending on the soil type, organic matter content, degree of reaction present, reaction desired, and liming material used. Heavy clay soils require more lime than light sandy soils. If soil pH tests indicate strong acidity, it is usually advisable to apply lime in several smaller rates rather than in one large application. For most vegetable soils, 4 tons per acre is the maximum amount of lime that is practical to apply at one time.

Liming Materials

Several types of lime are generally used for vegetable crops (Table 6.1). Liming materials having the highest total oxide content and the finest particle size will neutralize soil acidity most rapidly per unit weight of material used. However, fine lime breaks down rather quickly, and applications may have to be made more frequently to maintain the desired soil pH.

Table 6.1. Types of Liming Materials

Material	CaO Content	MgO Content	Solubility
	(%)	(%)	
Calcite	50–56	1–4	Very high
Magnesian	39–42	5–15	Moderate
Dolomite	30	20	Low–moderate
Hydrated lime	60	12	High

Calcitic or high-calcium lime should be used where soil pH and calcium are low and magnesium is high. This material is generally more soluble than other types of ground limestone and corrects soil acidity rapidly. Magnesian or hi-mag lime is intermediate in solubility and should be used where pH, calcium, and magnesium are low. Dolomitic lime is recommended where magnesium is particularly low. This is the least soluble of the materials, and too much magnesium is much more likely to cause harmful effects than too much calcium. Hydrated lime reacts more rapidly than other types of lime but is expensive and difficult to use, since it can burn plants. Liquid lime or fluid lime is a water suspension of finely ground limestone. There is generally no difference in the rate of activity of liquid lime over dry limestone, provided both materials are ground to the same fineness.

Lime should be mixed in the top 3 to 4 inches of soil. A commercial lime spreader is best for making application, although a shovel can be made for small areas. A grain drill can also be used, when light applications are made.

VEGETABLE NUTRITION

Sixteen chemical elements, known as nutrients, are required by vegetable crops to maintain life and growth. Three of the sixteen elements (carbon, hydrogen, and oxygen) are supplied primarily from air and water. The remaining thirteen are normally absorbed by plant roots. Very often, the soil levels of these nutrients are inadequate to support optimum growth, and they must be supplied by fertilizers.

Primary Plant Nutrients

Nitrogen, phosphorus, and potassium are the major fertilizer nutrients, since they are required in relatively large quantities and are most often lacking in vegetable soils.

Nitrogen is a vital component of protoplasm, chlorophyll molecules, nucleic acids (DNA and RNA), and amino acids, from which proteins are made. Nitrogen builds up the vegetative portions, producing large, green leaves, and is also necessary for filling out fruits. If it is present in large amounts in relation to other elements, it can cause excessive vegetative growth and succulence, and can seriously delay fruiting.

Phosphorus is necessary for cellular metabolism and is utilized by the plant in the storage and transfer of radiant energy to chemical energy through energy-rich linkages (ATP and ADP). Phosphorus stimulates early growth and root production and promotes maturity and seed development. It is especially essential in fruit production. The plant will be stunted and the fruit will fail to set if phosphorus is inadequate, especially if nitrogen is high.

Phosphorus is an immobile element in soils, and soon after application becomes absorbed on the clay particles and does not remain in solution. Consequently, roots must come in direct contact with the fertilizer, so phosphorus is often applied in bands at the time of planting to provide high concentrations near the roots of young plants (see "Starter Solutions" under "Methods of Application").

Potassium is important in the formation and translocation of carbohydrates and therefore is especially important for root and tuber crops (particularly potatoes) and in the formation of rigid stems in celery and rhubarb. It is also important in disease resistance, cell division, and water relations. Potassium enhances fruit size and quality and has been shown to influence ripening in tomatoes.

Secondary Plant Nutrients

Calcium, magnesium, and sulfur are generally described as secondary plant nutrients since they are not deficient as often as nitrogen, phosphorus, and potassium, and because their plant contents tend to be lower than the primary elements. In many vegetable soils, calcium and magnesium are naturally plentiful and are the dominant cations.

The main function of calcium in the plant is maintaining the structure of membranes and cell walls. It is also believed that calcium counteracts toxic effects of organic acids in the plant and the harmful effects of too large amounts of other elements such as magnesium, sodium, and boron.

