Growing greenhouse tomatoes in soil and in soilless media

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La *culture des tomates en serre sur sol et sans sol*

Contents

Introduction

Tomatoes are the most important greenhouse vegetable crop in Canada. They are grown in spring or fall, with conditions and problems varying for the two seasons. The spring crop is normally seeded in the first or second week of November, set in the greenhouse the first week of January, and harvested from mid March to July, with some plantings extended to the fall. Because of the short and dull days of winter, this crop gets a slow start and demands superior handling from the grower, who must ensure maximum use of available light and minimum waste of available photosynthates. Failing to maintain a good balance between vegetative and reproductive growth during the first 2-3 months of this crop results in either excessive growth with little fruit-setting or in overbearing of fruit on hardened plants that grow very slowly. Longer and brighter days that occur later in the season cannot compensate for lost early, premium-priced production, resulting in an uneconomical crop for the grower. Despite its difficulties, the spring crop has always been the most important of the two because of higher prices received and the longer season. The fall crop, on the other hand, is seeded around the end of June, set in the greenhouse during the first week of August, and harvested from the beginning of October to the middle of December. Fall tomatoes, in contrast to the spring crop, get an excellent start under the bright and relatively long days of August and September, but they mature during the short days of late fall and winter:

Chapter 1. The tomato plant

Origin

The genus *Lycopersicon* of the family Solanaceae is believed to originate in the coastal strip of western South America, from the equator to about 30” latitude south; the greatest genetic diversity is found here. The genus is divided into two subgenera, *Eulycopersicon* and *Eriopersicon,* of which the former contains the species *Lycopersicon pimpinellifolium* and *Lycopersicon esculentum. Lycopersicon pimpinellifolium,* often known as the red currant tomato, has exceedingly small fruit (less than 10 mm). *Lycopersicon esculentum* contains large-fruited types that grow wild or are grown in cultivation as annuals or perennials. Plants of those species allocated to the subgenus *Eriopersicon* are generally found in the wild as perennials, with hairy and whitish green fruit that is most unattractive in appearance and flavor.

Determinate versus indeterminate

Based on plant habit and vigor the cultivated tomato is divided into two types: indeterminate (or vine), whose plants are trained to single stems with the side shoots removed, as is done in greenhouse tomatoes; and determinate (or bush), which are used for field cropping where all side shoots are left on the plants to terminate in a cluster (Fig. 1). Theoretically all indeterminate types are perennial plants, whereas all determinate types are annuals.

Plant improvement

Traditionally, the oldest and simplest way to improve tomatoes was to save seed from plants that had desirable characters, e.g., high yield, good flavor. This approach leads to crop improvement only when there is genetic diversity to begin with and the plants breed true (i.e., desirable characters are transferred unaltered from generation to generation). In recent years the cultivated tomato has been improved greatly by many cross-breeding techniques. Most frequently, new F_1 hybrids are created by crossing preexisting cultivars or pure lines bred for that purpose (Fig. 2). This method is based on the breeder's skill in selecting the parents that should be crossed in order to produce a good hybrid and provides a convenient way of obtaining desirable combinations of characters from the parents. However, F_1 hybrids do not breed true, and so each crop must be raised from fresh hybrid seed produced every year from the parental lines. Thus, the seed company that has the parents has a monopoly on the seed supply of the hybrid. It is hopeless for the grower to try and economize by saving the seed of a tomato hybrid, as such seed is useless.

Seed germination

The tomato seed, 3-5 mm in size, has a silky appearance and contains a large coiled embryo surrounded by a small amount of endosperm; it nevertheless retains its viability for many years after harvesting. Well over 90% germination is possible after 10 years when the seed is stored under cool dry conditions. The first sign of germination is the appearance of the small white root (radicle) (Fig. 3). As the radicle pushes downward into the growing substrate, the hypocotyl (primitive stem part) takes on a crook-like form known as the plumular hook. The plumular hook grows to the soil surface, where in response to light it begins to straighten and turns green. When the seed is firmly anchored in the soil and the plumular hook is straight, the colyledons (seed leaves) are pulled out of the seed coat (testa), which remains in the soil. However, when the growing medium is too loose the colyledons cannot separate from the testa, and sometimes the seedling is distorted (Fig. 3). Tomatoes have a well-defined taproot, with an abundance of lateral fibrous roots. It is possible to encourage the development of more fibrous roots by pruning the taproot, as happens when a seedling is pricked out from a seeding tray and transplanted into a pot. The plant readily forms adventitious (aerial) roots on the stem, which is of great value if the roots become diseased or damaged; a layer of moist soil or peat (the latter is preferable) at the stem base encourages new roots to form at this point. Once the cotyledons are fully grown the true leaves soon appear at the growing point.

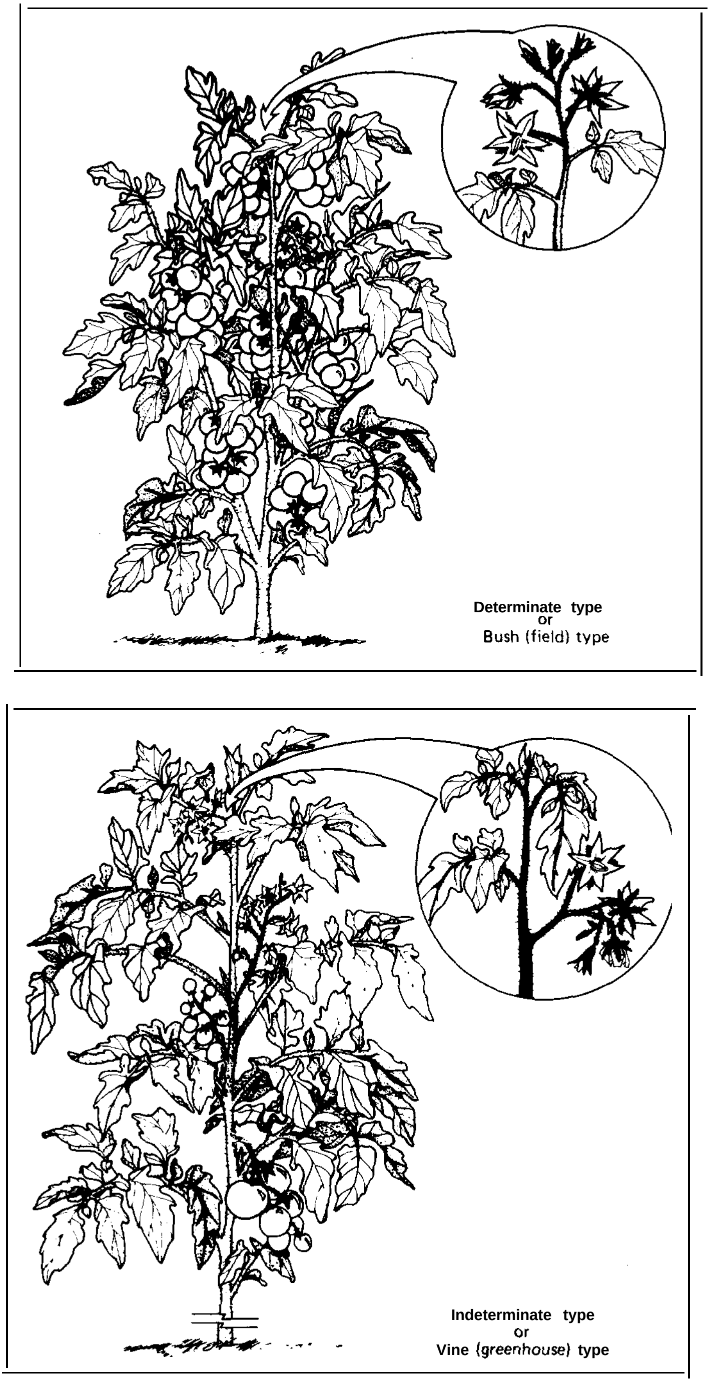

Fig.1 **Two types of tomato growth.**

Initial growth and development

After several leaves have formed (7–12) the growing point changes from vegetative to reproductive, and a cluster of flower buds are formed that ultimately develop into the first flower cluster or truss. Vegetative growth continues in the form of a side shoot growing from the axil of the last leaf. This side shoot forms a small number of leaves (2–4) and then differentiates to form the second flower truss along with a new vegetative growing point. Thus, the greenhouse tomato develops as a succession of side shoots; this process is known as a sympodial, or indeterminate, growth (Fig. 4). A peculiar thing happens every time the plant turns vegetative and a new growth starts to develop from the axil of the last leaf: this last leaf, which is formed before flower initiation, is carried up on its axillary growth and ultimately appears at a higher position than the truss.

The final result is that the stem appears continuous and the trusses seem to arise at internodal positions, whereas in fact they are growing out of the axil of the first leaf above them. Occasionally, strong side-shoots develop from several leaves, resulting in confusion as to which shoot is the leader and which shoots should be removed by pruning. To be certain that the leader is not accidentally removed, always pull out the side shoots arising from the leaf immediately below each truss, thus allowing the main growing point of each plant to remain intact. The number of leaves that form before the first flower truss varies from cultivar to cultivar but is also influenced by environmental conditions. Most cultivars produce a minimum of seven leaves before the first flower truss and thereafter usually three leaves between trusses.

The flower

The tomato truss is composed of a succession of axils, each bearing a single flower (Fig. 5). The main stem of the truss (peduncle) is capable of branching one or more times; such branched (or double) trusses can be encouraged by low-temperature treatment, a procedure discussed later. Branching is desirable because it usually increases the number of flowers per truss and allows the number of flowers on each branch to remain fairly constant, irrespective of the degree of branching (Fig. 5). The characteristically bright yellow flowers of the cultivated tomato usually have five sepals (constituting the calyx) and five petals (constituting the corolla) although six or more such segments are possible (Fig. 6).

The stamens (male organs) are composed of short filaments and enlarged anthers, which are united in the form of a narrow-necked cylinder (anther tube). The style, which is part of the pistil (female organ), is usually shorter than the anther tube, and therefore the pollen-receptive stigma is enclosed within the anther tube. This ensures self-pollination because the pollen is shed from inside the anther tube (Fig. 6). The importance of self-pollination is exemplified by the fact that when light is at low levels and the style becomes longer than the anther tube, fruit set is greatly reduced.

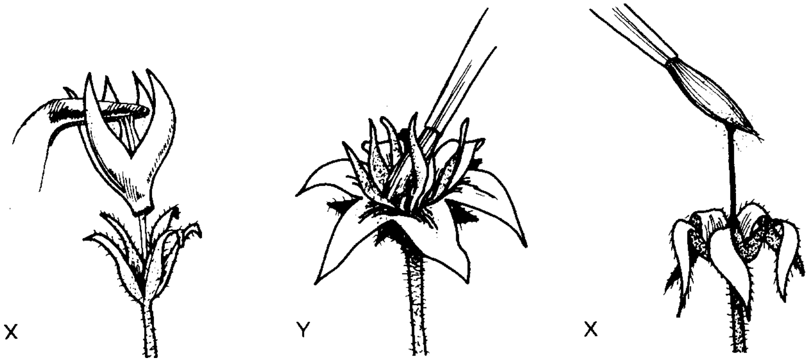

Fig. 2 Cross pollination of two tomato parent lines for the production of F_1 hybrid seed.

Cross pollination requires the removal of the anthers of parent X before pollen is released.

The Y parent's anther tube is opened when pollen is present. The pollen is picked up with a soft brush.

The pollen is deposited on the stigma of parent X. The seeds from the resulting tomato have characteristics of both X and Y.

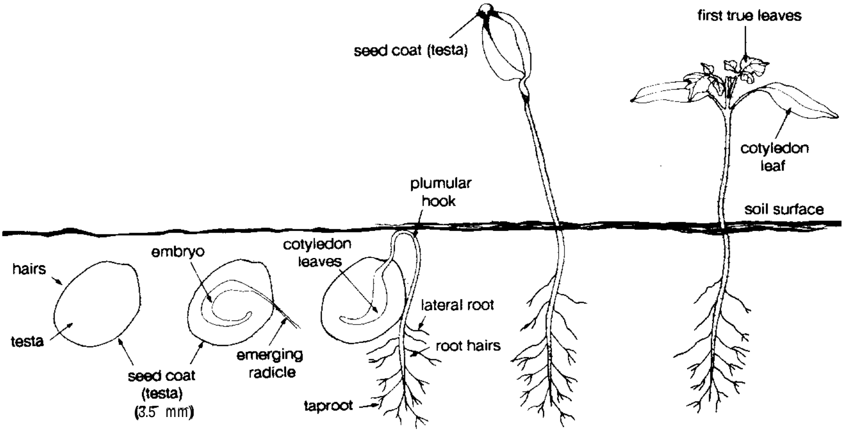

Fig. 3 Germination of the tomato seed.

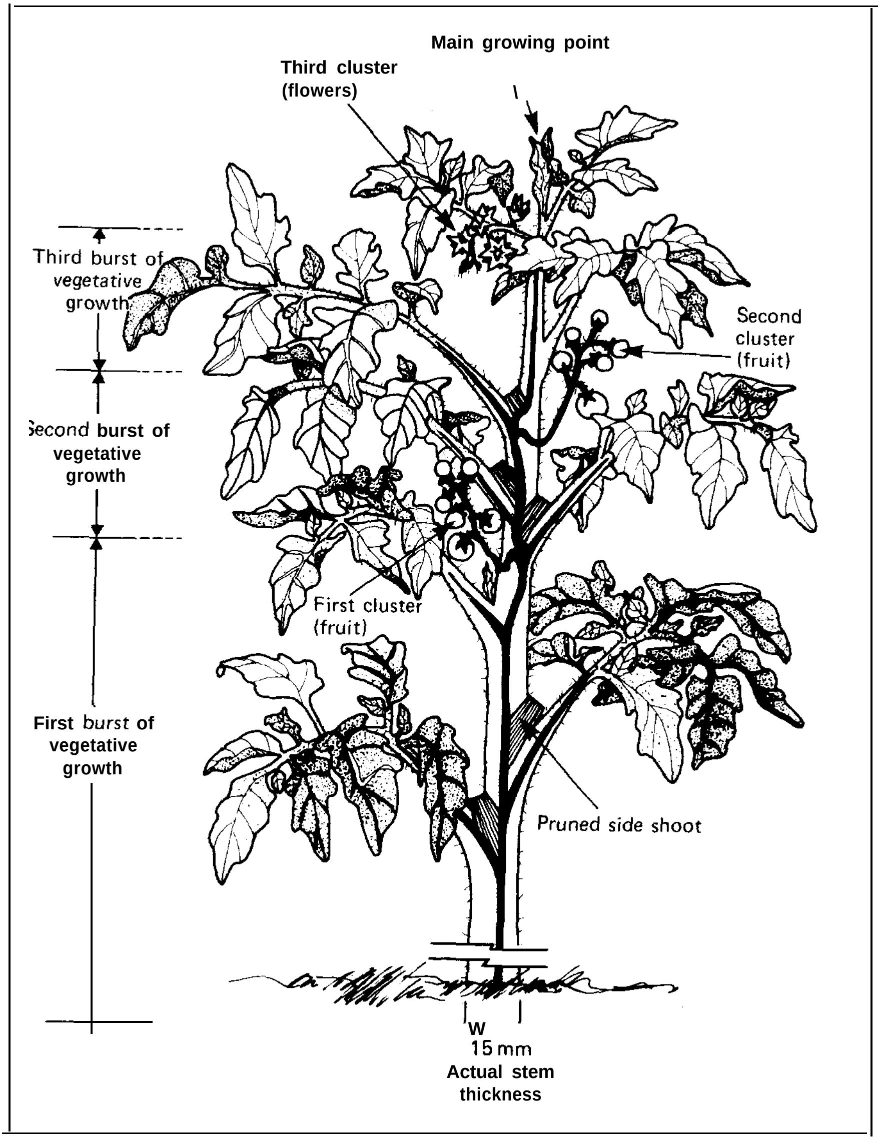

Fig. 4 The sympodial type of growth of the indeterminate ***tomato grown*** commonly in greenhouses.

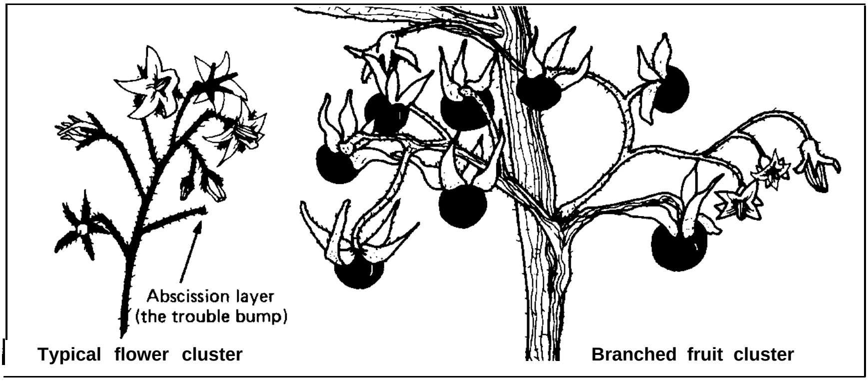

Fig. 5 The flower cluster of tomato.

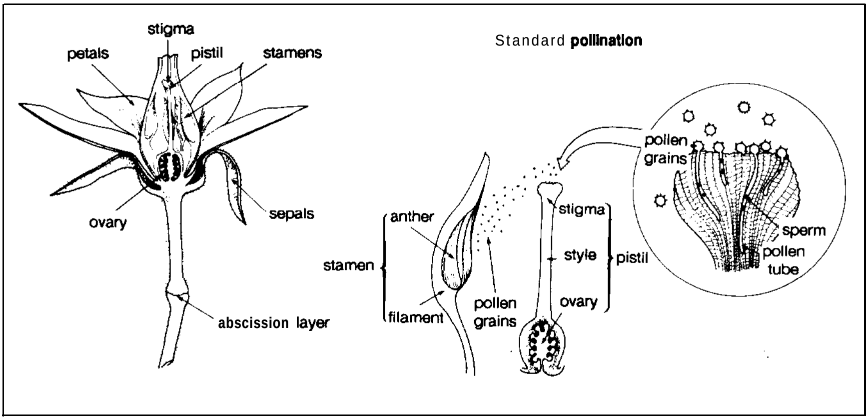

Fig. 6 The flower of the tomato and its pollination.

Tomato flowers are complete, with both male and female organs, and are mostly self-fertilizing. When fruit fails to set, blossoms separate at the abscission layer and then drop.

Pollination: Pollen grains are released by the anthers. Some fall or float in the air to the stigma, usually of the same flower, where they adhere to the sticky surface.

Fertilization: The fruit is set when pollen grains germinate and send tubes with the pollen tube nucleus (sperm) down the style. There they unite with the ovules, in the ovary.

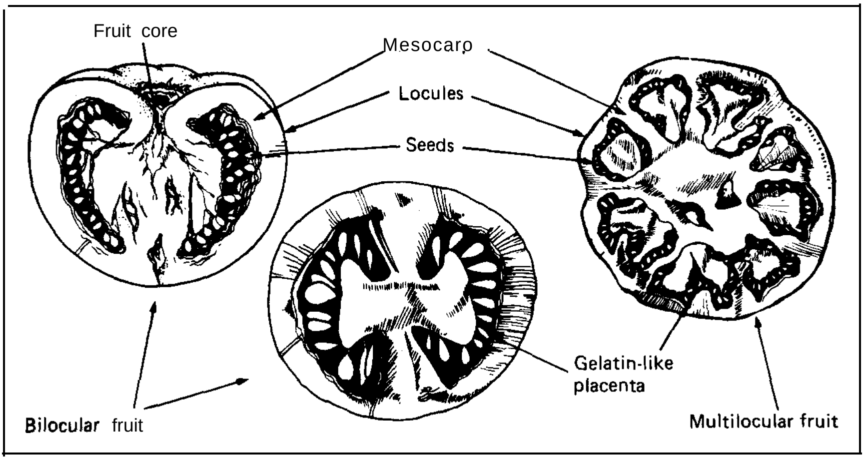

Fig. 7 The tomato fruit.

The fruit

The tomato fruit, which is classified as a berry, is an enlarged ovary of two or more chambers (locules) containing the seeds (fertilized ovules), which are imbeded in a gelatin-like placenta (Fig. 7).

Chapter 2. Environmental requirements

The greenhouse environment has a profound effect on crop productivity and profitability. In this chapter, environment is taken in its narrow meaning and includes_ only temperature, light, relative humidity, carbon dioxide, and air movement. Other related subjects, such as water and nutrients, are discussed elsewhere.