Most vegetable crops need relatively small amounts of calcium, and "true" deficiencies of this nutrient are uncommon since most agricultural soils are relatively abundant in this element. The major requirement as a fertilizer usually occurs on very acid soils where lime is needed. This is most common in vegetable regions of the Midwest and Southeast. However, in some areas of the West, the decreased use of well water and increased irrigation with project water has created a greater need for calcium on some crops. Project water, which originates as snow-melt and mountain runoff, contains very small amounts of calcium, compared to many well waters that can contain enough calcium to supply crop needs. In areas such as these, where calcium may be needed, but there is no need to increase soil pH, gypsum (calcium sulfate) should be used.

There are times, however, when calcium deficiencies occur in vegetables even though the actual amount of calcium in the soil is quite high. These are most often caused by other factors, such as water stress and environmental influences that restrict the movement of calcium to specific sites within the plant, most commonly fruits and growing points. In reality, these are not true deficiencies that affect the whole plant, but are localized areas of calcium stress in the plant, and are generally referred to as calcium disorders. The list of these calcium-related disorders in vegetable crops is quite long and includes blossom-end rot in tomatoes, peppers, and watermelons, tipburn in cabbage and lettuce, cavity spot in carrots and parsnips, blackheart in celery, and internal browning in brussels sprouts. Soil application of calcium may not alleviate the problem; foliar applications of calcium (as calcium nitrate or calcium chloride) are usually more effective.

Magnesium is essential to plant growth since it comprises the central position in the chlorophyll molecule, making it vital to photosynthesis. Much of the magnesium in plants functions as an enzyme activator for a wide diversity of reactions. Magnesium is most likely to be deficient in vegetables grown on acid sandy soils in areas of moderate to high rainfall or when large amounts of calcitic limestone or potassium have been applied. A magnesium deficiency may occur in carrots, celery, tomatoes, and spinach. Dolomitic limestone can be applied on acid sandy soils that need both magnesium and lime, or magnesium sulfate (epsom salts) may be used when magnesium is low but lime is not needed.

Sulfur is needed by most vegetable crops in about the same quantities as phosphorus and is an essential component in proteins. Among vegetable crops, crucifers have perhaps the highest sulfur requirement.

In many vegetable growing regions, environmental sources of sulfur supply a major portion of plant sulfur requirements. These sources include mineralized organic matter, atmospheric sulfur released from emissions of fossil fuels and returned to the soil in rain water, and sulfur impurities in fertilizers and pesticides. Annual precipitation deposits of sulfur can range from 1 to over 100 pounds per acre. In recent years, however, this source of sulfur, along with that from fertilizer by-products, has diminished considerably with increased environmental controls of emissions and increased use of high-analysis fertilizers. This has led to speculation that sulfur deficiencies may develop in the next 5 to 15 years.

The need for sulfur would most likely occur in sandy soils or in soils low in organic matter located upwind from urban industrial centers. Either elemental or sulfate forms of sulfur fertilizers can be used on vegetable crops, although sulfate forms are more readily available to the plant. For most crops, an application of 10 to 30 pounds per acre of sulfur should correct a sulfur deficiency.

Micronutrients

The elements boron, copper, manganese, iron, zinc, and molybdenum are classified as essential micronutrients because they are required for proper plant growth, although in relatively small amounts. Even though their requirements are relatively low, micronutrients are just as essential for plant growth as the larger amounts of primary and secondary nutrients. A micronutrient deficiency can be just as limiting and reduce yields just as much as a deficiency of any of the major nutrients.

Vegetables show a wide range of response to micronutrients, and a micronutrient deficiency usually occurs only in specific crops. If the soil is low or deficient in a certain micronutrient, response to application of that micronutrient would likely occur if the crop has a high requirement for that micronutrient (Table 6.2). For example, boron is the most widely deficient micronutrient in vegetable crops, and beets, broccoli, cauliflower, celery, and turnips are particularly susceptible to a boron deficiency. However, in certain situations, crops may respond to micronutrient fertilizers, even though their requirements may be low to moderate.

Very often problems that arise in micronutrient nutrition in vegetables result from low availability and not from the soil micronutrient content. In

Table 6.2. Relative Response of Selected Vegetable Crops to Micronutrients

Vegetable	Iron	Manganese	Zinc	Copper	Boron	Molybdenum
Asparagus	M[a]	L	L	L	M	L
Beans	H	H	M	L	L	M
Beets	H	H	M	H	H	H
Broccoli	H	M	—	M	H	H
Cabbage	M	M	L	M	H	M
Carrots	—	M	L	M	M	L
Cauliflower	H	M	—	M	H	H
Celery	—	M	—	M	H	L
Cucumbers	—	M	M	M	L	L
Lettuce	—	H	M	H	M	H
Onions	—	H	H	H	M	H
Peas	—	M	L	L	L	M
Potatoes	—	M	M	L	L	L
Radishes	—	H	—	M	M	M
Spinach	H	H	H	H	M	H
Sweet corn	M	M	H	M	M	L
Tomatoes	H	M	M	M	M	M
Turnips	—	M	—	M	H	M

[a]Relative response: low (L), medium (M), high (H).

general, deficiencies of most micronutrients are accentuated by five situations: (1) strongly weathered soils, (2) coarse-textured soils, (3) soils high in pH, (4) highly organic soils, such as peats and mucks (especially for copper), and (5) soils inherently low in organic matter.

Perhaps the single most important factor determining micronutrient availability in vegetable soils is soil pH (Figure 6.2). The availability of boron, copper, manganese, zinc, and iron decreases as pH increases. Molybdenum is an exception, and its availability increases as pH increases. For vegetable crops, maintaining soil pH between 6.0 and 6.8 is best, both to avoid a deficiency and to avoid toxicity from excess micronutrient solubility.

When present in the soil at higher than optimum concentrations, or when applied in excessive amounts, some micronutrients (most commonly boron and manganese, but sometimes zinc and copper) can have adverse effects on plant growth. Sensitive vegetables, such as snap beans and cucumbers, can be damaged from residual carry-over of boron applied to previous crops.

Micronutrients should be applied to vegetables only on competent advice or where experience has proven their application to be necessary. Soil and plant tissue tests will aid in diagnosing a micronutrient deficiency, although these are not always reliable. In most situations, either soil or foliar applications can be used to correct a micronutrient deficiency. Plant response is quicker with foliar application, but crop injury is more likely from fertilizer misuse.

FERTILIZING VEGETABLE CROPS

Commercial fertilizers are added to a soil for the purpose of directly increasing the amounts of nutrients available to plants. They are not added to improve physical conditions or to make soil reserves available. Manures and lime do more than simply add nutrients and, for this reason, often produce better results than commercial fertilizers alone. However, manures and lime cannot be depended on to provide enough available nutrients in soils with low reserves; and even in fertile soils, organic materials and lime may cause improper nutrient ratios. Commercial fertilizers are necessary to furnish limiting elements in the most economical manner and to maintain proper ratios of the nutrients for the particular crop (Figure 6.3).

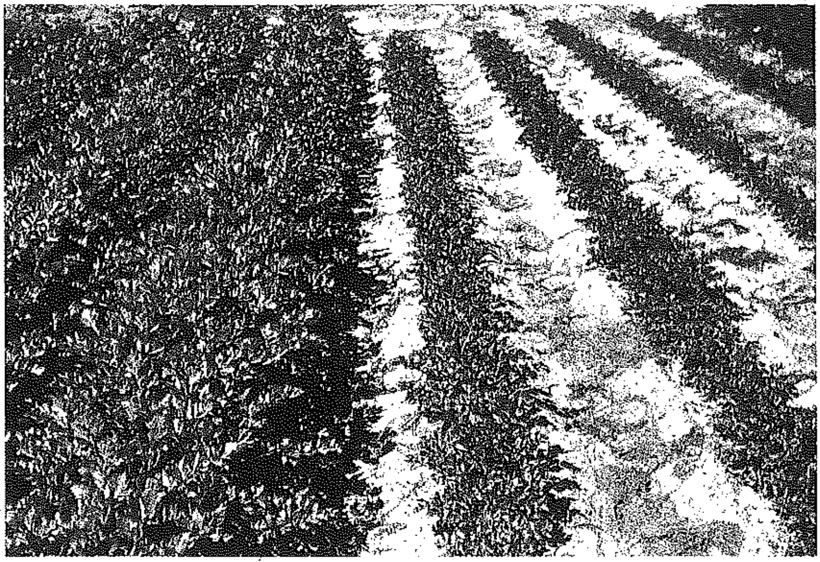

Figure 6.3. Celery grown on sandy soil in Florida; plants on left received well-balanced fertilizer regime, while those on right were unfertilized.