Temperature

Air temperature is the main environmental component influencing vegetative growth, cluster development, fruit setting, fruit development, fruit ripening, and fruit quality The average 24-h temperature is believed to be responsible for the growth rate of the crop-the higher the average air temperature the faster the growth. It is also believed that the larger the variation in day-night air temperature, the taller the plant and the smaller the leaf size. Although maximum growth is known to occur at a day and night temperature of approximately 25°C, maximum fruit production is achieved with a night temperature of 18°C and a day temperature of 20° C. The recommended temperatures that follow are therefore a compromise and are designed for sustained, high fruit productivity combined with modest crop growth throughout the growing season.

Recommended air temperatures

	Low light	High light	With carbon dioxide
Night minimum	**17°C**	**18°C**	18°C
Day minimum	19°C	21°C	21°C
Ventilation	21°C	24°C	26°C

Note

- When growing cold-tolerant, cultivars such as Vendor, air temperatures can be l-2°C lower than those indicated. However, when growing vigorous cultivars such as Ohio CR-6, the indicated temperatures are the absolute minimum.
- During very bright weather, temperatures higher than 26°C do not harm the plants; but, above 29°C, blossoms of most cultivars sustain injury (Ohio CR-6 is an exception).
- A minimum soil temperature of 14°C is recommended.

Light

Light is a prerequisite of plant growth. Plant matter is produced by the process of photosynthesis, which takes place only when light is absorbed by the chlorophyll (green pigment) in the green parts of the plant, mostly in the leaves. In the process of photosynthesis the energy of light is used in fixing atmospheric carbon dioxide with water in the plant to produce such carbohydrates as sugars and starch. Generally, the rate ofphotosynthesis is related to light intensity, but not proportionally. The importance of light in tomato production is greatest in the winter, when it is in short supply. In the short dull days of late fall, winter, and early spring, flower bud development is arrested and clusters fail to produce flowers and fruit. This failure is due to the low daily levels of radiant energy, which result in insufficient carbohydrate production. Not only do the poor light conditions limit photosynthetic productivity but the limited carbohydrates produced during the day are expended by the respiring plant so that it can survive through the long nights. A fully grown tomato crop benefits from any increase in natural light intensity, provided the plants are well supplied with water, nutrients, and carbon dioxide, and the air temperature is prevented from becoming too high.

Relative humidity

The effects of relative humidity on crop performance are not well understood. The crop can withstand a wide range of relative humidity, from very low to very high, as long as the changes are not drastic or frequent. At low relative humidity, irrigation becomes critical, whereas at high relative humidity diseases can manifest themselves. Growth in general is favored by high relative humidity; high relative humidity during the day can also improve fruit setting. However, high relative humidity, when not managed properly, can easily lead to water condensation on the plants and the development of serious diseases.

Carbon dioxide

In cold weather, with no ventilation, a minimum carbon dioxide concentration of 1000 vpm (≃1000 ppm) is recommended during the day. In the summer, with ventilation, the application of supplemental carbon dioxide at a concentration up to 400 ppm has been found economically useful in other countries, but this technique is too new in Canada to support definite recommendation. Regions with a moderate (sea) climate, such as British Columbia, are more likely to benefit from carbon dioxide applied in the summer. But in regions with a continental climate, such as southwestern Ontario, the need to ventilate the greenhouse actively throughout the hot summer probably renders the practice uneconomical.

Air movement

Horizontal air movement is beneficial for several reasons. An approximate air speed of 1 m/s,[1] which causes leaves to move slightly, is recommended. Horizontal air movement helps minimize air temperature gradients in the greenhouse, removes moisture from the lower part of the greenhouse (under the foliage), distributes moisture in the rest of the greenhouse, helps the carbon dioxide from the top of the greenhouse to travel into the leaf canopy where it is taken up and fixed in photosynthesis, and may even assist pollination. As a result of modest air movement in the greenhouse the uniformity of the greenhouse environment is improved, which is generally beneficial to crop productivity and energy conservation.

Chapter 3. Nutritional requirements

Soil-plant relationships

Plants in their natural environment have lived, with almost no exception, in association with soil, an association known as the soil-plant relationship. Soil provides four basic needs of plants: water, nutrients, oxygen, and support. With the advancement of science and technology, humans have provided for these needs in an artificial way and have successfully grown plants without soil. All the various methods and techniques developed for growing plants without soil are collectively called soilless methods of plant culture. These methods include a great diversity of systems, from the purely hydroponic, which are based on water and nutrients only (e.g., nutrient film technique, or NFT), to those based on artificial mixes that contain various rates of soil. In between these extremes lie a great number of soilless methods that make use of some sort of growing medium, either inert (e.g., rockwool slabs, polyurethane chunks, and perlite) or not inert (e.g., gravel culture, sand culture, and peat bags).

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[1] metre per second

Soil as a growth medium

Soil consists of mineral matter, organic matter, water, and air. An average soil in optimum condition for plant growth might consist of 45% mineral matter, 5% organic matter, 25% water, and 25% air space. The mineral matter is made up of a great diversity of small rock fragments. The organic matter of a soil is derived from plant and animal remains and is a mixture of these materials at various stages of decomposition. In the process of decomposition, some of the organic entities are oxidized to their end-products and others to an intermediate product called humus. Both the type and the relative quantity of the mineral and organic constituents of a soil determine its chemical properties. Chemical properties of a soil are the amounts of the various essential elements present and their forms of combination, as well as the degree of acidity or alkalinity, known as pH.[2] The extent of nutrient availability to the plants depends not only on the chemical properties of the soil but also on its physical properties.

Soil structure and texture

The physical properties of a soil describe its texture, i.e., the size distribution of its mineral constituents, expressed as a percentage of content of sand, silt, and clay (Fig. 8), and its structure, i.e., the type and extent of formation of the various mineral and organic constituents into crumb-like soil aggregates. The organic matter of a soil plays an important role in soil structure because of the diversity in the size of its components but, even more importantly, because of the role of humus in cementing together the various soil constituents into crumb-like aggregates.

Soil structure in turn plays an important role in soil fertility (the ability of soil to sustain good plant growth and high yields) because it determines, to a great extent, the water-holding capacity and aeration of a soil. The water held within the soil pores, together with the salts dissolved in it, make up the soil solution that is so important as a medium for supplying nutrients and water to growing plants. The air located in the soil pores supplies oxygen for the respiration of root and soil microorganisms and removes the carbon dioxide and other gases produced by them. Plant nutrients exist in soil as either complex (organic or inorganic). compounds that are unavailable to plants or in simple forms that are usually soluble in water and are therefore readily available to plants. The complex forms, which are too numerous to mention, must first be broken down through decomposition to simple soluble forms to be available and therefore useful to plants (Fig. 9). The available forms of all essential nutrients for plant growth are summarized in Table 1.

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[2] The pH value of a solution is the negative logarithm of its hydrogen ion concentration ($pH = -\log[H+]$). A pH of 7 indicates neutral conditions; values lower than 7 indicate an acid environment; and values higher than 7 indicate an alkaline environment.

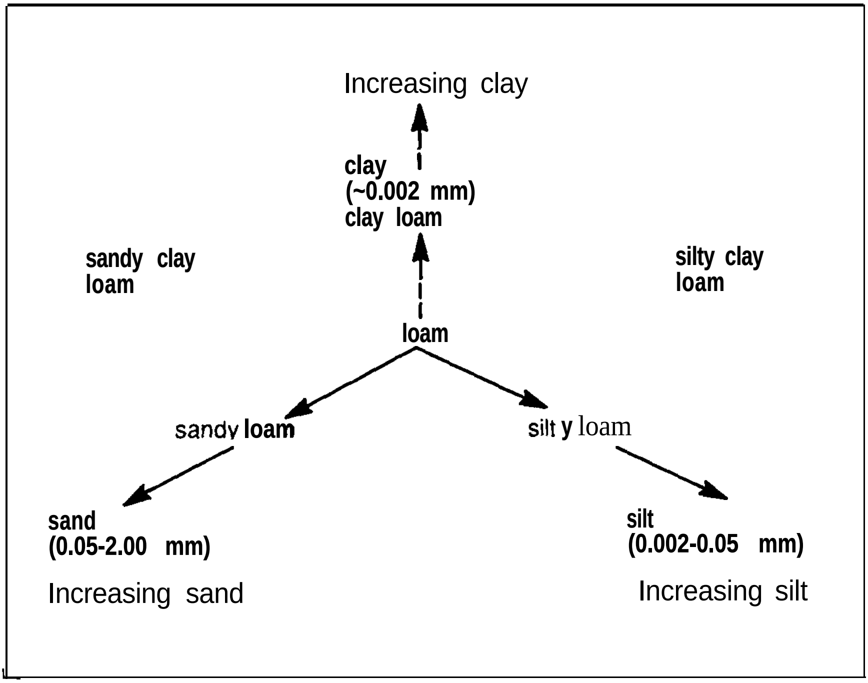

Fig. 8 Classification of soils according to texture.

Soil reaction (pH)

The reaction of the soil solution (pH) also affects the solubility of the various nutrients and thus their availability to plants; this process is illustrated in Fig. 10.

In acid soils ($pH < 7$) the nutrients calcium and molybdenum are less available, whereas in alkaline soils ($pH > 7$) the nutrients iron, manganese, and zinc are less available, and excessive amounts of bicarbonate (HCO_3^-) may interfere with the normal uptake of certain nutrients. Most nutrients are available when the pH range is between 6 and 7, which explains why most plants grow best in soils of that reaction.

The cation exchange capacity of the soil

When small quantities of inorganic salts, such as the soluble mineral matter of soil and commercial fertilizers, are added to water they dissociate into electrically charged units called ions. The positively charged ions (cations) such as hydrogen (H^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), ammonium (NH_4^+), iron (Fe^{2+}), manganese (Mn^{2+}), and zinc (Zn^{2+}) are absorbed mostly on the negatively charged surfaces of the soil colloids (microscopic clay and humus particles) and exist only in small quantities in the soil solution. Thus, the humus-clay colloids serve as

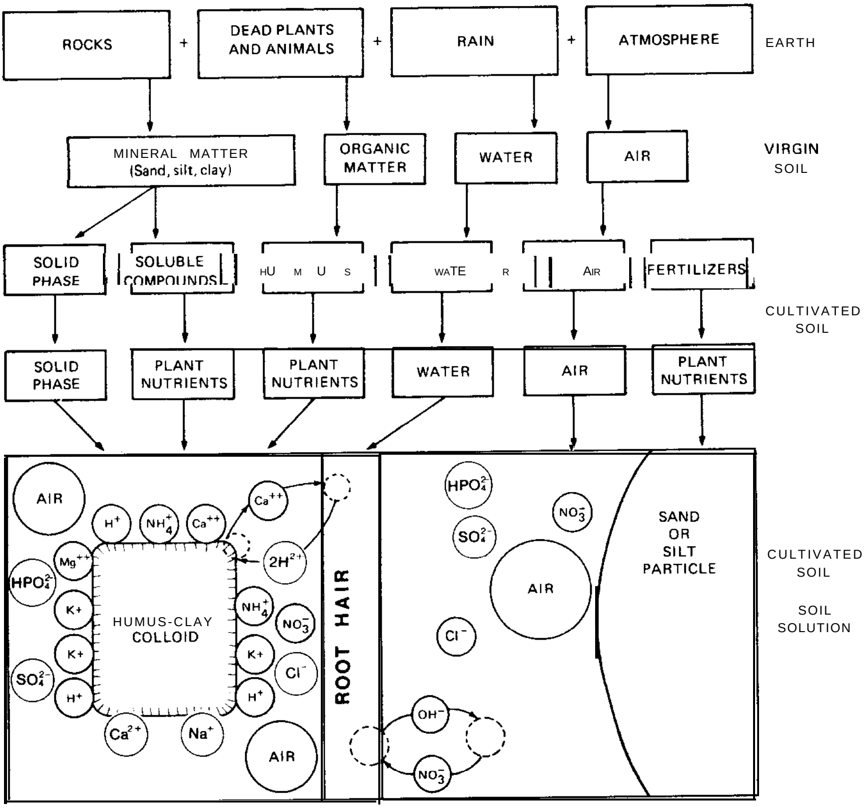

Fig. 9 The processes of mineralization, soluhilization, cation exchange, and nutrient absorption.

a storehouse for certain essential ions (cations). The negatively charged ions (anions), such as nitrates (NO_3^-), phosphates (HPO_4^{2-}), sulfates (SO_4^{2-}), and chlorides (Cl^-), are found almost exclusively in the soil solution and can therefore be leached away easily with overwatering. The roots and root hairs are in intimate contact with the soil colloidal surfaces, which are bathed in the soil solution, and therefore nutrient uptake can take place either from the soil solution or directly from the colloidal surfaces (cation exchange).

The soil solution is the most important source of nutrients, but since it is very dilute its nutrients are easily depleted and must be replenished from soil particles. The solid phase of the soil, acting as a reservoir of nutrients, slowly releases them into the soil solution by the solubilization of soil minerals and organics, by the solution of soluble salts, and by cation exchange. A more dramatic increase in the nutrient content of the soil solution takes place with the addition of commercial fertilizers.

As plants absorb nutrients (ions) they exchange them for other ions. For example, for the uptake of one potassium (K^+) ion or one ammonium

Table 1 Essential elements for the growth of most cultivated plants

Element	Symbol	Atomic weight	Available form
Organic elements (obtained from the air and water)			
Hydrogen	H	1.00	H_2O
Carbon	C	12.00	CO_2
Oxygen	0	16.00	O_2, H_2O
Macronutrients (needed in large quantities)			
Nitrogen	N	14.00	NO; , NH_4^+
Potassium	K	39.10	K^+
Calcium	Ca	40.08	Ca^{2+}
Magnesium	Mg	24.32	Mg^{2+}
Phosphorus	P	30.92	$H_2PO_4^-$, HPO_4^{2-}
Sulfur	S	32.07	SO_4^{2-}
Micronutrients (needed in small quantities)			
Iron	Fe	55.85	Fe^{3+}, Fe^{2+}
Manganese	Mn	54.94	Mn^{2+}
Copper	c u	63.54	Cu^{2+}, cu+
Boron	B	10.82	BO_3^{3-}, $B_4O_7^{2-}$
Zinc	Zn	65.38	Zn^{2+}
Molybdenum	Mo	95.95	MoO_4^2 +

(NH_4^+) ion, one hydrogen (H^+) ion is released into the soil solution or directly into the soil colloids by the process of cation exchange. Similarly, for the uptake of one calcium (Ca^{2+}) or one magnesium (Mg^{2+}) ion, two hydrogen (H^+) ions are released by the root. Thus, as the plant absorbs these essential cations, the soil solution and the colloidal particles contain more and more hydrogen (H^+) ions, which explains why the removal of cations (ammonium (NH_4^+) nitrogen is a good example) by crops tends to make soils acidic, i.e., having a low pH. Also, as the plant absorbs essential anions such as nitrates (NO_3^-) and phosphates (HPO_4^-), the soil solution is enriched with more and more hydroxyl groups (OH^-) and bicarbonates (HCO_3^-), which explains why the removal of anions (nitrate (NO_3^-) nitrogen is a good example1 by crops tends to make soils alkaline, i.e., having a high pH.

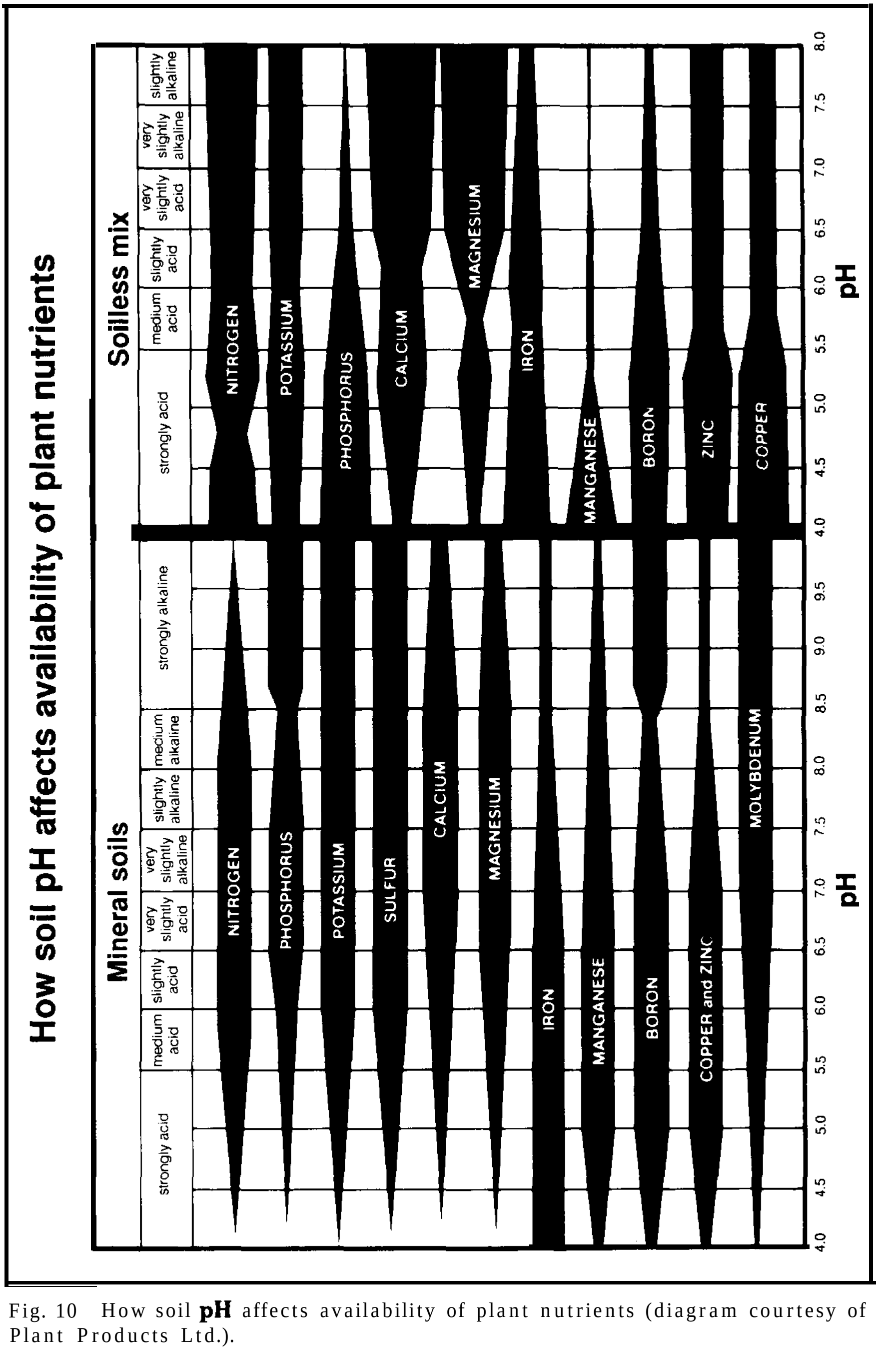

Fig. 10 How soil **pH** affects availability of plant nutrients (diagram courtesy of Plant Products Ltd.).

Vegetativeness versus reproductiveness

Growing a successful tomato crop depends on the grower's ability to maintain an optimum balance between vegetativeness and reproductiveness. Long, sustained fruit production is accomplished only under optimum environmental conditions and by timely application of water and nutrients. A well-balanced plant is judged by its thick stem, dark green leaves, and large, closely spaced, readily setting flower clusters. A properly nourished plant should have a stem 1 cm thick at a point 15 cm below the growingpoint. Thicker stems are an indication of overvegetativeness and are usually associated with poor fruit set and low productivity. Thinner stems are an indication of overproductiveness, which leads into carbohydrate starvation, slow growth, and ultimately low productivity.

Regulating the nitrogen and the water supply is the most common and effective technique for controlling crop growth. The water supply can be regulated directly, by adjusting the irrigation, or indirectly, by adjusting the relative humidity in the greenhouse and the electrical conductivity of the irrigation water. Light irrigation, low relative humidity, and high electrical conductivity in the irrigation water tend to make water less available to the plants and result in hard plants and slow growth. Of the three approaches, the regulation of electrical conductivity is the most preferred because of its simplicity, effectiveness, and dependability. The nitrogen supply can also be regulated directly, by adjusting the nitrogen fertilization, or indirectly, by varying the supply of other nutrients, e.g., potassium. Maintaining a high potassium-to-nitrogen ratio in the fertilizer feed is a technique that, is used by some growers to reduce the rate of growth.

Nutrient requirements and effects

Although only 1% of the total plant weight is made up of inorganic nutrients, fertilizer application is critical; it influences greatly the growth and development of the crop, as well as the quantity and quality of the fruit. A tomato crop absorbs the major nutrients at the following average rates: nitrogen, 370 kg/ha; phosphorus, 50 kg/ha; potassium, 680 kg/ha; magnesium, 290 kg/ha; and calcium, 45 kg/ha.

Over a season a grower should apparently apply twice as much potassium as nitrogen and almost as much magnesium as nitrogen to fulfill the plant's needs. However, that interpretation is too simplistic. In fact, fertilizer feeding programs are adjusted regularly throughout the production season to suit the changing nutritional needs of the crop according to crop and environmental conditions. Furthermore, the fertilizer feed is used as a tool to control crop growth and fruit quality.

The role of each nutrient in the growth and productivity of tomatoes is described in the sections that follow.

Nitrogen

This nutrient contributes more toward the vegetative components (leaves and stems) of the plant than the reproductive components (fruit). High rates of nitrogen induce vigorous vegetative growth to the detriment of fruit production. However, under hot and bright conditions, the nitrogen level must be increased to enable the plant to continue growing and to realize the maximum production potential of the fruit.

An excess of nitrogen is marked by strong thick stems, curled leaves in the head of the plant, large clusters and flowers, and poor fruit set. A deficiency of nitrogen expresses itself in hard plants with thin heads, light green foliage, and pale yellow flowers.

Potassium

Potassium has a great influence on fruit quality and is effective in hardening growth at high rates. Potassium levels are particularly important at planting time for growth control and later for the prevention of ripening disorders. The ratio between potassium and nitrogen is also important in growth control-the higher the ratio the slower the growth. Problems with fruit quality, such as blotchy ripening, boxy fruit, and even to some extent, greenback, are associated with low levels of potassium and in most cases can be counteracted with high-potassium feeds. The proper management of irrigaton and a stable salt content of the soil solution are also factors in avoiding blotchy ripening.

Phosphorus

Although phosphorus is used in much smaller quantities than nitrogen and potassium, its presence is needed continuously Initially, phosphorus is important for early root growth, especially under cool soil conditions, but it also has a profound effect on both vegetative growth and fruit set throughout the crop. Symptoms of deficiency include a characteristic purple color of the veins and stem, thin growth, and poor cluster development. Phosphorus toxicity is uncommon. Phosphorus is stored well in soil but is easily leached in peat media. It is therefore imperative that phosphorus always be included in the feed of peat-grown crops.

Magnesium

Although magnesium deficiency is common, it rarely results in yield reduction. However, its presence might offer entry points for botrytic and other diseases. The deficiency usually exists only in the plant, not in the soil, and is related to high-potassium feeds or poor root development. Both these make it difficult for the plant to take in sufficient magnesium, thereby forcing the plant to move magnesium from the old leaves to the new. Magnesium, being a vital part of chlorophyll, is easy to monitor because its absence is made obvious by the absence of chlorophyll. A magnesium deficiency is easily corrected with Epsom Salts, in a 2% solution spray. In fact, some growers provide most of the magnesium requirements of a crop in frequent sprays.

Calcium

Calcium deficiency is usually expressed as blossom-end rot of the fruit and as dieback of the growing tips. In most cases the calcium deficiency is not in the soil but is induced. The most likely cause is water stress on the plant resulting from inadequate or uneven watering, frequent and large variations in relative humidity, or a high level of salts. Sprays of calcium nitrate or calcium chloride, in a 2% solution, help correct a calcium deficiency, but improving the water balance in the plant is a more practical solution to the problem.

Calcium, magnesium, and potassium are believed to compete with each other, with a varying degree of success, for the same sites of absorption by the plant; it is useful to remember that increasing one of them affects the other two.

Sulfur

This element is rarely a problem because it is present in many fertilizers as a carrying element and because it is a commonplace pollutant. However, high sulfur levels can become sources of excessively high salts and could also be detrimental to the uptake of molybdenum.

Iron

Iron deficiency, a frequent problem, is usually expressed in chlorotic young leaves. Similar to calcium deficiency, iron deficiency is, in most cases, induced. Indirect causes of iron deficiency may be soil pH that is too high, a manganese level that is too high, and poor root growth or poor anaerobic soil conditions resulting from overwatering. In many cases, improved soil aeration or drying out the soil or peat corrects the problems. Soil applications and foliar sprays of iron salts or iron chelates are helpful, but as usual the most recommended action is the elimination of the source of the problem.

Manganese

Manganese deficiency is frequently confused with iron deficiency and is often an expression of iron toxicity. Manganese toxicity is a more serious problem, encountered when steaming is not well controlled and is not followed by leaching.

Copper

Peat media may occasionally be deficient in copper, but the widespread use of copper plumbing ensures an adequate copper supply in most cases.

Boron

Boron deficiency is expressed as brittleness of leaves, premature wilting, and, in acute form, as dieback of the growing tips. This deficiency can be corrected easily with foliar sprays of a Borax solution, but the rate of application must be monitored carefully because boron toxicity can cause severe plant damage.

Zinc

This element is rarely in deficiency. Toxicity is a potential problem in recirculating hydroponic systems, as there is always some zinc released from galvanized pipes.

Molybdenum

A molybdenum deficiency can be induced by acid soil conditions or high sulfur levels. Although symptoms of molybdenum deficiency are not easily distinguishable, leaf tissue analysis is a dependable diagnostic tool.

Chapter 4. General cultural practices

Crop scheduling

Early spring tomatoes

- Sow seed 25 October-25 November
- Set plants in permanent bed 1 January-15 January
- Harvest April to July
- Remove plants 1 July-20 July
- Sterilize soil 1 July-25 July

Fall tomatoes

- Sow seed 15 June-15 July
- Set plants in permanent bed 20 July-15 August
- Harvest October to December
- Remove plants 15 December-l January
- Sterilize soil 16 December-l January

The early-spring tomato crop is usually replaced by a late-spring tomato crop in old single plastic houses where light transmission is poor and heating costs are high.

Late-spring tomatoes

- Sow seed 15 December-15 January
- Set plants in permanent bed 1 February-l March
- Harvest May to July
- Remove crop 20 July-25 July

Sometimes the spring crop of tomatoes is extended to the following November if plants are healthy. The replacement of the spring crop of tomatoes by a spring crop of cucumbers and the fall crop of tomatoes by a fall crop of cucumbers or two fall crops of lettuce are variations to the standard scheduling of one spring and one fall crop of tomatoes per year.

Cultivar selection

The first decision that must be made is whether to grow a red-fruited or a pink-fruited cultivar This decision is normally based on market conditions, but it could also be influenced by the growing conditions and by the availability of cultivars. In general, the selection of red-fruited cultivars is greater than that of pink-fruited cultivars. However, a shortage of red-fruited cultivars with resistance to fusarium crown and root rot disease is often encountered. Canadian farmers have grown the followingcultivars, which have received commercial acceptance.

Red-fruited cultivars

Michigan-Ohio hybrid

This cultivar produces medium-size fruit. It is very vigorous and occasionally difficult to pollinate. The Michigan-Ohio hybrid is not recommended for fall production or production under plastic and is susceptible to leaf mold. Once widely grown, this cultivar is now commercially insignificant, although seed is still commerically available.

Vendor

This cultivar ripens uniformly Its fruit size is small, mainly because fruit is set readily, which results in overloading. Fertilizing should start earlier than for other recommended cultivars. Vendor is recommended as a spring or a fall crop under glass but can be especially valuable as a short spring crop under plastic. This cultivar produces excellent-quality fruit, even under slightly cooler greenhouse conditions than normal, but unfortunately its usefulness has been limited by its susceptibility to leaf mold and its lack of resistance to tomato mosaic virus (TMV) and to fusarium crown and root rot disease.

Dombito

This large-fruited cultivar has vigorous growth and high fruit production. It has good general disease resistance but lacks resistance to fusarium crown and root rot disease.

Caruso

Although large-fruited, Caruso is not as vigorous as Dombito; however, its fruit production is as good or better. This cultivar has good general disease resistance but lacks resistance to fusarium crown and root rot disease.

Dombito and Caruso were the most important red-fruited cultivars at time of writing. New red-fruited cultivars with resistance to fusarium crown and root rot disease have been introduced and tested recently with some success. Although their development is still being pursued actively by several seed companies, the cultivar Trend has already gained considerable commercial acceptance.

Pink-fruited cultivars

Ohio MR-13

This cultivar ripens uniformly, producing medium to large fruit. It resists cracking and requires heavy feeding after fruit set is well under way. Ohio MR-13 is relatively free from blotchy ripening but is susceptible to leaf mold and blossom-end rot. It can be grown as a spring or fall crop when leaf mold is kept under control. This cultivar is TMV-resistant. Once widely grown in Ontario and Ohio, its usefulness and cropping fell drastically when fusarium crown and root rot became a problem.

Ohio CR-6

This large-fruited cultivar, with resistance to fusarium crown and root rot disease, has extremely vigorous growth requiring delicate nutritional and environment control to ensure fruit set. Fruit on first clusters has a rough shape. Some improvement in fruit quality is normally achieved by raising the air temperature and feeding low nitrogen. Ohio CR-6 produces fruit a week later than most other cultivars, with the first cluster appearing too high on the main stem.

KR-1 5 and KR-381

These two closely related cultivars have resistance to fusarium crown and root rot disease.

Ohio CR-6 was the most important pink-fruited cultivar for some time previous to writing, but after extensive testing, the KR lines are now receiving wider commercial acceptance. As the development and testing of new red and pink cultivars are continuing research activities, consult the local adviser on horticultural crops for the latest cultivar recommendations before starting a crop.

Plant propagation

Most greenhouse operators in Canada grow their own transplants. This is a desirable practice because it reduces the possibility of importing diseases and insects. However, transplant raising in other countries has been practiced successfully by specialized nurseries that ensure a reliable supply of low-cost high-quality transplants to local growers through the application of modern technology. Plant propagation is a vitally important stage in greenhouse vegetable production. The success of a crop depends largely on the attention paid to detail and the care taken during plant raising. Moreover, with early spring crops, propagation must take place in the winter, when natural light is limited. To make the best use of available light, other factors such as spacing, temperature, irrigation, and nutrition must be subject to close and accurate control. Artificial light is now used widely to enhance transplant growth when natural radiation is limited, with the result that the performance of early-planted spring crops has improved significantly.

Propagation schedules

In deciding when to seed, the desired harvesttime should be considered. It usually takes 5 months from seed to first pick in a normal spring crop but only 4 months in a normal fall crop. A spring crop that comes into production in the beginning of April requires seeding to take place in the latter part of November. In recent years, an increasing number of growers are planting a late spring crop in plastic houses. In that case, seeding takes place in January and planting in-house in March. Harvest is in May, June, July, and later. The late spring crop is easier and less expensive to grow but comes into production when prices are relatively low.

Seed sowing

Each gram contains about 300 seeds. Assuming a planting density of 25 000 plants per hectare, a germination rate of 80%, and a safety margin of an additional 10%, seed should be sown at approximately 120 g/ha.

The most common approach is as follows. Fill a plastic tray (55 x 27 cm) with a soilless mix, such as a commercial peat mix, and strike it off level. Press the medium down evenly with a wooden board to about 1.5 cm from the top. Broadcast the seed or sow it in rows, as evenly as possible, at a rate of 500-600 seeds per tray. Cover the seed with 0.5 cm of fine-grade growth medium to assist the prompt shedding of the seed coat, thus reducing the risk of transmitting tomato mosaic virus and of distorting the seed leaves. After sowing, cover seed trays with glass or paper, which conserves moisture; no further watering is needed before germination. Place the seed trays in a small greenhouse or special propagation room (no light is needed at this stage) at a day and night temperature of 24°C until daily inspection shows seedlings to be breaking the surface of the growth medium; the higher the air temperature of the propagation room during germination the faster and more uniform the germination will be. However, seedling growth is fast at high temperatures, which makes the use of a high germination temperature risky because a delay of a few hours in removing the seed tray cover can result in excessive elongation of the seedling stems and carbohydrate depletion. Once seedling emergence is well under way, remove the seed tray covers, reduce the day and night air temperature to 20°C, and supply as much light as possible. Maintain these conditions for

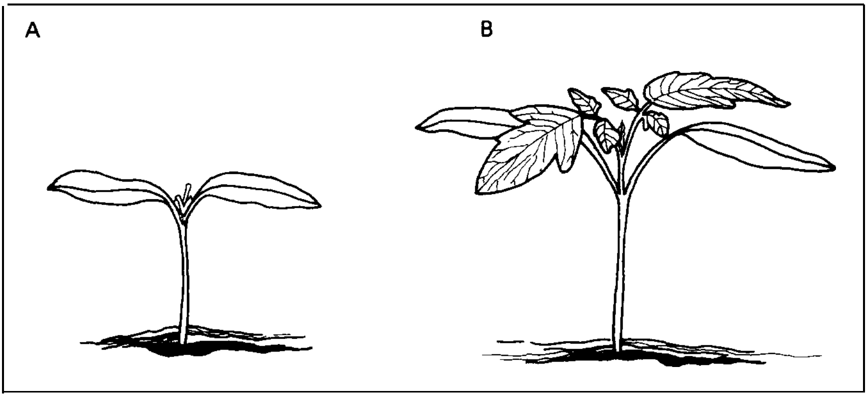

Fig. 11 Typical stages of seedling growth frequently **used** as markers of the ideal time for initiating (plant A) and terminating (plant **B)** the cold treatment.

2-3 days to allow all seedlings to emerge and become photosynthetically active and to prevent excessive elongation.

Cold treatment

Under a cold treatment regimen, place young tomato seedlings in a day and night air temperature of 10–13°C for approximately 2 weeks, while providing as much light as possible for 9-12 h. Seedlings should be subjected to cold treatment just after the seed leaves (cotyledons1 unfold and the first true leaves start to appear (Fig. 11). Shoots kept at low temperatures at this stage of growth produce a small number of leaves below the first cluster and therefore flower earlier; roots kept at low temperatures cause branched clusters, i.e., many flowers in the first and possibly the second cluster. Cold temperatures during both day and night are effective. The cold treatment increases the number of flowers but does not influence the setting of fruit. If later conditions for fruit setting are right, a greater number of flowers will set fruit because of the increased number of blossoms. If, however, the temperature for fruit set remains less than ideal, the pollen does not germinate and grow normally resulting in poor fruit set and cat-faced fruit. When the cold treatment is used, seed 10–14 days earlier than usual to compensate for the slow growth rate during the cold treatment. The growth medium in the seedling trays must be sterile, because when plants are grown at relatively low temperature the danger of damping-off is increased.

Transplanting into pots (pricking out)

The best time to prick out tomato seedlings is at cotyledon expansion, just after the cold treatment. Seedlings are too hard to handle before this time and if pricking out is delayed further, the transplanting shock will be greater because more roots are broken. Transplants are grown in 7.5cm or

10-cm plastic pots or in soil blocks. In addition to good topsoil, peat mixes are used extensively as growth media but always after proper sterilization. Growers should avoid modifications to recommended mixtures, as the results could be disastrous. A worldwide trend toward peat-based mixtures is replacing those containing loam, because loam of desirable specifications is difficult to obtain. However, greenhouse soil that has good texture and structure is a valuable asset as a growth medium for transplant raising, provided it is sterilized effectively before use. Heavy leaching following soil sterilization is also highly recommended. This treatment ensures the removal of excess salt, which can be harmful to young seedlings and results in low nutrient levels, especially nitrogen, in the growth medium. Low nutrient levels allow for better control of plant growth through the manipulation of liquid feeding.

Do not change frequently the substrate used for raising transplants because seedlings respond differently to different substrates, and the experience gained over the years on one substrate is not entirely transferable to other substrates.

Although larger pots (10 cm) appear to increase the cost of producing plants, they are, in fact, the best choice because they allow growers to hold their plants longer in the propagation house, which is much less expensive to heat than the entire greenhouse. Furthermore, an extended propagation time results in greater use of artificial light whenever available. Finally, the use of large pots for transplant raising has frequently been associated with increased early yields. Pots can, of course, be used again the following season, but they should first be washed and soaked in a bleach (10%) solution, or any other approved disinfectant.

Watering and nutrition

Immediately after pricking out the seedlings, water them thoroughly to bring the growth medium to field capacity and to settle it around the roots. Careful watering is necessary during the propagation period. Keep the young plants well supplied with water without depleting the growth medium of its oxygen by overwatering. Because it is difficult to judge the moisture content of growth media in plastic pots, pull out two or three plants regularly and make sure that the medium at the bottom of the pots is kept moist but not too wet. Transplants raised in 10-cm pots require watering daily in good weather; in very bright weather, more than one watering a day may be necessary; in dull winter weather, watering as infrequently as once every 3 days may be adequate. The use of smaller pots requires more frequent watering. A deliberately short water supply in the propagation pots restricts growth and helps produce hard, stocky, dark green plants. However, this type of growth control invariably results in excessive hardening of the transplants because of the difficulty of regulating the water supply, resulting in yield losses early in the production season when prices are best. In recent years, research has identified more dependable means of growth control. Fertilizer is now fed continuously at every watering, with the fertilizer concentration in the solution used as an osmoticurn in regulating water availability to the plants (Table 2). The recommended fertilizer concentration in the irrigation water, measured as its electrical conductivity (EC), varies according to the environmental conditions. For transplants raised during the winter, complete nutrient solutions of an EC that ranges between 3000 and 6000 µS/cm have been used with good results (Table 3). Higher conductivities now appear safer when the potassium-to-nitrogen ratio in the nutrient solution is higher than 4:1 (Plate 1).

Also, the supply of artificial light allows the use of higher ECs than normal, but not when artificial light results in overheating the transplants and in drier conditions in the greenhouse.

The individual nutrient concentration in the final solution varies according to EC, but in the standard case, where 1 L of each stock solution is diluted in 100 L of water (1:100 mixing ratio), the concentration of nutrients is as described in Table 4.

Transplants of similarly good quality can also be raised when commercial mixes of fertilizer such as those commonly known as starters are used at appropriate rates. A simple solution of starter fertilizer (3 g of 10-52-10 per litre of water) with an approximate EC of 4000 µS/cm used in continuous feeding produces transplants acceptable to most growers in a simple and safe way Alternatively, commercial fertilizer mixes that contain all nutrients except calcium and that offer a potassium-to-nitrogen ratio of about 5:1 can be used safely with acceptable results at ECs up to 5000 µS/cm.

Table 2 Stock solutions required for the preparation of complete fertilizer solutions with a varying potassium-to-nitrogen ratio

Fertilizers (kg)	Potassium-to-nitrogen ratio		
	2:1	4:1	6:1
Stock A, 1000 L			
Calcium nitrate	67.0	70.0	70.0
Potassium nitrate	74.0	9.5	9.5
Stock B, 1000 L			
Potassium sulfate	13.5	92.5	150.0
Stock C, 1000 L			
Monopotassium phosphate	22.5	22.0	22.0
Magnesium sulfate	50.0	50.0	50.0
Iron chelate (13% iron)	0.6	0.6	0.6
Micronutrient mix (STEM)	0.8	0.8	0.8

- The stock solutions described can be used, as shown in Table 3, to produce fertilize1 solutions of various ECs for raising transplants.
- A typical micronutrient mix, e.g. Peters soluble trace element mix (STEM), contains 1.45% boron, 3.2% copper, 7.5% iron, 8.15% manganese, 0.046% molybdenum and 4.5% zinc.