Fertilizer Analysis, Formula, and Ratio

Any substance that can supply nutrients to growing plants should be considered as a fertilizer. Animal manure, ammonium nitrate, bone meal, compost, and superphosphate are all examples of fertilizer materials, although the amount of nutrients supplied may differ. Plant response and economics should dictate the form of fertilizer used. If animal manure is available and can be spread easily, it makes an excellent fertilizer. However, when fertilizer must be purchased, more nutrients for the least amount of money are usually found in a bag of commercial inorganic fertilizer, such as the 5-10-10 and 10-20-20 formulations.

The grade, or analysis, of a fertilizer should always be printed on the bag, such as 5-10-5. These numbers represent respectively the total nitrogen (N), available phosphorus (expressed as P_2O_5), and water-soluble potassium oxide or potash (K_2O) content of the fertilizer in terms of percent by weight. For example, a 100-pound bag of 5-10-5 would contain 5 pounds of nitrogen, 10 pounds of P_2O_5, and 5 pounds K_2O. From the standpoint of economy, the higher the analysis, the more economical the fertilizer; a 10-20-10 fertilizer furnishes more nutrients per dollar than a 5-10-5. However, the high-analysis fertilizers are a little more difficult to distribute evenly and are more likely to burn on contact with seeds or plants; other than this, they are as good as the low-analysis fertilizers.

Fertilizer ratio differs from analysis in that it expresses the fertilizer in the relative proportions of one element to another, usually in terms of nitrogen. For example, 5-10-5 is the analysis, but 1-2-1 is the ratio. Therefore, as in this case, the ratio simply indicates that there is twice as much available phosphorus as nitrogen and the same amount of soluble potassium as nitrogen.

The formula indicates the quantity and composition of the various ingredients or compounds that are mixed together in a ton of the fertilizer. For a standard vegetable fertilizer with an analysis of 5-10-10, the formula may read: 365 pounds ammonium sulfate (21% N), 484 pounds calcium nitrate (15.5% N), 667 pounds triple superphosphate (45% P_2O_5), and 484 pounds potassium chloride (62% K_2O). When choosing fertilizers, one should know the formula, the rate of availability of the nitrogen, and the effect the compounds have on soil reaction.

Fertilizers

The composition of various fertilizers is shown in Table 6.3. Nitrogen and potassium fertilizers should be used with caution since there could be some danger of injury from high salt levels when placed in close contact with seeds and roots. Vegetables such as beans, carrots, and onions are particularly salt-sensitive and can easily be injured by banding high fertilizer rates.

As indicated earlier, ammonium-based fertilizers will generally leave an acid residue, while nitrate materials are mostly basic (ammonium nitrate is slightly acid). Anhydrous ammonia contains the highest percentage of nitrogen of any fertilizer and is the cheapest source of nitrogen. It is commonly used for preplant applications. However, free ammonia is toxic to vegetables, especially seedlings, and it should not be placed near seeds or roots.

Many vegetable growers prefer to use urea (a high N solid fertilizer produced by reacting ammonia with carbon dioxide under pressure) or nonpressure nitrogen solutions (aqueous solutions of nitrogen salts, most commonly mixtures of ammonium nitrate and urea). These materials, along with diammonium phosphate (DAP), are safe when broadcast but can cause injury when banded on alkaline soils. Granular ammonium nitrate and nitrogen solutions are most often used for sidedressed nitrogen applications. Problems from fertilizer injury are more likely to occur on light-textured soils than on silt loams or clays.

Table 6.3. Typical Composition of Fertilizer Materials

Organic Material	Nitrogen	Phosphorus	Potassium
	(% dry wt.)	(% dry wt.)	(% dry wt.)
Bat guano	10.0	1.8	1.7
Blood	13.0	0.9	0.8
Blood and bone	6.5	3.1	—
Bone, black	1.3	6.6	—
Bone meal, raw	3.0	6.6	—
steamed	2.0	6.6–14	—
Castor bean meal	5.5	0.9	0.8
Cattle manure (dried)	1.5	2.0	1.2
Chicken manure (dried)	3.5	2.0	2.6
Cottonseed meal	6.0	1.3	0.8
Fish meal	10.0	3.8	—
Garbage tankage	1.5	0.9	0.6
Horn and hoof meal	12.0	0.9	—
Seaweed (kelp)	0.2	0.1	0.6
Sewage sludge	1.5	0.6	0.3
Activated sewage sludge	6.0	1.3	0.1
Tankage	9.0	2.6	—
Inorganic Fertilizer	**Total N**	**Available P_2O_5**	**Water-soluble K_2O**
	(%)	(%)	(%)
Nitrogen materials			
Ammonium nitrate	33.5–34	—	—
Ammonium nitrate-sulfate	30	—	—
Monoammonium phosphate	11	48	—
Ammonium phosphate-sulfate	16	20	—
Ammonium phosphate-nitrate	27	12	—
Ammonium polyphosphate	10	34	—
Diammonium phosphate	16–18	46–48	—
Ammonium sulfate	21	—	—
Anhydrous ammonia	82	—	—
Aqua ammonia	20	—	—
Calcium ammonium nitrate solution	17	—	—
Calcium nitrate	15.5	—	—
Calcium cyanamide	20–22	—	—
Sodium nitrate	16	—	—
Urea	45–46	—	—
Urea formaldehyde	38	—	—
Urea ammonium nitrate solution	28–32	—	—
Phosphate materials			
Single superphosphate	—	18–20	—
Triple superphosphate	—	45–46	—
Phosphoric acid	—	52–54	—
Superphosphoric acid	—	76–83	—
Potash materials			
Potassium chloride	—	—	60–62
Potassium nitrate	13	—	44–46
Potassium sulfate	—	—	50–53
Sulfate of potash-magnesia	—	—	22–26

Organic materials, such as cottonseed meal, linseed meal, castor-oil meal, blood tankage, fish tankage, and guano, are neutral in their effect on soil reaction. The high cost of organic carriers and their slow availability tend to make them impractical in most situations for use in commercial production.

Methods of Application

Broadcasting. Scattering the fertilizer on the soil surface, either by hand or by machine, followed by incorporation with a plow or disk is the most common method of application used. Usually 50 to 60 percent of the recommended nitrogen and all of the phosphorus and potassium (except on sandy soils) are broadcast. Broadcasting fertilizer too far ahead of planting on sandy soils, however, can cause leaching losses of nitrogen and sometimes potassium. Since the fertilizer is intimately mixed with a large volume of soil, there is also an opportunity for increased phosphorus fixation on alkaline or very acid soils.

Banding. Although broadcasting is necessary when soil tests call for large amounts of fertilizer, small amounts can be applied more efficiently in a band. The fertilizer is placed 2 inches to the side and 2 inches below the level of the seed in the row at planting. This is especially effective when phosphorus is added to either cold or calcareous soils. Also, since banding places the fertilizer close to the plant roots where it is needed, less nitrogen and potassium are likely to be lost through leaching. When applied in a band, rates of nitrogen and potassium combined generally should not exceed 80 to 100 pounds per acre because of possible injury to roots.

Sidedressing. A sidedressing is an application of fertilizer (usually nitrogen, and sometimes potassium on sandy soils) during the season, 6 to 10 inches from the base of the plant, and lightly incorporated into the soil. The purpose of sidedressing is to supply additional nutrients during growth of the crop (Figure 6.4). Although fertilizer nutrients are needed for early growth, the greatest quantities of nutrients are usually taken up during the second half of the season. On sandy soils, much of the nitrogen fertilizer applied at planting may be leached out before it can be used by the plant.

Starter Solutions. Water-soluble and liquid fertilizers high in phosphorus, and usually containing some nitrogen and potassium, are used to stimu-