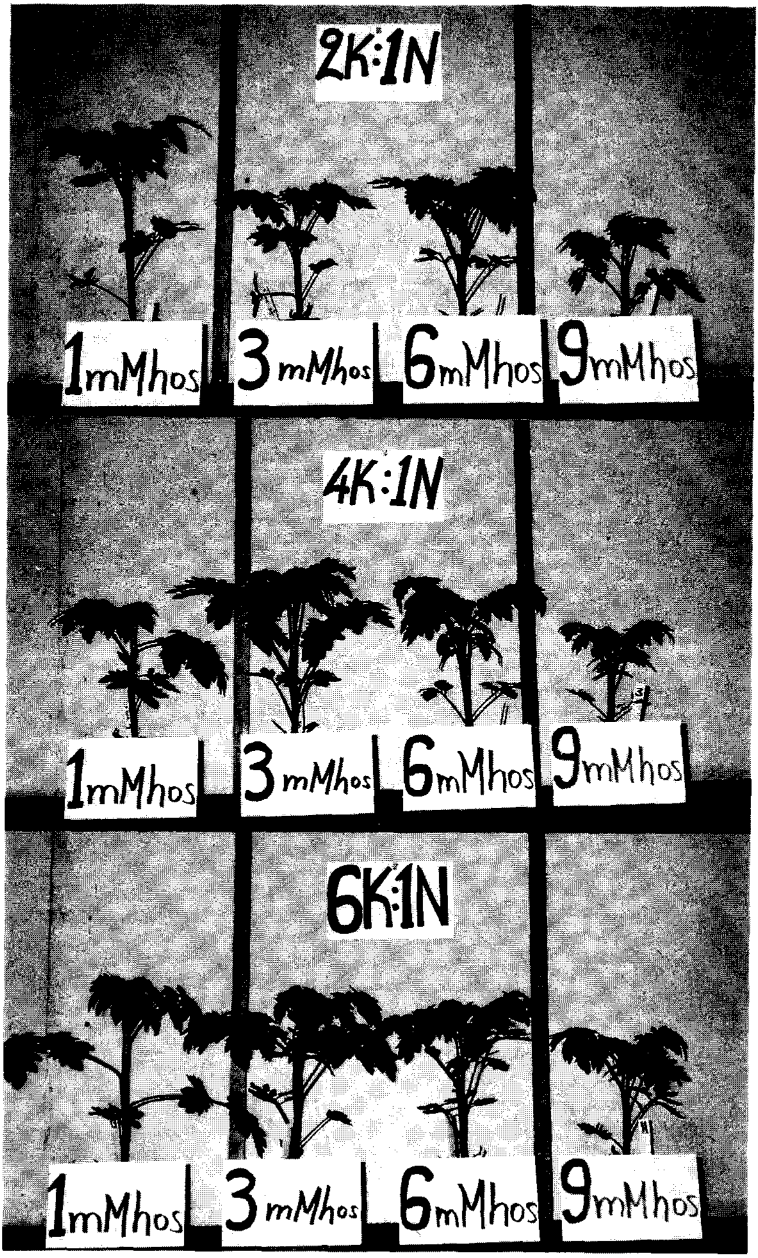

Plate 1 Effect on cultivar Ohio CR-6 of the potassium-to-nitrogen ratio and EC (**μS/cm**) of the fertilizer solution applied on tomato transplants. Note the excellent quality of transplants produced with nutrient solutions of moderately high EC (i.e., **3000–6000μS**) when the potassium-to-nitrogen ratio is also high (i.e., **4:1** or **6:1**).

Table 3 Amount of each stock solution (in litres) required to produce 100 L of final nutrient solution with varying EC

EC (µS/cm)	Potassium-to-nitrogen ratio		
	2:1	4:1	6:1
1000	**0.375**	**0.375**	**0.275**
3000	**1.450**	**1.450**	**0.875**
6000	**3.350**	**3.150**	**2.400**

Table 4 Nutrient concentration in final nutrient solution*

Nutrients	Potassium-to-nitrogen ratio		
	2:1	4:1	6:1
		ppm	
Nitrogen, nitrate (NO_3^{2-})	**193.00**	**113.00**	**113.00**
Nitrogen, ammonia (NH_4^+)	**7.00**	**7.00**	**7.00**
Phosphorus	**50.00**	**50.00**	**50.00**
Potassium	**400.00**	**480.00**	**720.00**
Calcium	**127.00**	**133.00**	**127.00**
Magnesium	**50.00**	**50.00**	**50.00**
Iron	**8.00**	**8.00**	**8.00**
Zinc	**0.07**	**0.07**	**0.07**
Copper	**0.07**	**0.07**	**0.07**
Boron	**0.30**	**0.30**	**0.30**
Manganese	**2.00**	**2.00**	**2.00**
Molybdenum	**0.05**	**0.05**	**0.05**

* Stocks described in Table 2 are diluted with a fertilizer injector having a 1:100 mixing ratio.

Artificial light

Artificial light, as mentioned earlier, is first used immediately after germination. A relatively small installation is needed at this stage, and high light intensity is economically feasible. Both fluorescent (ideally in mixture with some incandescent) and high pressure sodium (HPS) lamps are acceptable and are widely used to generate a minimum light intensity of 100 µmol/s per square metre (equivalent to 20 W/m^2 or 8000 Lux or 760 fc) in growing rooms. The fluorescent lamps produce slightly shorter plants with a deeper green bluish color than HPS lamps, but the latter are the most economical to install and operate. During the first few days after pricking off, when the pots can be arranged close together, it is still economical to maintain a high light intensity (75–100 µmol/s per square metre) for approximately 16-18 hours daily. However, as plants grow they are spaced progressively to avoid crowding and becoming spindly, making the use of high light intensity less and less cost effective. For the rest of the time, while the plants are in the propagation house, provide supplemental light (artificial light in addition to natural light) at a light intensity of about 50 µmol/s per square metre. Obviously, whenever cost is not a factor, the highest light intensity available should be provided for a maximum of 18 h daily, as this treatment results in shorter propagation time and heavier, stronger, sturdier transplants. There is no advantage in using low-intensity incandescent light on tomato plants in midwinter to extend the daylight period.

Temperature control

Recommended temperatures for transplant raising, along with those mentioned earlier for seed germination and cold treatment, are summarized in Table 5.

Table 5 Recommended temperatures for tomato transplant raising

		Air temperature in °C	
Growth stage	Light conditions	Day	Night
Seed germination	Not critical	24	24
For 2 weeks after cotyledon expansion (i.e., cold treatment)	Maximum available light intensity for 9-12 h daily	10-13	10-13
After pricking out (i.e., while in pots)	Good light conditions	21*	18
After pricking out (i.e., while in pots)	Poor light conditions	19	17”

* When growing cold-tolerant cultivars such as Vendor, air temperatures can be 1–2°C lower than those indicated. However, when growing vigorous cultivars such as Ohio CR-6, a similar reduction in air temperature results in poor-quality, cat-faced fruit.

Carbon dioxide enrichment

During propagation an atmosphere enriched with carbon dioxide at a nominal concentration of 1000 vpm (≃1000 ppm) increases plant vigor and early fruit set and may partly compensate for poor light conditions. The beneficial effects of carbon dioxide enrichment are more evident when air temperatures are on the high side and are proportional to the duration of enrichment. Apply carbon dioxide during the day or any part of the night when artificial light is supplied. Because raising transplants occupies only a small area, it is economically feasible and highly advisable to use liquid carbon dioxide (carbon dioxide gas liquefied under pressure) because of its guaranteed purity and amenity to accurate concentration control. Liquid carbon dioxide is also preferred because burning natural gas or propane to generate carbon dioxide increases the risk of plant injury from gaseous pollutants.

Grafting

Grafting is a useful technique when soil sterilization is not available or when certain diseases, e.g., fusarium crown and root rot, cannot be controlled by soil steaming. Wild species closely related to the tomato, or even tomato cultivars with resistance to a number of diseases, are used as rootstocks. Rootstocks are currently available with resistance to corky root rot, fusarium and verticillium wilt, root knot nematode, and fusarium crown and root rot. Figure 12 shows various grafting methods suitable for tomatoes.

All types of grafting require a sharp knife and a clean working surface so that cuts are not contaminated with soil; a razor blade or scalpel are ideal tools for grafting. Type A grafting is the fastest but is associated with the most check in the growth of the transplant. Type B grafting is also fast and results in a stable grafting union, but some check in the growth of the transplants can be found. Type C grafting is the slowest but is usually associated with the greatest success in grafting.

Because the germination of rootstock seed is slow and nonuniform, sow rootstock seed before the scion cultivar so that by grafting time both scion and rootstock are of similar size and stem thickness.

If the diseases to be controlled include fusarium wilt or verticillium wilt, remove the scion root system by cutting through the stem of the cultivar below the graft union. Gradually extend the cut through the stem of the scion over a period of 1 week, to minimize the wilting of the grafted plants; some misting during this time may also be needed to aid recovery.

Although grafting can be very helpful in saving soil sterilization costs and in allowing the cropping of cultivars that are productive but devoid of adequate disease resistance, it poses its own problems. The graft union is an inherited obstacle in the movement of water and nutrients from the roots to the top of plant and of photoassimilates from the top of the plant to the root. Grafting is therefore a potential limiting factor in maximizing yield.

Grafting also requires skilled labor, which is either expensive or not readily available. The difference in vigor between scion and rootstock can result in significant differences in stem diameter (a minimum diameter of 3 mm is desirable), which slows down the speed of grafting and reduces the success rate.

Finally, the repeated handling of plants at grafting may help spread tobacco mosaic. It is therefore extremely important to make sure that the knife is cleaned regularly and that the hands are washed frequently with milk during grafting. Of course, every effort should always be made to eliminate tobacco mosaic virus by starting with heat-treated seed.

Plant spacing

The optimum space per plant is generally agreed to be 0.35-0.40 m^2. Ideally, the same spacing should be used between rows of plants as between plants in the row However, to facilitate working among the plants, use double rows for planting. Place the first two rows 80 cm apart and allow 1.2 m for a walking path before repeating two more rows spaced at 80 cm apart; repeat the process as necessary. Then space the plants in the rows at 35–40 cm. When light conditions are favorable, such as for late spring crops and fall crops, space the plants more closely Although it is important to use all the space in the greenhouse as efficiently as possible, excessive crowding tends to result in small fruit and outbreaks of leaf disease.

Pruning and training

Modern tomato cultivars grown as greenhouse crops retain the characteristic weak stem of their wild ancestors and therefore require support when grown with a single vertical stem.

Prune greenhouse tomatoes to a single stem. Remove all side shoots or suckers at least every week. Support the plants by plastic twine. Tie one end of the twine loosely to the bottom of the plant with a small, nonslip loop. Attach the other end to an overhead wire supported 1.8-2.5 m above the plant row. As the plant grows, it is wound around the twine in one or two easy rotations for each fruit cluster. Use twist ties or plastic snap-on clips to attach the plant to the twine when the plant becomes larger and carries a lot of fruit. For the spring crop, use an additional 1.5–2.0 m of twine at the top wires when initially tying the plant. As the plant reaches the wire, untie it and release some of the reserve twine, allowing the plant to be lowered and its lower section to lie on the ground. Pinch off, or top, the growing point of the plant about 6-7 weeks before harvest ends.

It is not certain whether removing the lower foliage from the plants is always necessary for better air circulation. However, the lower foliage usually must be removed and the crop laid down when the plants eventually reach the overhead wires. When the overhead wires are low (less than 2 ml, the early removal of the lower foliage, sometimes exposing more than one cluster, raises concerns about how this practice affects yields. In general, 1.2 m is the minimum recommended length for a stem that bears leaves. This problem can be avoided in new greenhouses by fixing the support wires higher than 2 m.

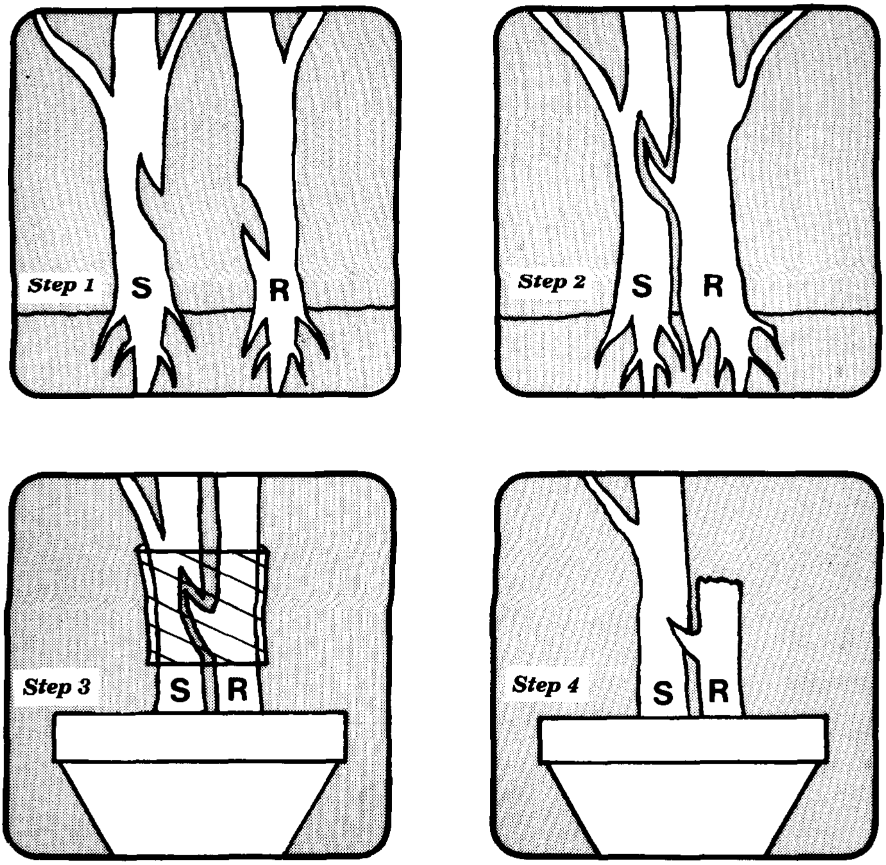

Fig. 12 Types of grafting for tomatoes; R, rootstock; S, scion ***(continued)*.**

Type A. Bare-rooted plants (bench graft).

Step 1
Select a rootstock and a scion plant of similar size. Make an upward cut in the stem of one and a downard cut in the stem of the other.

Step 2
Join the two stems, which are then held together **by** the flaps of tissue.

step 3
Bind both plants together with adhesive tape and plant them in a pot with the graft union well above soil level.

Step 4
Remove the top of the rootstock and the adhesive tape when the graft union has healed.

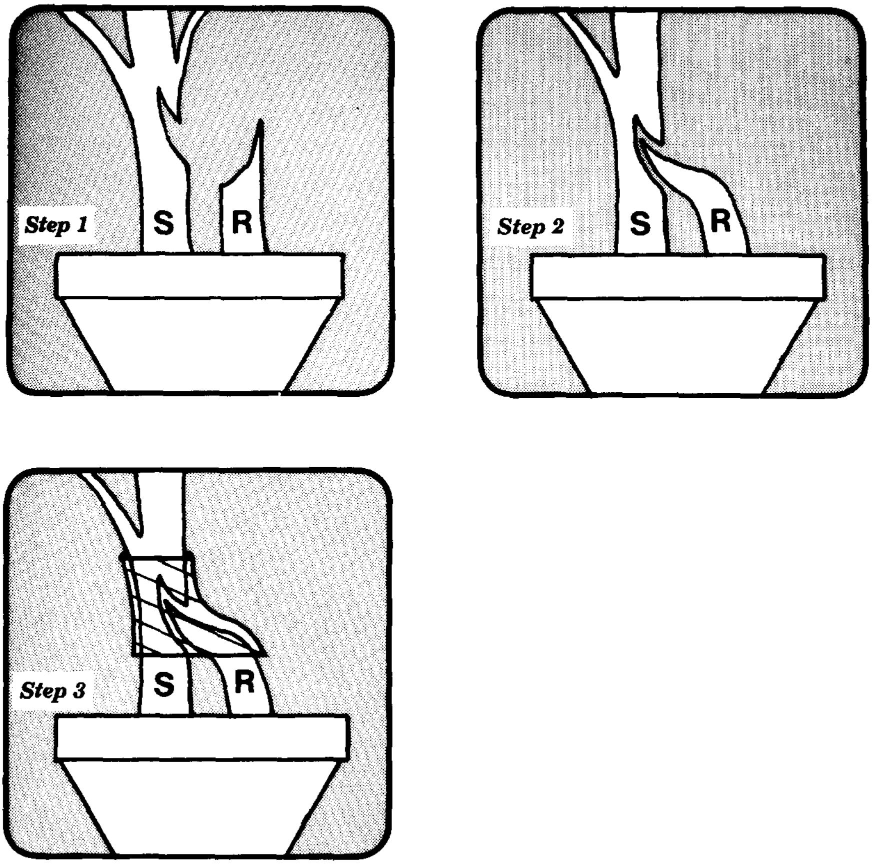

Fig. 12 Types of grafting for tomatoes; R, rootstock; S, scion (continued).

Type B. Rootstock and scion-plants grown in same pot; immediate detopping of the rootstock.

Step 1
Make an upward cut in the scion and remove the rootstock top with a diagonal cut.

Step 2
Place the top of the rootstock stem into the cut of the scion stem.

Step 3
Remove obstructing leaves and bind the two plants together with adhesive tape.

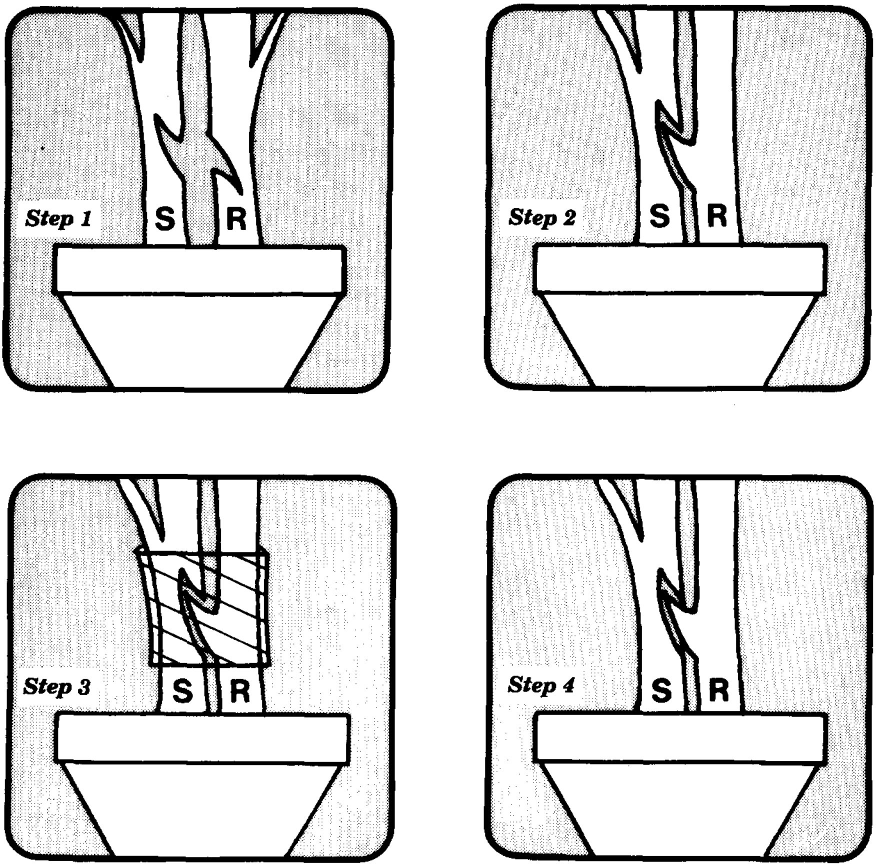

Fig. 12 Types of grafting for tomatoes; **R,** rootstock; S, scion (*concluded*).

Type C. Rootstock and scion plants grown together in same pot; delayed detopping of the rootstock.

Step 1
Plant scion and rootstock 10 mm apart in the same pot and grow them until they are ready for grafting. Make an upward cut in the scion and a downward cut in the rootstock.

Step 2
Join the two stems, which are then held together by the flaps of tissue.

Step 3
Bind both plants together with adhesive tape.

Step 4
Remove the top of the rootstock and the adhesive tape when the graft union has healed.

Pollination and cluster pruning

Once a flower bud has been initiated, four additional processes must be completed before a healthy tomato fruit is set: the anthers must produce viable pollen; the anthers must release pollen to the stigma; the pollen grams must germinate on the stigma; and the pollen tubes must grow down the stigma, resulting in fertilization of the ovules in the ovary. Adverse temperature, light, and nutritional conditions can cause these processes to fail, resulting in poor fruit set and poor fruit quality Day air temperature undoubtedly plays an important role in fruit set, and once flowering starts, it should not fall below 18°C. Other potential causes of poor fruit set include excessive growth, poor light, incorrect nutrition, and any kind of crop stress. During late fall, winter, and early spring, flowers of most cultivars grow with a slightly different shape, making natural pollination difficult. This change in shape appears to be the result of low night-air temperature and is occasionally aggravated by high nitrogen availability To assist flower pollination, vibrate all flower clusters with open flowers at least every other day Use electric vibrators, known as electric bees, to vibrate flower clusters, preferably between 11 a.m. and 3 p.m., when flowers are moderately dry and pollen is shedding. As alternatives to the labor-intensive electric bee, the tapping of the strings supporting the plants and the use of coarse water sprays have been tried, but the results were not satisfactory Hormone sprays were also used when pollination failed, but the quality of the resulting fruit was not acceptable for North American markets. Lately, bumblebees have been used for tomato flower pollination, with reasonable success. The bees are already commercially available, and growers’ experience with them in the past has been good. Problems of fruit quality related to inadequate pollination are invariably the result of poor and uneven seed set within the fruit, which is known to cause hollow, misshapen fruit.

Overbearing can sometimes become a problem. To prevent exhaustion of the plants and to improve fruit size, control the number of the flowers per cluster through the recently developed technique of cluster pruning. This is a powerful technique and therefore must be applied with great caution. Prune the first two clusters to three marketable fruits and later clusters to four fruits. However, the optimum number of fruits per cluster varies with the cultivar and even more with the growing conditions. Although, a limited number of fruits per cluster invariably results in premium-priced large fruit, there is always a risk that a grower, underestimating the potential of the crop or failing to forecast good weather, might decide to remove too many fruits and thus unnecessarily limit production. Cluster pruning is undoubtedly most useful in the hands of an experienced grower who can use it to maximize financial return. Obviously, fruit to be pruned must be removed as soon as it can be handled, before it is too large.

Harvesting and storage

After all the effort and money invested in production, it is essential that fruit be handled well at harvesting and transportation to the market.

Most growers pick twice and even three times a week, in hot weather. Pick fruit carefully and place in rigid, padded containers to avoid bruising and damage. The color of the fruit should be as uniform as possible to speed up grading in the packing house and to enable uniform treatment of all fruit in storage. It is critical that every effort be made to minimize a loss in fruit quality while the produce is in transit.

Maturity of the fruit at harvest time is important. Fruit harvested before it is fully developed is more susceptible to handling injury because of inadequate development of the protective waxy layer. Tomato fruit is sometimes harvested with the calyx so as to identify it as a greenhouse product. Take care to ensure that the calyx does not puncture the fruit. Overfilling the crate or stacking the produce too high may damage the bottom layer.

Harvest fruit in the early morning, when it is cool and when fruit temperature is not too high. Move produce out of direct sunlight and into cool, shaded, and ventilated areas immediately after harvest so that fruit temperature is not increased.

Use a covered vehicle to transport the produce to the packing shed, thus protecting the fruit from direct sunlight and exposure to the drying effect of air. Do not park a loaded truck in direct sunlight for any length of time. During transportation, minimize heat gain and place produce in cold storage (12°C) as soon as it arrives at its destination, Stacking the crates too high or too tight does not allow the crates in the middle to cool down adequately when the product is stored in a cooler.

Packing and storing produce in the same place as active ethylene producers, such as apples, accelerates ripening and results in overripe produce. When the fruit is removed from cold storage, do not allowwater to condense on it. Prevent condensation by keeping the environment dry through ventilation or by raising the storage temperature gradually before the fruit is removed. Once the fruit is harvested its quality can only be preserved, not increased.

Chapter 5. Conventional cropping in soil

Conventional cropping in soil is the simplest cropping system and involves the planting and raising of a crop as would be done outdoors. The actual planting is an important stage in the growth of the crop. First, dig a trench at least 10 cm deep and 15 cm wide. Then place the plants in soil blocks or peat pots in the trench and heel in with 0.25 L of starter fertilizer solution (5 g of 10-52-17 per litre of water) per plant; pull only a little soil around them. Spot-water plants as needed for 2 weeks after transplanting. Once the plants are established, general watering usually is not needed for 4-6 weeks, depending on soil type and light intensity On light soils general irrigation begins sooner than on the heavier soil.

What type of soil to look for

To achieve maximum production, greenhouse vegetables in general need a well-aerated soil with a high water-holding capacity, rich in nutrients and free from pathogens. Although greenhouse tomatoes can be grown on a wide variety of soils, the most suitable are those classified as loams, sandy loams, and some silty loams, all with a high organic-matter content, if possible (see Fig. 8). Other types of soils can be used, but they are more difficult and expensive to manage. For example, coarse sandy soils have low water-holding capacity, poor nutrient retention, and poor cone formation when drip-irrigated; silty soils have an unstable structure that breaks down with heavy watering; and clay loams are poorly drained, difficult to leach, and their structure is damaged by cultivation when wet. Proper management can render almost any soil suitable for greenhouse production. For example, both light and heavy soils can be improved by adding organic matter. If natural drainage is poor, as in most clay, silty clay, and sandy clay loams, a tile or pipe drainage system is necessary. The main purpose of the soil is to provide a medium in which there is a proper balance between air, water, and nutrients. If this balance is ensured, the roots can easily obtain water and nutrients, resulting in rapid growth.

Drainage

Install tile drainage in ground beds to ensure that all excess water is carried away. For drainage, use perforated or nonperforated clay tiles, 10 cm in diameter, and lay them with a small space between them to allow for expansion; a few 7.5-cm tiles make effective slip joints for 10-cm tiles. To improve the effectiveness of drainage, cover the tile lines with glass fiber matting made for this purpose or with 2-cm gravel. Set tiles at a depth that prevents their being broken by rototilling or other cultural practices. Place tiles 35 cm deep and 45 cm apart, with a slope of 10 cm for every 150 m of 10-cm clay tiles. The same tiles, with perforations on the bottom or the sides, are also used for steam sterilization. Loop adjacent rows of tile together at the ends, with elbows and tees for more equalized steaming from line to line. Introduce steam into the rows of tile through a header. This header, with a 50-cm capped riser on each end for steam input, extends across the width of the house and is equipped with nipples 2-3 cm in diameter and about 25 cm long; one nipple corresponds to, and is cemented into, each row of tile. Both the header and the rows of tile should be no longer than 15 m because beyond that length steam condenses into water and sterilization is poor.

Table 6 Leaching requirements after steaming

Electrical conductivity (µS/cm)		Water required (L/m^2)	
Saturated-paste method	1:2 Water extract	Sandy soils	Other soils
up to 1.5	up to 0.5	15	25
1.5-3.0	0.5-1.0	30	50
3.0-5.0	1.0-1.5	70	100
Over 5	Over 1.5	100	150

- The numbers suggested for litres per square metre of required water also indicate equivalent rates of rain in millimetres.
- The rates apply to leaching and are added to the requirement for bringing the soil to field capacity (usually 20-50 L/m^2).
- The rates apply to use of overhead sprinklers at intervals over 2-5 days.
- It is difficult to leach salts from heavy-textured soils, especially if no effort is made to improve their structure.
- If the conductivity before leaching is higher than the recommended range, it must be checked again after leaching and before planting.
- Flooding reduces nitrates and conductivity markedly, and may reduce potassium reserves slightly, but it produces little change in other nutrient levels.

Flooding and leaching

To achieve the best results with steam sterilization, the soil is first cultivated and its water content is brought to field capacity. The amount of water required varies with the original moisture content of the soil and the soil type, but it is generally between 20 and 50 L/m^2.

Steam sterilization, particularly oversteaming, often releases toxic amounts of ammonium and manganese. Other elements, such as potassium, iron, and zinc, may also be increased. Water leaching is usually necessary to remove an excess of these substances, as well as an excess of other soluble salts, and to cool the soil following steam sterilization. When soil analysis shows an undesirable excess of soluble salts in the rooting medium, leach the soil with much greater quantities of water. The amounts given in Table 6 can be used as a guide.

Organic matter

A high level of organic matter helps to maintain a stable soil structure and improves the water-holding capacity of the soil. In the past, growers used to steam sterilize greenhouse soils and then add well-rotted manure after sterilization. This procedure reduced the release of ammonia and other toxic substances, and it also helped to reinoculate the soil with beneficial organisms. However, the danger of introducing disease organisms and weed seeds always remained. An additional complication in the use of manure or muck soil as a source of organic matter is the inherent potential for contaminating the greenhouse soil with herbicide residues. The recommended amounts of manure varied from 45 to 225 t/ha, depending on the kind of manure and the soil conditions. For example, spent mushroom compost has a high nutrient content and can cause soil conductivity problems, whereas uncomposed straw may induce nitrogen deficiency.

In recent years the addition of organic matter has increasingly been viewed as a means of improving the soil condition (structure) and not so much as a means of increasing the nutrient content of the soil. In fact, the nutrient content of most manures and other nonstandardized sources of organic matter is considered a liability rather than an asset because of its extreme variability and the unpredictable effects the various nutrients can have on the crop to follow. At present, coarse peat is the most satisfactory material as a source of organic matter. This type of peat is acid, with a pH of about 4, and therefore has the added benefit of reducing the pH of calcareous soils; where the soil is noncalcareous, add ground limestone to loose peat at an approximate rate of 5 kg/m^3 to neutralize the peat's acidity When used to improve the soil conditions, e.g., on new sites, apply peat generously at rates of up to 500 m^3/ha. When the soil reaches the desired condition, reduce the rate; the need for an annual dressing remains because soil organic matter decomposes under glass rapidly. Apply loose peat to soil at a yearly rate of 100 m^3/ha.

Broadcast peat and lime before the main cultivation and incorporate them into the top 30 cm of the soil.

Control of **pH**

Greenhouse vegetables in general grow quite well in a wide range of soil pH (5.5–7.5), but a pH of 6.0-6.5 for mineral soils and a pH of 5.0-5.5 for organic soils are generally accepted as optimum. When the pH is too low, add ground calcitic limestone, or equal amounts of dolomitic limestone when the magnesium level in the soil is low, to raise it to a desirable level. The rates given in Table 7 should be used only as a guide; the actual lime requirement is best assessed by an appropriate laboratory test. When the pH is too high, as is usually the case in most greenhouse mineral soils, take steps to reduce the pH to within the optimum pH range (6.0-6.5 for mineral soils).

A simple, though temporary, solution to a high pH problem is to add peat, without neutralizing its acidity with limestone. Peat also helps to maintain a good soil structure, but it must be added yearly to make up for loss through decomposition. If additional calcium is needed, supply it either as calcium sulfate (gypsum), which has no affect on soil pH, or in soluble form, with each irrigation. Adding elemental sulfur, i.e., flowers of sulfur, provides a more long-term solution to a high pH soil. No definite recommendations can be made regarding the amount of sulfur that should be applied, because it depends on the buffering (cation exchange) capacity and original pH of the soil, both of which are variable from one soil to the next. In general, apply flowers of sulfur at a rate of 50-500 kg/ha. Theoretically, 320 kg of elemental sulfur could neutralize 1000 kg of

Table 7 Lime requirements (in tonnes per hectare1 for soil pH correction to 6.5

Soil pH	Sandy loam	Loam, silty loam	Clay loam, organic
6.0	3.0	4.5	6.0
5.5	6.0	9.0	12.0
5.0	9.0	12.0	18.0
4.5	12.0	15.0	24.0
4.0	15.0	18.0	30.0

Note: The rates of lime suggested are for the top 15 cm of soil. If acidity has to be corrected to a greater soil depth, the rates should be increased accordingly.

limestone, but this equation assumes that all sulfur is converted to sulfuric acid instantly. However, the conversion of sulfur to sulfuric acid is performed by soil microorganisms (*Thiobacillus*) over time and is more rapid in moist, warm, well-aerated soils. Broadcast and thoroughly mix ordinary ground sulfur with the top 15-30 cm of soil several weeks before planting the crop because the initial velocity of the reaction may be slow in cold soils.

Iron sulfate can also be applied to soils for acidification. When this salt is hydrolyzed it releases sulfuric acid, which drastically lowers the pH and liberates some of the iron already present in the soil. At the same time, soluble, i.e., available, iron is being added. However, on a weight basis, iron (ferrous) sulfate is four to five times less effective than sulfur and is usually more expensive. Sulfuric acid can be added directly to the soil, but it is unpleasant and dangerous to work with and requires the use of special acid-resistant equipment. In some areas it can be applied by custom suppliers who have the equipment necessary for handling it. Sulfuric acid has the advantage of reacting quickly with the soil.

Under most conditions it may be advisable to acidify only a zone near the plant roots, in which case much smaller amounts of chemicals are required. This method is particularly applicable when drip irrigation is used, which results in the root systems occupying a restricted, well-defined area of soil. Injecting phosphoric or nitric acid, appropriately diluted for convenience and safety, offers an attractive alternative for lowering the pH of the soil near the plants; furthermore, these acids prevent salt precipitation and clogging of the irrigation lines and add useful nutrients to the plants. To determine the rate of acid to be injected, add a known amount of acid to a known volume of water until the desirable pH is obtained. Alternatively, start injecting small amounts of acid into the irrigation line while checking the pH with an in-line pH meter; gradually increase the amount of acid injected until the desired water pH is obtained. When other conditions allow, try to select the regularly applied fertilizers on the basis of their ability to lower or increase the soil pH according to individual soil needs. For example, ammonium sulfate and ammonium phosphate tend to decrease the soil pH, whereas calcium nitrate tends to increase it.

Preplant fertilizer application

Apply base, or precrop, fertilizers after soil steaming and leaching, and incorporate them into the greenhouse soil by rototilling. Add these fertilizers to the limestone that might be required for adjusting the pH level of the soil (see Table 7). In general, add as much of the required calcium and phosphorus as possible as a base dressing because these nutrients can be stored effectively in the soil and their absence from liquid feeds prevents most clogging problems of the irrigation system; the calcium should be in the form of limestone and the phosphorus in the form of superphosphate, both finely ground. Furthermore, these nutrients, by nature of their source and their ability to bind to soil particles, are released slowly into the soil solution and therefore do not raise the total amount of salts dramatically, nor do they upset the nutrient balance of the soils to which they are added as a base dressing.

Because tomatoes require a large amount of potassium, supply a good portion of it, along with magnesium, as base fertilizer; the ratio of potassium to magnesium in the soil should be 2:1. Avoid applying nitrogen. Make the final decision on base fertilization after receiving the soil test results and consulting with your horticultural crop adviser. Treat the recommended rates of base fertilizers (Table 8) as a general guide only.

Table 8 Base fertilizer recommendations

Fertilizer	Amount
Superphosphate (o-20-0, fine grade)	250 kg/ha
Potassium sulfate	500 kg/ha
Magnesium sulfate	250 kg/ha
The following can be added in combination, if needed:	
Peat	800 bales/ha
Calcitic limestone	800 kg/ha

Cultivating

Some cultivation is necessary to prepare the soil for sterilization, to incorporate organic matter, lime, and fertilizers, and to produce planting tilth. Rotary diggers are generally preferred because they provide more uniform cultivation with less damage to the soil structure. Repeated cultivation with rotary diggers can lead to a compacted soil layer if the depth of cultivation is not occasionally altered.

Watering

Irrigation is usually the flood type, although some automated equipment might be used. The objective of watering is to maintain a fully adequate supply of water to the plant roots without wetting the soil to the extent that air cannot get to the roots. Waiting until the plants start to wilt is not recommended. A good practice is to reach down into the soil and judge how much water is left before starting the next irrigation.

Regular watering on the same day of the week is unwise. The water requirement of the plants changes daily and seasonally. Water young plants planted in the greenhouse in January or February only once every 10 days or 2 weeks, and then only enough to soak 15–20 cm of the soil. Similar plants growing in June may need five to ten times as much water.

Each producer of greenhouse tomatoes should know how much water to add to the soil at each application. With this information and by examining the soil before watering and several hours thereafter, the effectiveness of the water application can be determined.

Scheduling the application of fertilizer

In addition to preplant fertilizer application, fertilizers must also be added regularly thoughout the production season. When applied to a growing crop, fertilizers are in dry form, as with base fertilizers, and are broadcast on most or all the cropped greenhouse soil. Recommended rates are listed in Table 9.

Mulching

The soil should be mulched when tomato plants are about 0.5 m high. Straw is the most common mulch material, but ground corn cobs are also acceptable. The mulch reduces evaporation and soil compaction. Also, when mulch is present, little soil is splashed onto plants during watering, thus avoiding dust in the greenhouse. Furthermore, mulch releases a considerable amount of carbon dioxide as it breaks down, which helps plant growth. Mulch also turns into useful organic matter after it is incorporated into the soil at the end of the cropping season. However, mulching with organic by-products gives rise to the well-known problems associated with the addition of any organic matter to intensely cultivated soils, as discussed earlier. In recent years, mulching has not been practiced widely; instead, a white polyethylene film is used to cover the ground whenever the irrigation method permits it. This mulchingalternative has several advantages and is best practiced in conjuction with drip irrigation.

Table 9 Recommended fertilizer application rates (kg/ha)

	Stock solution 1		Stock solution 2*			
Week from planting	10-52-10 starter	20-5-30	Magnesium sulfate	Potassium nitrate	Calcium nitrate	Amonium nitrate
1	100					
2	50					
3	50					
4	100					
5		100	100	50	50	
6		100		50		
7		100	100	50	100	
8		100		50		
9		100	100	100	100	
10		100		100		
11		100		100	100	
12		100	100	100		
13		100		100	100	
14		100		100		
15		100	100	100	100	0.5
16		100		100		
17		100		100	100	0.5
18		100	100	100		
19		100		100	100	0.5
20		100		100		
21		100	100	100	100	0.5
22		100		100		
23		100		100	100	0.5
24		100		100		
25		150				
26		150				

- Choose soluble fertilizer formulations that are as free as possible of chlorides, sulfates, and carbonates.
- For a spring crop do not vary the schedule.
- For a low-fertility soil or early setting cultivars (e.g., Vendor) omit, weeks 3 and 4 and proceed immediately to week 5 after week 2.
- For a fall crop omit weeks 2, 3, and 4 and proceed immediately to week 5 after week 1.

* Caution : If fertilizers are first mixed in thick stock solutions before they are applied to the crop, they should be grouped as indicated. Do not mix in the same concentrated solution a fertilizer containing calcium and one containing sulfate or phosphate, as such a mixture results in a thick suspension that can plug watering equipment.

Chapter 6. Cropping in soil with drip irrigation

The drip irrigation cropping system is similar to but better than the conventional soil cropping system because it can be used to control crop growth through a regulated supply of water and nutrients. In addition, the system allows reduced relative humidity in the greenhouse because not all the soil is irrigated and because it is compatible with the use of white polyethylene film as a light-reflecting mulch. Resources, including energy, are thus used more efficiently with this system.

Irrigate the crop up to four times a day, and use the irrigation system to apply fertilizer to the crop. Fertigation is the application of fertilizer through the irrigation system and is a popular method of fertilizing greenhouse vegetables. Fertilizers are either dissolved in a large holding tank and the solution is pumped to the crop or they are mixed in concentrated stock solutions, which are then incorporated, with fertilizer injectors, into the irrigation water

Several makes and models of fertilizer injectors are available at varying costs and offer varying degrees of fertigation control. A sophisticated fertilizer injection system capable of meeting the nutrient requirements of a series of crops automatically from the same set of stock solutions was developed recently at the Agriculture Canada Research Station in Harrow, Ont. (Plate 2).

The Harrow FM uses an IBM-compatible computer to activate a series of dosimetric pumps at varying frequencies for the preprogrammed application of a desired concentration of individual nutrients. In addition, the Harrow FM automatically adjusts the supply of water and nutrients to the crops in accordance with both expert information stored in the memory of the computer and with crop and environmental conditions as monitored by appropriate sensors.

Introducing drip irrigation and fertigation has made it necessary to consider the fertilizer needs of a crop in terms of the concentration of fertilizer (and therefore the concentration of nutrients) in the irrigation water rather than on the basis of the cropped area. Base fertilizers are not normally applied when drip irrigation is used; the exceptions are peat and lime, which might be desirable for the benefit of soil structure and soil pH adjustment.

Plate 2 The Harrow Fertigation Manager, a computerized multifertilizer injection system. (Harrow Fertigation Manager and HFM are registered trademarks of **Labbate** Climate Control Systems Inc., 1 Wilkinson Drive, Leamington, Ont.)

Plate 3 An early spring tomato crop in rockwool. Artificial light is used for growth enhancement, fine misting (fogging) for relative humidity control, and white plastic on the ground for light reflection, dust control, and evaporation control. Other services, not visible in this modern greenhouse, include computerized environmental control, liquid carbon dioxide supply, hot-water heating, and thermocurtains.

Plate 4 The deep-flow, or deep-culture, technique **(DFT)** was developed in Japan and is practicedwidely in the Far East. The modular construction of the cropping system includes plant support, extensive use of preformed polystyrene in trough construction, coextruded black-and-white polyethylene film used for protecting the nutrient solution from contamination and light exposure, and white plastic surfaces on the ground and the troughs for light reflection.

Table 10 illustrates a fertilizer feeding program recommended for most soils in the Loam to Sandy Loam categories.