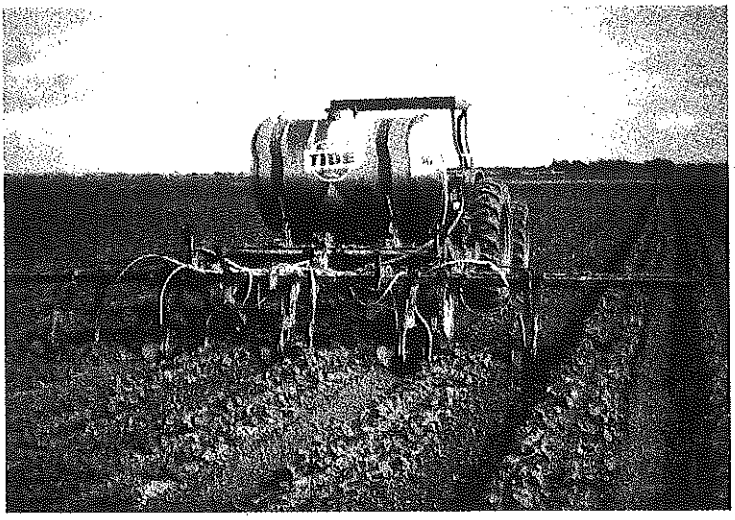

Figure 6.4. Vegetables on sandy soils are commonly sidedressed with liquid nitrogen solutions.

late the growth of young transplants. The solution is directly applied to the roots at planting and provides nutrients in a highly available form. The use of starter fertilizers should be considered standard practice for plantings made early in the season in cool, wet soils. Starter fertilizers are used commonly with tomatoes, peppers, melons, and cole crops (cabbage, broccoli, cauliflower). Typical starter fertilizers include 9-45-15, 10-52-8, and 16-32-16, but any water-soluble fertilizer high in phosphorus will do.

Foliar Fertilization. Plant leaves can absorb and use nutrients sprayed directly on them. This method of application has had the greatest use with nutrients required in only small amounts and when a quick plant response to fertilization is desired. Nutrients required in large amounts, such as nitrogen, phosphorus, and potassium, are usually added to soil rather than foliage because sufficient amounts of these nutrients needed for plant growth applied to leaves may damage vegetation due to leaf burn.

Fertigation. Applying fertilizers with irrigation water has been in practice for about 30 years. The advent of center-pivot, lateral-move, and solid-set sprinkler systems has made fertigation a practical system for uniform application of fertilizers. Multiple small applications are used to increase fertilizer efficiency, and as a precaution against burning foliage, especially from nitrogen fertilizers. When used in conjunction with drip irrigation, growers benefit from the reduction in water consumption and from greatly increased efficiency of fertilizer use.

This method requires considerable management input, including calibration of irrigating equipment, operation of the sprinkler system, check valves, and safety equipment. Fertigation and foliar application are useful methods to supplement normal soil application.

DETERMINING FERTILIZER REQUIREMENTS

Due to strict requirements for produce quality, and for marketing reasons, fertilizer recommendations for vegetable crops usually are in excess of crop removal requirements. For example, nitrogen recommendations for sweet corn commonly exceed yield requirements and are designed to keep the husk green to allow marketing of the fresh product. Potassium recommendations in tomatoes are made to assure uniform ripening of fruits. In both cases, lower fertilizer rates would likely not affect yields but could sharply reduce market quality.

Soil Testing

Vegetable crops are fertilized on the basis of annual soil tests, along with soil type, crop requirements, field history, and good judgement based on experience. Standard tests for vegetable soils include pH, lime index, soil cation exchange capacity, soluble salts, available phosphorus, exchangeable potassium, calcium, and magnesium, and the percent base saturation. Special tests are also available to determine organic matter and some micronutrients (boron, manganese, and zinc). Tests for nitrogen are highly variable and are of little value in estimating the true nitrogen status of the soil.

Separate soil tests should be made for every field that differs in color, slope, drainage, or previous fertilization and cropping. Each sample should represent no more than 2 to 4 acres and should consist of several subsamples collected at random locations throughout the field. Samples are collected from the top 6 to 8 inches in the late fall when the soil is relatively dry but not frozen.