Table 10 Fertigation schedule for drip-irrigated crops (kilograms of fertilizer per 1000 L of stock solution)

Week from planting	Calcium nitrate	Potassium nitrate	Ammonium nitrate	Monopotassium phosphate	Potassium sulfate	Magnesium sulfate	L/day	EC (μS/cm)
Spring crop								
1, 2, 3, 4,	44.0	6.0	0	22.0	126.0	50.0	0.4	3500
5, 6, 7, 8	44.0	25.0	0	22.0	108.0	50.0	0.6	3000
9, 10, 11	44.0	44.0	0	22.0	68.0	50.0	1.0	2500
12, 13	44.0	64.0	0	22.0	0	50.0	1.2	2300
14, 15	60.0	64.0	0	22.0	0	50.0	1.4	2200
16, 17	76.0	64.0	7.0	22.0	0	50.0	1.6	2000
18, 19, 20	76.0	64.0	22.0	22.0	0	50.0	1.6	1800
21, 22, 23, 24, 25	76.0	64.0	30.0	22.0	0	50.0	1.6	1600
26, 27, 28, 29, 30	76.0	64.0	30.0	22.0	0	50.0	1.6	1400
Fall crop								
1, 2, *3, 4*	*76.0*	*64.0*	*7.0*	22.0	**0**	50.0	0.6	1400
5, 6, 7, 8	*60.0*	*64.0*	*0*	22.0	**0**	50.0	0.8	1500
9, 10	*44.0*	*64.0*	*0*	22.0	**0**	50.0	1.0	1800
11, 12	44.0	44.0	0	22.0	*68.0*	50.0	1.0	2000
13, 14	44.0	25.0	0	22.0	108.0	50.0	0.8	2200
15, 16, 17, 18	44.0	6.0	0	22.0	126.0	50.0	0.4	2500

- Trace elements (e.g. 0.7 kg of STEM) and 0.5 kg of iron chelate (13% iron) must also be added to all the above fertilizer feeds; atypical trace element mix, e.g. Peters soluble trace element mix (STEM) contains 1.45% boron, 3.2% copper, 7.5% iron, 8.15% manganese, 0.046% molybdenum, and 4.5% zinc.
- Dissolve given amount of each fertilizer, including trace elements, in 1000 L of water and add to the irrigation water in equal doses, ideally with a multihead fertilizer injector. Start injection at a very low rate and increase progressively until the desired EC is achieved. Adjust the pH of the fertigation solution to 5.5 by injecting a dilute solution of phosphoric, nitric, or sulfuric acid.
- The recommended strength of the stock solutions is within the working range of a fertilizer injector with a 1:100 mixing ratio. If a fertilizer injector with a 1:200 mixing ratio is used, double the amount of each fertilizer. Similar adjustments can be made for fertilizer injectors with other mixing ratios. If the solubility limit, of a fertilizer (e.g., potassium sulfate) is exceeded, more than one stock solution of the same fertilizer can be prepared and the amount, of the fertilizer divided equally between the stocks.

Chapter 7. Cropping in peat moss and other organic media

Peat is lightweight and provides good water-holding capacity, drainage, aeration, and biological and chemical stability. Furthermore, peat is an abundant resource in Canada and therefore is readily available. It has been used alone or in combination with other materials such as vermiculite, perlite, turface, polystyrene beads, and other materials, in a variety of mixtures with diverse physical characteristics. In addition to a high water-holding capacity, peat moss has a high cation-exchange capacity and maintains an adequate structure during cropping. Horticultural-grade vermiculite releases some potassium and magnesium during the crop season, which could be more problematic than beneficial because of reduced control over the availability of those nutrients. However, vermiculite has a high cation-exchange capacity, which increases the buffering capacity of the mix and thus reduces the risk of overfertilization. On the other hand, perlite, turface, and Styrofoam beads are completely inert and do not affect the nutrient availability in the mix other than by improving the degree of aeration; these materials are now preferred because they do not break down as quickly as vermiculite and they allow for more exact nutrition of the crop. Recent research has indicated that the porosity of peat plus perlite declines readily over time but the porosity of peat plus polysterene does not. Although polysterene effectively increases the air content of the substrate, a great deal of that air-in the polysterene beads themselves-is not useful to the plants. Sand also behaves almost as an inert material and has been used extensively in the past, but like any soil it is not recommended unless sterilized. In contrast, perlite, vermiculite, turface, and Styrofoam beads are sterile on delivery because of the high temperatures used during their manufacture.

In addition to peat, sawdust is also an important organic medium for tomato cropping, especially in Canada. However, this system is described only in general terms, in a later section, because it has already been treated in detail in other publications.

The trough system

After the growing medium is mixed, it is usually placed in a container. When soilless mixes were first developed, a wooden trough (15–20 cm deep and lined with polyethylene) was the most common container used. A drainpipe laid along the centre of the trough drained the water and acted as a duct for steam during sterilizing (Fig. 131. A layer of gravel provided general drainage and protected the polyethylene during cultivation. Since soilless mixes are naturally low in nutrients, fertilizers must be added to promote optimum plant growth. Two major methods have been used for supplying fertilizers to crops grown in peat media: the simplest is to add all the nutrients required by the crop when the peat mix is prepared (see Table 11).

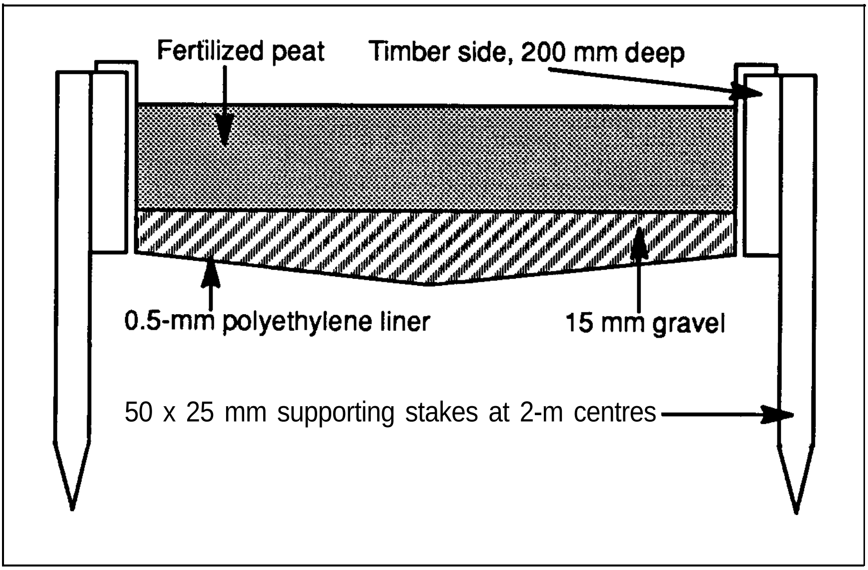

Fig. 13 Trough culture of tomatoes.

Table 11 Ingredients for a complete soilless mix based on peat moss and vermiculite (1.0 m^3)

Medium	Amount
Peat moss	0.5 m^3 (2 compressed bales of 0.17 m^3)*
Horticultural vermiculite	0.5 m^3 (4.5 bags of 0.11 m^3)
Ground limestone (dolomitic)	7.5 kg
Gypsum (calcium sulfate1	3.0 kg
Calcium nitrate	0.9 kg
Superphosphate 20%	1.5 kg
Epsom salts (magnesium sulfate)	0.3 kg
Osmocote 18-6-12 (9 months)	5-6 kg
Fritted trace elements (FTE 503)	225 g
Chelated iron (NaFe 138 or 330)	30 g

* Expansion of compressed bales is estimated to be 50% above original volume.

The success of this technique depends on slow-release fertilizers to provide a continuous supply of nitrogen, phosphorous, and potassium throughout the growing season. The calcium requirements of the crop are met mostly by the calcitic limestone normally added for pH adjustment of the peat. Micronutrients are also available and are added as fritted trace elements, which ensures their slow release over the cropping season. The main advantage of this approach is that regular feeding throughout the cropping season is not required unless the presence of nutrient deficiencies indicates a need. Some of the most serious disadvantages of this procedure are the low level of nutrition control and the potential for crop failure caused by excessive salts that result from rapid breakdown of the delayed-release fertilizer at very high to medium temperatures.

A more popular approach to nutrition involves combining a base application of soluble fertilizer when the peat is mixed (Table 12) and adding soluble fertilizers at regular intervals through the irrigation system (see Table 131.

The vigor of a crop, and the balance between vegetative growth and fruit development, can be adjusted to some extent by the composition of the feed. For example, high-potash (1:0:3.5) feed is normally used to control growth for a short time after planting, when light conditions are poor. Conversely, high-nitrogen (1:0:1) feed is used to maintain adequate vigor throughout much of the summer, when light and productivity are high. A major difference between peat-grown crops and soil-grown crops in feeding requirements is the need for a regular supply of phosphate; this nutrient is readily leached from peat and has to be replaced to maintain adequate levels. Alternating a phosphate-containing feed (e.g., 1:0.5:2) with a standard feed such as 1:0:2 supplies phosphate throughout the season. Phosphorus can also be supplied continuously in the form of a special phosphate-containing feed, but this system necessitates supplying calcium or magnesium in separate feeds. Always remember that concentrated solutions containing calcium that come in contact with phosphate-containing solutions can result in insoluble calcium phosphate, which blocks the irrigation system. Likewise, magnesium sulfate should not be mixed in high concentrations with phosphate-containing feeds. Minor elements are generally provided in peat substrates as glass-fritted mixes

Table 12 Ingredients for a base mixture of peat moss and vermiculite (1 m^3)

Medium	Amount
Peat moss	0.5 m^3 (2 bags of 0.17 m^3)*
Horticultural vermiculite	0.5 m^3 (4.5 bags of 0.11 m^3)
Limestone (pulverized FF)	5.9 kg
Superphosphate 20%	1.2 kg
Potassium nitrate	0.9 kg
Magnesium sulfate	0.3 kg
Chelated iron 10%	35 g
Borax (sodium borate)	35 g
Fritted trace elements (FTE 503 or FTE 302)	110 g

* Expansion of compressed bales is estimated to be 50% above original volume.

Table **13** Fertilizer feedings for crops grown in peat troughs

Type of feed	Feed ratio (N:P:K)	Fertilizer	Amount (kg/1000 L)	Amount of N:P:K:Ca:Mg (ppm)
High potash	1:0:3.5	{potassium nitrate	110}	145:0:500:0:0
		{potassium sulfate	20}	
Medium potash with magnesium	1:0:2	{potassium nitrate	90}	175:0:350:0:30
		{ammonium nitrate	20}	
		{magnesium sulfate	30}	
Medium potash with phosphate	1:0.5:2	{potassium nitrate	90}	175:85:350:0:0
		{ monoammonium phosphate	30}	
		{ammonium nitrate	7}	
Medium potash with calcium	1:0:2	{potassium nitrate	90}	175:0:350:70:0
		{calcium nitrate	401	
High nitrogen with magnesium	1:0:1	{potassium nitrate	65}	250:0:250:0:30
		{ammonium nitrate	501	
		{magnesium sulfate	301	
High nitrogen with phosphate	1:0.5:1	{potassium nitrate	65}	250:125:250:0:0
		{monoammonium phosphate	451	
		{ammonium nitrate	33}	
High nitrogen with calcium	1:0:1	{potassium nitrate	65}	250:0:250:85:0
		{calcium nitrate	45}	
		{ammonium nitrate	28}	

Note: Fertilizer rates are in kilograms per 1000 L of stock solution. Stock solutions have been formulated on the assumption that a fertilizer injector with a feeding ratio of 1:100 (one part stock per 100 parts of water) is used to incorporate one stock solution at a time to the irrigation water. Alternatively, the recommended fertilizers in each feed can be dissolved in 100 000 L of water for direct application to the crop.

that release their nutrients slowly over a cropping season. Trace-element deficiencies can be corrected by the application of chelated trace element mixes.

Chelates are applied either continuously in the liquid feed or as a foliar spray for corrective action. The rate used depends on the product. It is usually best to follow the manufacturer’s recommendations. In general, the feeding guidelines given in this publication should be adequate for crops grown in peat substrate throughout the season. However, if nutrient levels in the substrate become too high or too low, it is possible to reduce or increase the strength of the liquid feed to compensate accordingly. Ideally, an injection system that is equipped with a continuous-monitoring and feed-back control unit should be available for optimum water and nutrient supply to the substrate in accordance with the needs of the crop. (see Plate 2).

The higher conductivity and potassium levels in the suggested ranges apply to the early part of the cropping season, when light is limited. If an initial peat-substrate analysis shows nutrient levels outside the ranges given, the medium may still be suitable for vegetable growing, with some modification to the feeding program to bring the nutrient status back within acceptable limits. After attaining an optimum analytical range for the peat substrate, devise a feeding program that maintains optimum nutrient levels in the substrate. In general, apply liquid feed at every watering, using a medium potash feed (1:0:2) that contains potassium at a nominal strength of 300 ppm.

Peat bags

Plastic bags filled with a peat-based medium are now generally available. Each peat bag, which measures 35 cm x 105 cm when flat and contains 42 L of fertilized peat (or a mixture of peat with vermiculite, perlite, or polystyrene), can support up to three tomato plants as long as regular watering and fertilizing through a drip irrigation system are provided.

Cover the greenhouse floor with polyethylene film (Plates 3, 4) and lay the bags on it. Some growers use a double-layered polyethylene material as a floor covering, with a black bottom layer to prevent weed growth and a white top layer to reflect sunlight into the crop canopy Make three or four 4-cm slits in the sides of the bags to provide drainage after the medium is wet. The planting depth in the peat substrate is an important factor that affects later growth. The shallower the depth of peat, the more critical the planting depth becomes, especially if a permanent reservoir of water is present, making part of the peat bag unavailable for active root growth. This water reservoir is at the base of the peat bag and is developed by positioning drainage holes above it. A minimum substrate depth of about 10 cm, a planting depth of 2.5 cm, 5 cm of drained peat beneath the pot, and a water reservoir of 2.5 cm below the drainage level are recommended. Only two aspects of the general culture in peat bags are different from those of soil: watering and feeding. Watering crops grown in peat is easy, provided some basic rules are followed, the moisture content of the peat substrate is examined frequently, and appropriate action is taken when indicated. In fact, crops grown in peat may be easier to water than crops grown in soil because the moisture content of the latter is more difficult to assess, and the drainage characteristics of the soil and subsoil make decisions on watering less certain. Because peat bags contain only a small volume of growth medium, they offer a much lower water-holding capacity than most soils. Failure to apply water when it is needed can therefore have a more rapid detrimental effect on the crop than with soil-grown crops. The following rules are recommended for watering crops grown in peat bags:

- Use a drained peat bag with a water reservoir beneath.
- Provide additional irrigation outlets to areas that need extra water.
- Maintain an efficiently operating irrigation system by preventing or clearing blockages as soon as they occur
- Check the moisture level of the substrate frequently and modify the watering regime if necessary.
- Vary the frequency of watering rather than the quantity applied each time, so that the substrate is aerated between waterings and a uniformity of moisture content is maintained from one bag to another.

Problems arising from a faulty watering program can be classified as waterlogging, excessive drying back, and excessive variation of moisture from bag to bag. Waterlogging is easy to detect, as it results in slow growth and thin plant heads. When this problem is more serious the plants develop yellow heads characteristic of iron deficiency. Waterlogging problems usually develop when the watering regime does not allow enough time for proper soil aeration between applications. An excess amount of water applied on one occasion may not matter, as the surplus drains to waste, but a second application made before the substrate has dried to its normal minimum water content reduces root action and starts the cycle of waterlogging. Regular and frequent checks to control water frequency help to avoid this problem. Once waterlogging has occurred and the plants are showing symptoms, correcting the problem is a slow process; hold back the water to the substrate until it has dried to its normal minimum level, however long this might take. Invariably, some crop yield is lost while the problem is being corrected.

The problem of excessive dryness is equally serious but just as easy to avoid, provided the irrigation system works effectively and sufficient time is allocated to manage the watering program. If the medium is often allowed to dry to below the normal minimum water level, when water can no longer be squeezed out by hand, plant growth will be impaired, especially if the salt content of the medium is high. Media that are frequently allowed to dry too much also cause a general stunting of growth and considerable yield loss. The remedy is easy-apply more water by increasing the frequency of irrigation. The initial recovery may take several days; nothing can be gained by applying large volumes of water at every single irrigation, as most of it will run off to waste.

The third potential problem is excessive variation in water content within the crop. The application of water can never be accurate enough to cover all variation within .a crop, and extreme imbalances can develop. In addition, fast-growing plants can produce their own localized water deficiency problems, and weak, diseased, or removed plants can precipitate local waterlogging. Where the problem is not extensive, rebalance a crop by occasional hose watering to top up dry areas and by temporarily removing one or more irrigation outlets from areas of waterlogging. Occasionally inducing waterlogging can prevent or correct large-scale water imbalance, but use the technique only on an actively growing crop with a strong root system. This practice is also valuable for leaching out excess salts from the substrate. As a general irrigation rule, apply water until the driest area of the crop has recovered its full water requirement at each application. In this way, water is prevented from building up, and areas of substrate with a lower water requirement drain off any surplus without danger.

Anyone considering peat substrate culture of greenhouse tomatoes for the first time is aware that watering requires considerable managerial effort and a dependable irrigation system, and might well decide that the risk of mistakes does not justify the change from soil to peat substrates. However, the fact that water management errors in substrate culture are quickly manifested into visible symptoms makes peat substrate and other soilless culture systems attractive. In soil culture, incorrect watering usually becomes obvious only after the crop has changed its growth habit significantly. Consequently, although soil has a greater water-holding and buffering capacity, greater crop losses can still be incurred without the grower's awareness of any mistakes having been made. A competent grower in substrate can see potential errors in irrigation when they first appear in the peat mixture and correct them before they have any effect on the plants. The recent development of computerized irrigation controllers equipped with properly adapted soil water tensiometers has made the scheduling of irrigation of crops grown in peat bags much simpler and has resulted in significant water and nutrient savings while minimizing excessive nutrient leaching into the environment.

Nutrition is the other major area in which peat-grown tomatoes differ significantly from tomatoes grown in soil. Peat substrates have a much lower buffering capacity than most soils in relation to both major and minor elements. The grower therefore needs to monitor continually the nutrient availability in the substrate and to adjust accordingly the composition of the feed applied to it. This **work** requires a rapid and reliable analytical service, and a dependable and accurate technique for frequent application of fertilizers. The results of peat substrate analysis enable corrective action to be taken for an optimum root environment before any adverse symptoms are observed in the crop; to depend on crop symptoms alone for determining a necessary change in the feeding program greatly increases the risk of yield loss. As important as the analytical service is the ability of the grower to interpret the results and take any corrective action needed. Although the initial nutrient levels in peat substrates vary according to the supplier, the source, and type of peat used, the ranges in Table 14 can be regarded as normal and should be used only as a guide.

The results of peat analysis vary according to sampling and analysis procedures. The comparability of any peat-sample analytical results with the guidelines in Table 14 therefore depends on the following conditions:

- A peat sample should be taken from the full depth of substrate in the bag.
- The sampling point should be near a growing plant and should extend through the rooting zone.
- Several samples should be taken throughout the greenhouse area to be tested and mixed together to supply at least 0.5 L of substrate for analysis.
- Samples should not be taken immediately after watering or from areas that are clearly wetter or drier than the average for the house.
- Peat substrate samples taken as described above must be brought to a uniform water content by either adding distilled water to them or allowing them to dry out as needed before proceeding with analysis. The release of a small amount of water after a handful of peat has been squeezed moderately indicates a desirable water content.
- All analytical tests are performed on an aqueous suspension of the peat substrate sample, at a peat-to-distilled-water ratio of 1:1.5, by volume.

Experimental and commercial evidence suggests that the peat substrate can be recycled without a reduction in yield. However, the cropping potential of recycled peat substrate can be influenced by the following factors:

- the level and uniformity of nutrients in the peat
- the salt level in the medium
- the pest and disease status of the substrate.

Table 14 Desirable nutrient levels in the substrate of peat bags, based on a substrate-to-water dilution of 1:1.5

Nutrient	Concentration (ppm)
Nitrogen (nitrate)	30-80
Phosphorus	20-50
Potassium	140-400
Calcium	140-200
Magnesium	25-35
Acidity (pH)	5.5-6.6
Electrical conductivity (µS/cm)	1000-2500

If growers plan to reuse the bags they should reduce the strength of the fertilizer feed by half, starting about 6 weeks before the planned termination of the first crop, and should apply plain water during the last 2-3 weeks. This extended period of gradual nutrient leaching allows the nutrient levels in peat substrates to be reduced. The degree to which the nutrient levels are reduced varies with the ease with which they are leached. For example, in a well-leached substrate the nitrate level is very low, the phosphate and potassium levels are low, and the calcium and magnesium levels remain high. To minimize the problems caused by a lack of uniformity in the nutrient content of reused peat bags, sterilize the leached peat medium in bulk. After sterilization, analyse the peat medium and add base fertilizers as needed before rebagging. The principles of steaming are similar for both soil and peat. The objective is to destroy harmful organisms while preserving most of the beneficial organisms and nutrients, without allowing salts to build up. Excessive steaming should therefore be avoided; raising the temperature through the substrate to 82°C for 20 min is all that is needed. As with soil, the peat should not be too wet or too dry at steaming, otherwise the cost of the operation is unnecessarily high or the efficiency of the operation unnecessarily low. Because of the small amount of peat substrate used in a greenhouse, compared with soil, both the energy and labor expended in steaming peat are considerably less.

The Harrow peat-bag system

In the early 1980s the Harrow Research Station developed a peat-bag system for greenhouse tomato production. The recommendations for the peat-based growth medium and the corresponding fertigation schedule are presented in Tables 15 and 16, respectively

Table 15 Peat-bag growth medium recommended for tomatoes

3.0 (0.17 m^3) bags of peat moss (57% of total volume1 3.0 (0.11 m^3, 7 kg) bags of vermiculite (25% of total volume1 2.0 (0.11 m^3, 7 kg) bags of perlite (18% of total volume1	A
5.0 kg limestone (pulverized FF) 4.0 kg ground limestone (dolomitic) 1.5 kg ground superphosphate (20% phosphorus1 1.0 kg potassium sulfate 150.0 g fritted trace elements (FTE 302)	B
2.0 kg 18-6-12 slow release (9-month) fertilizer	C
2.0 kg potassium nitrate 0.3 kg magnesium sulfate 35.0 g Borax (15% boron) 35.0 g chelated iron (iron EDTA, 13% iron)	D
0.1 litre of wetting agent	E

Note: Mix ingredients of A and B separately. Add D (mixed) and E to 20 L of water for each ingredient. Combine A, B, and C and wet with solutions D and E, adding more water (if needed) as you mix. This medium should be enough for at least 32 peat bags measuring 0.35 m x 1.05 m, when flat.

Cropping in sawdust

In the 1950s and 1960s the Saanichton and Agassiz research stations developed a method of cropping greenhouse tomatoes in sawdust. This method received general commercial acceptance in British Columbia, and to some extent in Alberta, in the 1970s and 1980s, but it is now being replaced by rockwool. Some of the advantages of sawdust culture are its low cost, light weight, and the wide availability of sawdust itself. Although rockwool also claims some of these qualities, sawdust could again receive renewed attention because it is easier to dispose of than rockwool.

The sawdust used as a growing medium in the past was derived from Douglas-fir and western hemlock. Sawdust from western red cedar was found to be toxic, especially when fresh, and therefore should not be used. Other organic or inorganic media can be mixed with sawdust to improve the chemical and physical properties of the substrate. However, the various

Table 16 Fertigation schedule for tomato production in peat bags (in kilograms of fertilizer per 1000 L of stock solution)

Week from planting	Calcium nitrate	Potassium nitrate	Ammonium nitrate	10-52-10 Starter	Iron chelate (13% Fe)	Monoammonium phosphate	Magnesium sulfate	L/day	EC (μS/cm)
1, 2	0	0	0	40.0	0.0	0	0	0.4	5000
3, 4	0	0	0	40.0	0.0	0	0	0.2	4000
5, 6	0	90.0	0	0.0	0.0	20.0	9.0	0.4	3500
7, 8	18.0	90.0	0	0.0	0.0	20.0	9.0	0.6	3000
9, 10	18.0	90.0	0	0.0	0.0	40.0	9.0	0.8	2500
11, 12	18.0	90.0	0	0.0	4.0	40.0	9.0	1.0	2300
13, 14	18.0	90.0	50.0	0.0	4.0	40.0	9.0	1.2	2200
15-18	36.0	90.0	50.0	0.0	4.0	40.0	18.0	1.4	2000
19-22	36.0	90.0	50.0	0.0	4.0	40.0	18.0	1.4	2000
23	36.0	90.0	50.0	0.0	4.0	40.0	0	1.4	1500
24, 25	0	90.0	50.0	0.0	4.0	40.0	0	1.4	1500

- Trace elements (e.g. 0.5 kg of STEM) must, also be added to all the above fertilizer feeds; a typical trace element mix, e.g. Peters soluble trace element, mix (STEM) contains 1.45% baron, 3.2% copper, 7.5% iron, 8.15% manganese, 0.046% molybdenum, and 4.5% zinc.
- Dissolve given amount of each fertilizer, including trace elements, in 1000 L of water and add to the irrigation water in equal doses, ideally with a multihead fertilizer injector. Start injection at a very low rate and increase progressively until the desired EC is achieved. Adjust the pH of the fertilizer solution to 5.5 by injecting a dilute solution of phosphoric, nitric, or sulfuric acid.
- For a spring crop use the schedule unchanged; for a fall crop follow the schedule but start from week 4.
- The recommended strength of the stock solutions is within the working range of a fertilizer injector with a 1:100 mixing ratio. If a fertilizer injector with a 1:200 mixingratio is used, double the amount of each fertilizer. Similar adjustments can be made for fertilizer injectors with other mixing ratios.

substrate mixtures must be formulated and tested on a small scale under well-controlled conditions. The uncontrolled distribution of a wide variety of organic media mixtures with diverse chemical and physical characteristics is a major source of grower confusion and therefore an obstacle in the profitable use of this valuable Canadian resource.

Sawdust can be placed in troughs, beds, upright bags, bolsters, or even large pots. Regardless of the container, a minimum of 10 L of medium is recommended for each plant. The culture practices followed in sawdust culture are similar to those described for peat moss.

Fertilizer can be applied in two ways: all nutrients, with complete nutrient solution, can be supplied at each irrigation; or, some of the fertilizer can be incorporated into the growth medium before planting and the remainder can be delivered through the irrigation system.

The fertilizer rates described in Table 17 are recommended for tomato production in unfertilized sawdust.

The fertilizer rates described in Table 18 are recommended for tomato production in sawdust enriched with 2.4 kg of superphosphate (0-19-O) and 4 kg of domolitic limestone per cubic metre of sawdust. To ensure the long-term availability of calcium and magnesium, supply half the limestone as a coarse grind and half as a fine grind.

Table 17 Fertilizer application rates for tomato production in unfertilized sawdust

	Nitrogen level in final solution		
Fertilizer	N at 126 ppm	N at 168 ppm	N at 210 ppm
	Amount of fertilizer in final solution (g/1000 L)		
Potassium sulfate	360	44	–
Potassium nitrate	160	500	550
Magnesium sulfate	500	500	500
Ammonium nitrate	–	–	100
Calcium nitrate	680	680	680
	Stock solution (mL)		
Trace element, stock*	220	220	220
Phosphoric acid (75%)†	100	100	100

* The trace element stock solution is prepared by dissolvingthe following elements in 1 L of warm water: 70 g iron chelate (10% iron), 15 g manganese sulfate, 12 g boric acid, 2.2 g zinc sulfate, 0.6 copper sulfate, and 0.2 g molybdic acid. When this trace element stock solution is added to the final nutrient solution at a rate of 220 mL/L, the concentration of trace elements in the final nutrient solution, in parts per million, is as follows: iron 1.54, manganese 1.07, boron 0.46, zinc 0.11, copper 0.034, and molybdenum 0.023.

† Concentrated phosphoric acid (75%) can be carefully added directly to the final nutrient solution without, prior dilution.

Table 18 Fertilizer application rates for tomato production in fertilizer-amended sawdust

Fertilizer	Nitrogen level		
	N at 126 ppm	N at 168 ppm	N at 210 ppm
	Amount of fertilizer in final solution (g/1000 L)		
Potassium nitrate	550	550	550
Ammonium nitrate	160	280	410
	Stock solution (mL)		
Trace element stock*	220	220	220
Phosphoric acid (75%)†	100	100	100

* The trace element stock solution is prepared by dissolving the following elements in 1 L of warm water: 70 g iron chelate (10% iron), 15 g manganese sulfate, 12 g boric acid, 2.2 g zinc sulfate, 0.6 copper sulfate, and 0.2 g molybdic acid. When this trace element stock solution is added to the final nutrient solution at a rate of 220 mL/L, the concentration of trace elements in the final nutrient solution, in parts per million, is as follows: iron 1.54, manganese 1.07, boron 0.46, zinc 0.11, copper 0.034, and molybdenum 0.023.

† Concentrated phosphoric acid (75%) can be carefully added directly to the final nutrient solution without prior dilution.

In Tables 17 and 18 the recommendations for applying fertilizer can be implemented either by dissolving the fertilizers at the prescribed rates in water and directly applying the resulting nutrient solution to the crop or by preparing concentrated stock solutions (e.g., 100 times the prescribed rates) and incorporating the stock solutions into the irrigation water (i.e., by using a fertilizer injector with a 1:100 mixing ratio). Always remember that calcium and sulfates cannot be mixed together at high concentrations without some precipitation of calcium sulfate, and therefore at least two stock solutions must be prepared.

Chapter 8. Cropping in rockwool and other inert media

Rockwool is a fibrous material produced from a granite-like rock known as diabase, or basalt. During manufacture the minerals are melted at a temperature of around 1600°C and transformed into fibers bonded together with resins. Initially manufactured for the building trade as an insulator, this spongy material has recently become available in cubes or slabs, to which a wetting agent is added to make it water-absorbent for horticultural use. Other inert products that have been used as growing substrates, singly or in combination, include perlite, vermiculite, polyurethane (Oasis), and polystyrene beads. Vermiculite cannot be considered entirely inert as it contains some potassium and magnesium, which gradually become available to plants when it breaks down. All these inert materials are manufactured in a way similar to rockwool, and they all share physical and chemical characteristics. They are all sterile (free of pathogens and weed seeds), and they offer a low cation-exchange capacity (vermiculite is an exception1 and a high water-holding capacity They permit adequate root aeration and a high degree of control over watering and feeding. Furthermore, because of their light weight, they are easy to handle, making the interval between crops shorter than usual. Finally, they are conducive to energy savings, first because they eliminate soil steaming and second because their use makes root heating practical, which allows for more precise control of air temperature on the basis of minimum temperature requirements of the shoots rather than the roots.

Rockwool is by far the most important inert medium because of the extent to which it is used commercially around the world and because of the wealth of information available from experienced growers and plant scientists (Plate 3). However, with proper management, all the media mentioned have similar yield potential. Since most of the technology in inert media used in the production of greenhouse tomatoes is similar, a detailed management procedure on rockwool, with references to other media where necessary, is applicable to all the media.

Horticultural-grade rockwool is manufactured in several countries (UK, Denmark, Holland, Germany, France, United States, and recently, Canada) under various trademarks (e.g., Basalan, Capogro, Grodan, Pargro). Although the chemical composition of rockwool varies with the manufacturer, the ingredients making up the fibers are not available to the plants, and so all nutrients must be added regularly to the crop in a liquid feed.

Rockwool is available in the form of slabs, blocks, or granules. The slabs are rectangular pieces of varying lengths and widths, but they are usually 7.5 cm deep for raising long-season crops such as tomatoes, cucumbers, peppers, and eggplant, among others. Typical dimensions are 90 x 15 x 7.5, 90 x 20 x 7.5, and 90 x 30 x 7.5 cm. The blocks are also available in a variety of sizes and are used for seed germination and transplant raising. The granular form is used for soil or for a soilless mix amendment and can also be used in bags as a partial or complete substitute for peat.

Oasis is also available in block form, for transplant raising, and in granular form, for making bags; it is not readily available as a slab. An important difference between the two media is their pH. The pH of new rockwool is about 7.0–8.5, which must be corrected with a slightly acid fertilizer solution to about 5.5 before use. The pH of new Oasis is on the acid side, and a slightly alkaline solution, usually potassium bicarbonate, has to be added before use. In both cases the exact concentration of acid or base required can be determined by trial and error tests on a small scale, or the necessary information can be obtained from the manufacturer. The lack of a significant cation exchange capacity in inert media makes adjusting their pH simple and inexpensive, because low amounts of chemicals are required. Before the crop is started the growth medium should be watered thoroughly, to allow for pH adjustment, to fill the capillary tubes, and to ensure that the irrigation water added later will spread uniformly in the growth medium. Approximately 0.8 L of water should be added to each litre of rockwool to ensure complete saturation, which indicates its high water-holding capacity (80%) combined with adequate aeration (17%), even when fully wet.

A crop should be propagated and grown in the same type of medium, thus ensuring that the capillary connections between the transplant pot and cropping media are established quickly at transplanting and that no excessive drying out or water saturation occurs around the stems. Rockwool blocks are available in many sizes, but for tomato propagation the most commonly used size is the 7.5cm cube, individually wrapped in polyethylene to prevent excessive drying out. Raise seedlings in vermiculite or perlite and then prick them out into rockwool blocks with a cavity at the top. Alternatively, raise seedling by placing individual seeds into very small rockwool blocks (plugs), specially made to fit into the cavity of the transplant blocks, and cover them with fine vermiculite. Before using the rockwool blocks, place them on polyethylene and wet them with an acidic nutrient solution, to adjust the pH. After pricking out the seedlings, apply nutrient solution at each watering. Some form of bottom heat to raise the substrate temperature to 22–24°C is beneficial and always holds some promise for energy savings.

The nutrient composition of the fertilizer solution used in rockwool culture depends on the chemical composition of the existing irrigation water, the stage of plant growth, and the season. Once the original water has been analyzed, fertilizer and acid application rates can be calculated on the basis of a most desirable nutrient formula as determined by research and experience. The quality of the irrigation water is more important in rockwool culture than in soil and should always be considered when establishing a feeding program. For example, if the water contains a large amount of calcium or magnesium the rates of calcium nitrate and magnesium sulfate should be reduced accordingly, and the nitrogen lost in these adjustments should be made up by increasing the amount of another nitrogen-containing fertilizer. Other nutrients, such as potassium and nitrogen, are rarely present in significant quantities to necessitate an adjustment to the nutrient formula. The water supply sometimes contains a large amount of certain trace elements such as iron, zinc, and manganese, in which case some correction to the fertilizer feed is needed. Avoid saline water that contains more than 50 ppm sodium or 70 ppm chloride; when the concentration of these two ions reaches 100 and 140 ppm, respectively, the water cannot be used easily in rockwool culture. When using rainwater, raise the usually low level of bicarbonate by adding potassium bicarbonate to the final solution, not to the stock solutions, to increase the buffering capacity of the solution for a more stable pH in the rockwool slabs. On the other hand, when the bicarbonate in the water supply is higher than 60 ppm, add phosphoric or nitric acid (or both) to neutralize it. For a proper solution to these special problems, seek a second opinion, preferably that of an experienced grower or a horticultural adviser. Although rockwool systems may be used with either recirculating or nonrecirculating nutrient solutions, the use of a nonrecirculating system is preferred because of its simplicity and dependability. However, even a nonrecirculating, open-ended system has to be checked and repaired regularly, and the pH and electrical conductivity (EC) of the solution checked daily, given the inert nature of the substrate and the quick response of the crop to human error and mechanical failure.

Once transplant raising is complete, stand the plants on the rockwool slabs, through precut holes on the plastic liner, and ensure good contact between the propagation blocks and the slabs. Place one or more drippers in the irrigation system on each propagation block. It might also be advisable to stand the transplants on the rockwool slabs for several days before cutting holes in the plastic liner. This procedure limits root growth within the transplant block and slows down growth by holding back water at the early part of the spring crop, when light is limited. After the plants have established a good root system in the slabs, make slits for drainage on the sides of the plastic wrapping near the bottom of the slabs. The distance of the slits from the bottom of the rockwool slabs determines thevolume of nutrient solution on reserve and plays a major role in establishing the specifications of the irrigation system and the irrigation regime: the lower the slits the smaller the size of the nutrient solution reservoir in each slab and the more frequent the irrigation needed; however, the lower the location of the slits the less the volume of saturated rockwool and therefore the greater the efficiency in using the rockwool as a rooting substrate, which theoretically should result in higher productivity. An inexperienced rockwool grower with a drip irrigation system of modest performance is well advised to start with cutting drainage holes at some distance (1–3 cm) from the bottom of the slabs. Once the grower has gained experience he/she could progressively extend the slits downward to maximize the utilization of the available rockwool.

The rows of rockwool slabs should be as level as possible and should stand on boards of polysterene, which help level off small imperfections in the soil surface. The boards also form part of a substrate heating system, which is based on the circulation of warm water in polyethylene tubing set into grooves carved in the polysterene. In addition, the polysterene boards act as insulators between the warm rockwool slabs and the cold soil underneath.

Make at least two stock solutions from readily available fertilizers, to avoid precipitation in the concentrate storage tank that results when calcium- or magnesium-containing fertilizers are mixed with those containing sulfates or phosphates. Dilute the stock solutions and combine them in a mixing tank before applying them to the crop, thus providing a complete nutrient solution at every watering. Monitor the total concentration of nutrients in the irrigation water continually by a salt sensor (electrical conductivity cell) and, if necessary adjust the mixing ratio of the fertilizer diluter to achieve an optimum feeding strength for the crop; automatic adjustment is technically available. Similarly, monitor, with a pH meter, the pH of the irrigation water after adding all fertilizers and any acid,. Adjust the rate of acid application to achieve a desirable pH for the nutrient solution; automatic adjustment is technically available. Many alternative feed recipes can be used, depending on the cultivar grown, the water source, the stage of crop growth, and the season. The fertigation recommendations in Table 19 are based on using rainwater and should be treated only as a starting point in the search for finding the optimum for a given operation.

Daily checks of the pH and salt concentration of the slab solution are necessary and fortnightly analysis for all essential nutrients is highly recommended. Correct serious nutrient imbalances by making appropriate changes to the nutrient formula, but the changes should deviate as little as possible from the normal solution. The alterations should be double-checked by an experienced person and should be implemented only until the imbalance is corrected. Changes in the nutrient formula based on crop growth and appearance are also possible, but such changes should be made only by persons with experience in rockwool culture. To reduce costs, use rockwool slabs for more than one season, provided they are effectively steam-sterilized in between crops. Thoroughly flush out accumulated salts with plain water for 1 or 2 h before sterilization. Methyl bromide can also be used to sterilize rockwool between crops, but steaming is more effective over a greater variety of pathogens and is preferred when available. After the slabs are sterilized, rewrap them with polyethylene film so that they are ready again for use. Reused slabs do not require further pH adjustment and are easier to rewet than new ones. Rockwool slabs can be reused only a limited number of times, usually once, as some breakdown in the fiber structure occurs with handling and sterilization, and as a result the air pore space in the slabs decreases with every reuse. An interesting alternative to the reuse of rockwool slabs for reducing production cost is the recent introducion of a low-density, low-cost rockwool slab that is used for a single cropping season.

Other nearly inert media such as sand and gravel have also been used as growing substrates for greenhouse vegetables. Considerable information on sand and gravel culture is available, mostly from other countries; on occasion, Canadian growers have experimented with them. However, these media are heavy, difficult to handle, difficult to sterilize in between crops, and usually require extensive, permanent modifications to the greenhouse floor. Like most other media, sand and gravel have an equally high yield potential when managed properly and can be the best choice under certain conditions.

Table 19 Fertigation schedule for tomato production in rockwool (in kilograms of fertilizer per 1000 L of stock solution)

	Stock A		Stock B			Recommended irrigation	
Application time	Calcium nitrate	Potassium nitrate	Monopotassium phosphate	Potassium sulfate	Magnesium sulfate	L/day	EC (µS/cm)
Saturation of slabs	130.0	0	27.0	43.0	36.0		2500
For 4-6 weeks after planting	100.0	64.0	27.0	12.0	36.0	0.2-1.0	gradually increase to 3500
Normal feed	100.0	35.0	27.0	39.0	36.0	1.0-2.5	1800-2300
Heavy fruit load	100.0	37.0	27.0	42.0	36.0	1.5-3.5	1800-2500

- Trace elements (e.g. 0.7 kg of STEM) and 0.5 kg of iron chelate (13% iron) must also be added to all the above fertilizer feeds; a typical trace element mix, e.g. Peters soluble trace element, mix (STEM) contains 1.45% boron, 3.2% copper, 7.5% iron, 8.15% manganese, 0.046% molybdenum, and 4.5% zinc.
- Dissolve given amount of each fertilizer, including trace elements, in 1000 L of water and add to the irrigation water in equal doses, ideally with a multihead fertilizer injector. Start injection at a very low rate and increase progressively until the desired EC is achieved. Adjust. the pH of the fertigation solution to 5.5 by injecting a dilute solution of phosphoric, nitric, or sulfuric acid.
- **The recommended strength of the stock solutions is within the working** range of a fertilizer injector with a 1:100 mixing ratio. If a fertilizer injector with a 1:200 mixing ratio is used, double the amount of each fertilizer. Similar adjustments can be made for fertilizer injectors with other mixing ratios. In case the solubility limit of a fertilizer (e.g., potassium sulfate) is exceeded, more than one stock solution of the same fertilizer can be prepared and the amount of the fertilizer divided equally between the stocks.

Note: When a stock solution is mixed at a concentration of 1 part A, 1 part B, and 98 parts water, it supplies all essential nutrients to the crop at the following concentrations, in parts per million.