Determining Fertilizer Rates

Soil test results indicate the relative levels (very low, low, medium, high, very high) of plant-available phosphorus and potassium in the soil. The vegetable crops are divided into five categories according to their phosphorus and potassium requirements. These, along with the amounts of phosphorus and potassium to apply for each soil fertility level, are shown in Table 6.4. For

Table 6.4. Phosphorus (P_2O_5) and Potassium (K_2O) Requirements for Vegetables on Mineral Soils Related to Soil Test Results[a]

Vegetable	Fertilizer Requirement for									
	Phosphorus					Potassium				
	When Soil Test Results Are									
	Very Low	Low	Medium	High	Very High	Very Low	Low	Medium	High	Very High
	(lbs per acre)									
Asparagus (cutting bed)	200	150	100	50	0	350	300	250	150	50
Asparagus (new bed)	250	200	150	50	0	300	250	200	100	50
Beans	100	100	50	0	0	150	100	50	0	0
Beets	150	100	50	50	0	200	150	100	50	0
Broccoli	250	200	150	50	0	300	250	200	100	50
Brussels sprouts	250	200	150	50	0	300	250	200	100	50
Cabbage	250	200	150	50	0	300	250	200	100	50
Carrots	150	100	50	50	0	200	150	100	50	0
Cauliflower	250	200	150	50	0	300	250	200	100	50
Celery	250	250	200	100	0	350	300	250	150	50
Cucumbers	200	150	100	50	0	300	250	200	100	50
Eggplants	250	250	200	100	0	350	300	250	150	50
Horseradish	250	200	150	50	0	300	250	200	100	50
Lettuce	200	150	100	50	0	250	200	150	50	0
Melons	200	150	100	50	0	300	250	200	100	50
Onions	200	150	100	50	0	250	200	150	50	0
Parsnips	150	100	50	50	0	200	150	100	50	0
Peas	100	100	50	0	0	150	100	50	0	0
Peppers	250	200	150	50	0	300	250	200	100	50
Pumpkins	200	150	100	50	0	300	250	200	100	50
Radishes	150	100	50	50	0	200	150	100	50	0
Rhubarb	250	250	200	100	0	350	300	250	150	50
Spinach	200	150	100	50	0	250	200	150	50	0
Squashes	200	150	100	50	0	300	250	200	100	50
Sweet corn	200	150	100	50	0	250	200	150	50	0
Tomatoes	250	200	150	50	0	350	300	250	150	50
Turnips	150	100	50	50	0	200	150	100	50	0

[a]Timing and placement will vary with the specific crop.

example, if the soil test indicates that the relative levels of phosphorus and potassium are medium and low, respectively, the fertility recommendation for lettuce would be 100 pounds P_2O_5 per acre and 200 pounds K_2O per acre.

Phosphorus and potassium fertilizer recommendations are usually given in the oxide form of each element because most fertilizer grades are listed, sold, and discussed by the trade in this way. Some fertilizer is recommended even for soils testing high, in order to maintain adequate levels of fertility. A home garden may be treated as if all crops were in the highest fertilizer requirement category.

Since soil tests for nitrogen are of little value, the nitrogen recommendations (Table 6.5) are based on the needs of the crop, field trials, and yield potential. Previous cropping, the presence of decomposable residues, soil type, and leaching should also be considered when one is determining the amounts of nitrogen to apply. If the season is cool and wet, or the soil is poorly drained, additional nitrogen may be necessary. Light-colored soils usually have less than 2.5 percent organic matter and require higher nitrogen rates than dark-colored soils, where organic matter contents can range from 3 percent to more than 10 percent.

Table 6.5. Nitrogen Requirements for Vegetable Crops on Mineral Soils

	N Requirement (lbs. per acre)[a]	
Crop	Dark-colored Soils	Light-colored Soils
Asparagus	50	100
Beans	40	75
Beets	75	100
Broccoli	100	150
Cabbage	100	125
Carrots	75	100
Cauliflower	100	150
Celery	150	200
Cucumbers	75	125
Eggplants	75	125
Horseradish	50	100
Lettuce	80	120
Muskmelons	75	125
Onions	80	100
Parsnips	75	100
Peas	30	45
Peppers	75	125

(Continued)

Table 6.5 (Continued)

Crop	N Requirement (lbs. per acre)[a]	
	Dark-colored Soils	Light-colored Soils
Potatoes	120	180
Pumpkins and winter squashes	75	125
Radishes	30	50
Rutabagas and turnips	50	80
Spinach	80	120
Summer squashes	75	100
Sweet corn	80	120
Sweet potatoes	50	75
Tomatoes (processing)	60	100
(market)	100	150
Watermelons	75	125

[a]Timing and placement of N fertilizer will vary with the specific crop.

SELECTED REFERENCES

In addition to the references listed below, information on specific fertility recommendations for vegetable crops may be obtained from commercial production guides published by the cooperative extension service of the various state universities.

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