	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B	Mo
Saturation of slabs	201	62	253	247	36	0.8	0.57	0.32	0.22	0.1	0.005
For 4-6 weeks after planting	238	62	370	190	36	0.8	0.57	0.32	0.22	0.1	0.005
Normal feed	200	62	370	190	36	0.8	0.57	0.32	0.22	0.1	0.005
Heavy fruit load	203	62	390	190	36	0.8	0.57	0.32	0.22	0.1	0.005

Chapter 9. The nutrient film technique and other hydroponic systems

Of all the soilless methods, water culture, by definition, is a true hydroponic system. The nutrient film technique (NFT) is a new water culture system based on the simple principle of circulating a shallow stream, or film, of nutrient solution over the roots of growing plants to provide an adequate supply of water, nutrients, and oxygen (Fig. 14). The concept of the nutrient film is credited to A.J. Cooper, who while at the Glasshouse Crops Research Institute in Littlehampton, England, recognized its value and called international attention to its commercial potential as early as 1973. Since then, NFT has undergone intensive testing by scientists and commercial growers in many countries, including Canada, and is now considered a commercially viable form of water culture.

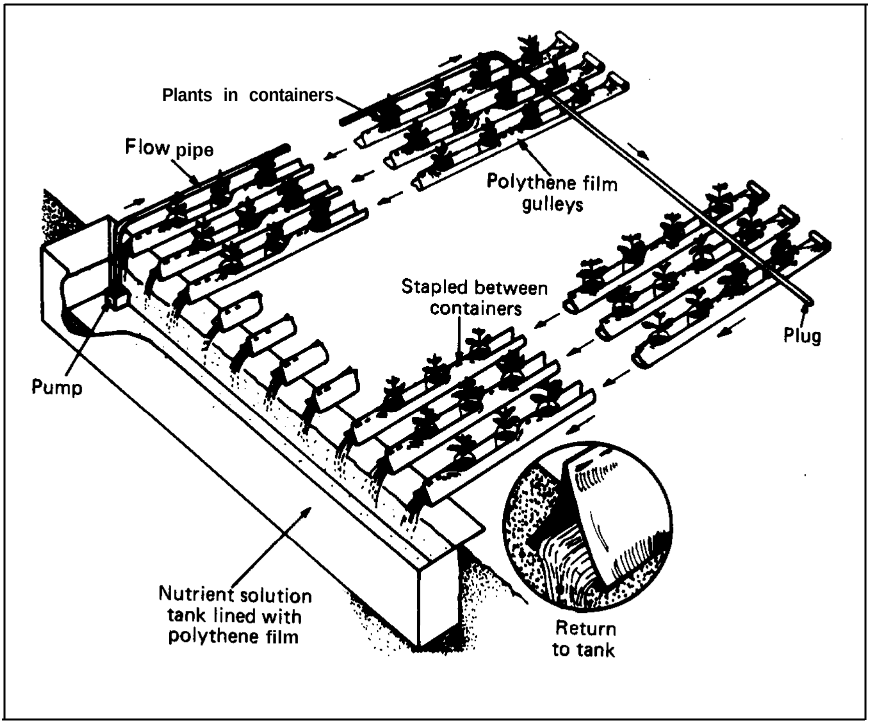

Fig. 14 The NFT, as a concept.

Although there are many versions of NFT in current use, the basic components of a typical NFT installation are as follows:

- Parallel gullies, or troughs, in which the plants are grown are laid on a 1–2% slope, on which the nutrient solution flows. Originally, the plants were grown with their roots in lay-flat tubing, but this method was not ideal for maximum aeration of the roots. Later, gullies were made from a strip of polyethylene folded lengthwise (Fig. 15). The gullies are now prefabricated from semirigid plastic.
- A catchment tank contains nutrient solution where fertilizers, water; and acid are added.
- A circulation pump draws solution from the catchment tank and delivers it to the upper ends of the gullies.
- A catchment pipe, into which the gullies discharge their solution, eventually finds its way to the catchment tank.
- Fertilizer and acid supply tanks store concentrated fertilizer stock solutions and an acid solution.
- Monitoring and control equipment maintain nutrient concentrations (including total amount of salts), pH, and water level. An electrical conductivity (EC) controller and a pH controller are commonly used to regulate the operation of dosimetric pumps or solenoid valves. These pumps and valves control the transfer of fertilizers and acid to the catchment tank. A constant water level in the catchment tank is easily obtained by a mechanical floating valve or by a variety of electronic controls.

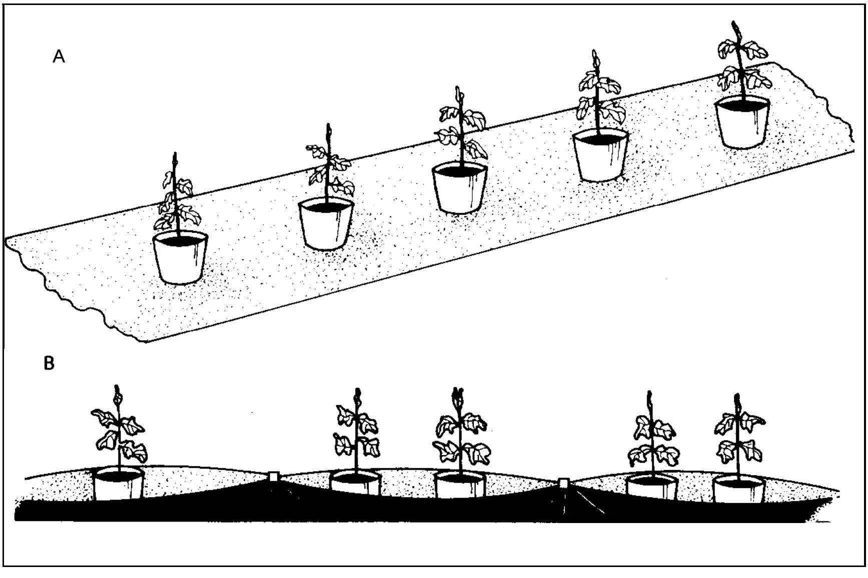

Fig. 15 Gully construction for NFT.

The general layout of an NFT installation, with its various components as described above, is illustrated in Fig. 16.

NFT has many advantages over other systems of crop production. It has been designed for simplicity, low cost, and dependability In particular, it gives absolute control of the root environment. Watering is greatly simplified, and a uniform nutrient supply across the whole crop is ensured. Root temperature can be raised easily whenever required merely by warming the nutrient solution, which can be circulated either continuously or intermittently to further conserve energy and to control the vegetative growth of young winter-grown plants. Other advantages include a rapid turnaround between successive crops, the potential for more efficient use of greenhouse space because of the possibility of plant mobility, and the potential for more efficient use of water. NFT's high degree of control over nutrition, water availability, and root environment makes it the most sophisticated of all commercial plant culture systems in practice today and theoretically offers the highest yield potential; practical trials attest to this claim. However, many of the advantages of NFT are also offered, to some degree, by other soilless methods, notably rockwool. Much scepticism therefore persists about the future of NFT because it is generally perceived as a technique that requires a high level of technical skill. Of some concern is the possibility that the recirculating nutrient solution may encourage the amplification and spread of diseases in the system, resulting in disastrous crop losses. Although the fear of disastrous crop failures has not been substantiated by facts, unexplainable outbreaks in root death have occasionally occurred and have helped to fuel the concern over potential spread of diseases in an NFT crop.

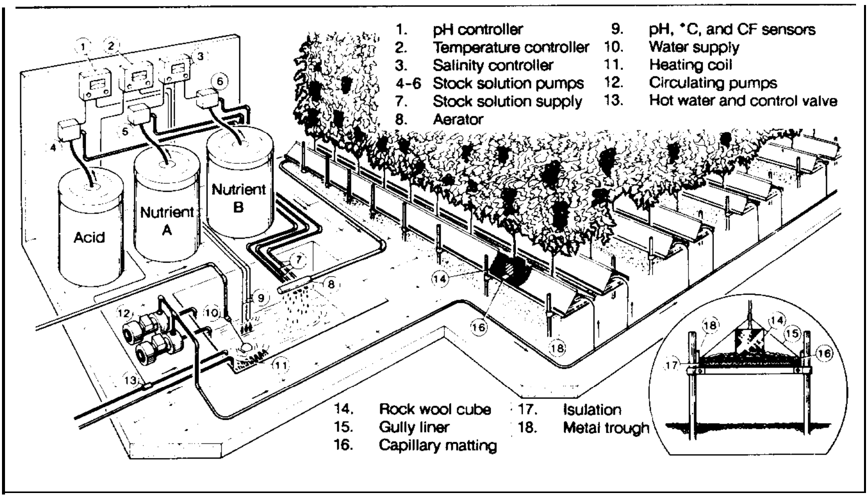

Fig. 16 A typical NFT installation.

The NFT method, the deep-culture technique (pioneered in Japan, Plate 4), and other closed-loop hydroponic methods are now being examined again with renewed interest because of their potential for minimizing fertilizer waste and environmental pollution.

NFT was originally developed as a low-cost system using lightweight, disposable gullies and simple salinity and pH controllers. However, as the system became a commercial reality, increased levels of automation, standardization, and sophistication were introduced that have made the capital cost of the initial installation a major concern for growers contemplating its use. Furthermore, a standardized commercial NFT system would likely have to be imported into Canada from overseas, making initial installation even more costly Fortunately, the original simple and low-cost NFT system is nearly as good as the high-cost ready-to-use ones in the international market and still offers the best opportunity to the average grower who would like to try NFT on a small scale without risking great losses. Many publications are now available describing the NFT technique in great detail. Also, several Canadian companies are offering turn-key operations or are well stocked with all NFT-related instruments and supplies. The following is a summary of some general rules and recommendations for NFT use, for the benefit of those who might not have access to the more detailed, specialized publications that are available. Particular emphasis is placed on aspects of NFT that proved problematic during its development.

The base of the gullies should be about 25-30 cm wide. A maximum length of 20 m is recommended for gullies when a nominal 1% slope is used; longer gullies can be used for the nutrient solution, with higher slopes or with several introduction points along the length of the gullies. For the construction of the gullies, especially for the fall crop, use coextruded polyethylene film (white on black) 0.1 mm thick, when available. Lay the plastic film (a strip about 75 cm wide) in position, black side uppermost, on the prepared supporting surface (e.g., polystyrene sheets on graded soil or elevated tray-supports manufactured from galvanized metal and other materials); raise the sides and staple them together between the plants to form a gully of triangular cross section. The inside black surface of the plastic serves to keep the light out of the gully and thus prevents algae from growing in the nutrient solution; the white outside surface of the plastic reflects the incoming light, thus enhancing plant growth and preventing the plastic from getting too hot. Overheated plastic gullies have burned the stems of transplants when a crop was started in the summer. A thin plastic film, as recommended previously, is preferred over a thicker film because the former tends to wrinkle and thus helps disperse the nutrient solution while a crop is being established and not enough roots are growing outside the propagation blocks. Various approaches have been developed in trying to ensure that young transplants do not dry out during the first few days after transplanting. For a simple and effective solution, place the transplants on a narrow strip of capillary matting at planting time. A second set of crop-supporting wires are usually necessary at a low level to help lay down a crop without moving the plastic gullies out of place, which can lead to serious losses of nutrient solution. Transfer the nutrient solution from the supply line into the gullies through at least two small-bore (2–3 mm inside diameter) flexible tubes, to guard against blockage. Of the NFT components that come in contact with the nutrient solution, as many as possible should be made of plastic because metal can release potentially toxic levels of certain micronutrients, such as zinc and copper, in the solution. Because of the widespread use of plastics, take care to select materials that are not phytotoxic. As a general recommendation, PVC and low- and high-density polyethylene or polypropylene are acceptable, but plasticized PVC, used in the manufacture of flexible hose, or butyl rubber sheet lining, used for waterproofing reservoirs, should not be used in NFT as they may be phytotoxic. Plastics are more likely to cause phytotoxicity when they are new Plastic surfaces quickly lose their potential phytotoxicity when exposed to nutrient solution. Therefore, before planting a crop, flush out the new hydroponic installation entirely for **1** day with a dilute nutrient solution that is discarded.

To ensure good root aeration allow an adequate rate of flow in the gullies, e.g., 2 L/min, and a depth of solution of no more than 1 cm, even when the root mat is well developed. To provide a suitable slope, grade the ‘surface carefully before laying the gullies to avoid localized areas of deeper, stagnant solution. In planning the layout, take advantage of any natural slopes in the greenhouse. A second slope at right angles to the flow in the gullies facilitates the return flow to the main (catchment) tank, which is most conveniently located at the lowest corner of the greenhouse complex. Although NFT at first relied on sloping soil surfaces, occasionally made of concrete, an increased interest is now evident in raised systems using rigid platforms, which support the gullies, and in adjustable stands. Pockets of deeper solution resulting from poor soil leveling are eliminated by such systems, which allow for slope adjustment, even during cropping. Furthermore, a raised NFT system can be installed and operated in an old greenhouse, where grading the soil might be difficult or even impossible. Widely available fiber glass or plastic containers have been used as catchment tanks, but because they are usually small their usefulness is limited to small NFT installations. For larger installations, deep holes or pits in the soil lined with polyethylene film are sometimes used. This system should be avoided, however, because the film often develops leaks and can create other problems. A pit liner made of polyethylene film reinforced with fiber glass or nylon fiber is a much better alternative.

A concrete tank, properly sealed with resin, or a tank prefabricated in plastic with external reinforcement, is an excellent choice for a permanent catchment tank in most NFT installations. Cover the tank to exclude light, to prevent algae growth, and to limit contamination of the solution by soil organisms. Adequately insulate the catchment tank to prevent the solution from becoming too cold and to conserve energy when the nutrient solution is heated. An NFT system that supports 1 ha of mature vine crop is estimated to contain around 50 m^3 of nutrient solution, of which only 5-8 m^3 is in the catchment tank; the rest is circulated in the gullies. Allow a minimum catchment tank capacity of 10 m^3 for every hectare of greenhouse area when designing an NFT system; if an intermittent flow of nutrient is contemplated, the capacity needs to be increased substantially.

Larger tanks would, of course, increase the nutrient supply and pH stability of the system, but the tank's cost-to-benefit ratio also has to be considered before a final decision is made. Like all aspects of NFT, the design of catchment tanks is still being developed, with the objective of improving mixing and aeration of the nutrient solution and ensuring optimum pH and EC control. Various techniques have been developed to further increase oxygenation of the nutrient solution. Two separate return pipes can be arranged to enter the catchment tank at right angles to each other so that the nutrient solution streams converge well above the solution in the tank. Also, instead of discharging the nutrient solution into the catchment tank through an open-ended pipe, a tee or other pipe modifications can be used to encourage dispersion. A more deliberate attempt to increase mixing and aeration of the nutrient solution in the catchment tank involves the direct return, under pressure, of some of the nutrient solution pumped by the main circulation pump. As with every component in contact with the nutrient solution, the main pump should be capable of handling corrosive solutions, and therefore stainless steel or plastic-bodied pumps should be used. Self-priming pumps are preferable, but avoid the submersible types because they eventually corrode and can cause failure. Use several smaller pumps instead of a single large one so that a flow of solution is maintained even when one pump fails. Also, a spare pump can be activated by a pressure-sensitive switch if the main one fails and the pressure in the system drops. To guard against total power failure, a stand-by generator is essential for large installations and for areas that experience frequent and extended blackouts. A small operator might be able to avoid the extra cost of a stand-by generator by connecting the main water supply through a one-way valve to the NFT system, which at least allows the crop to receive plain water during a power interruption. This approach, however, should be viewed only as an added safety feature built into the NFT system rather than as a first line of defence against power and pump failures.

Supply the catchment tank with an overflow of at least the same capacity as the maximum rate of the nutrient solution being returned from the crop to the catchment tank. Although providing an overflow might seem expensive and complicated, it is absolutely necessary as a last resort to avoid disastrous floodings when all other safety measures to keep the nutrient solution flowing fail.

Fertilizers and acid are normally added into the catchment tank in the. form of concentrated stock solutions. The dosimetric pumps used to inject nutrients and acids into the catchment tank should be chemically resistant-at least in those parts that come in contact with the relatively concentrated solutions. Two pumps are needed for fertilizerand one for acid; their size depends on the size of the operation, but most growers need an average capacity of 10 L/h. The two nutrient pumps used for fertilizer injection should be adjustable so that they can be set to deliver exactly the same volume of liquid. The operation of the fertilizer and acid injection pumps is regulated by their respective controllers. In large installations it might be more economical to replace the dosimetric pumps with solenoid valves that control the gravity-driven flow of stock solution. Several suppliers now have available complete nutrient and acid dosing sets in ready-to-use packages. However, growers can easily assemble tailor-made systems that suit individual needs because most of the needed components are widely available. In addition to the three dosimetric pumps, salinity and pH controllers are also required. A salinity controller provides the best method for determining the salt concentration by measuring and controlling the electrical conductivity (EC) of the solution, This method is based on the principle that the electricity conducted between two electrodes, immersed at a fixed distance (usually 1 cm) in a solution, is proportional to the total ionic (salt) concentration in that solution, The EC controller monitors and displays the conductivity of the nutrient solution and activates the metering (dosimetric) pumps when the measured conductivity falls below a preset value and only until the measured value is restored to the preset value. Electrical conductivity is usually reported in either microsiemens per centimetre (μS/cm) or micromho per centimetre (μmho/cm). Other units and conventions are used occasionally to express electrical conductivity (EC), but the relationships between them are straightforward: for example, 1 milliSiemen (mS) = 1 millimho (mmho) = 1000 microSiemens (μS) = 1000 micromho (μmho) = 10 conductivity factor (CF) units; reference to centimetres is usually omitted, but implied. The cells (sensors) used in conductivity measurements are encased in plastic, which makes them sturdy, requiring only minimal maintenance. Two main types of conductivity cells are available: a dip cell suspended in the solution and suitable for small installation; and a flow-through type cell incorporated in the pipeline. In the latter case a sampling loop is arranged by returning some of the main circulating pump's output solution directly back into the catchment tank after it has passed through the conductivity cell. The electrical conductivity of a solution increases by about 2% for every degree Celsius that the temperature increases. The conductivity controller should therefore be equipped with automatic temperature compensation, a standard option in most conductivity controllers. A general recommendation for the optimum conductivity setting on the salinity controller is difficult to provide because the setting varies according to the cultivar grown, the season, the stage of growth, and the quality of the water. A grower should first measure the electrical conductivity of the water (assume an x reading is obtained) and set the salinity controller at $x + 1500$ μS; a balanced nutrient solution suitable for the growth of most plants has a conductivity of about 1500 μS. Where the water supply contains nutrients in excess of plant requirements, or where the fertilizers are not supplied in a ratio proportional to nutrient uptake by the crop, a buildup of certain nutrients inevitably results. Nutrients that can accumulate over time include calcium (from hard water), sulfate (from fertilizers), sodium and chloride (from saline water), and possibly others. Under these conditions the background conductivity rises progressively, and proportionate increases in the EC setting of the salinity controller are necessary to maintain an adequate nutrient supply Unfortunately, no simple and practical procedure is available to determine the changes in background conductivity; the nutrient solution should therefore be discarded periodically and a new solution be brought into the system. The frequency with which the nutrient solution should be renewed depends on the stage of crop growth and the season, since both factors affect the rate of nutrient and water uptake by the crop. Generally, the solution should be renewed every month at the beginning of a crop and twice a month later, when the crop is fully grown, or whenever the crop appears to have stopped growing. As the grower gains experience with the system, the solution may be renewed less frequently. When the NFT operation is being established, weekly chemical analysis of the nutrient solution is essential for crop safety and for familiarizing the grower with the operation; as the grower gains experience, less frequent analysis can be conducted, e.g., twice a month. The pH of the nutrient solution also has considerable influence on crop growth and is continually monitored and controlled; a pH range of 5.5-6.5 is acceptable. Avoid values below 5; a pH below 4 damages most crops. At the other end of the pH range, the availability of trace, or minor, elements (except molybdenum) decreases when the pH rises above about 6.5, establishing the upper limit of a desirable pH level in the solution. Where the main source of nitrogen is nitrate or where the pH of the water is high (> 7.01, the pH of the solution rises during cropping; a control system consists of a pH monitor-controller and ameteringpump that adds an acid, usually phosphoric or nitric. However, when a significant portion of the nitrogen is supplied as ammonia and the buffering capacity of the water is low, the pH can drop below the lowest value acceptable and a base, such as sodium hydroxide, might have to be added to raise the pH to within the acceptable range. Both acids and bases can cause serious burns to workers if handled carelessly; always wear protective clothing, masks, and glasses when handling these chemicals. The concentrated acids as purchased should be diluted at a ratio of 1:10 or preferably 1:20 before use; the exact concentration required varies according to the capacity of the metering pump or solenoid and the size of the catchment tank. When **diluting** concentrated chemicals, always add the acid or base to the water; never add water to a concentrated acid or base because the solution could get overheated and explode, causing serious burns. For large installations seek the advice of a chemical engineer who specializes in designing the proper storage and handling procedures for dangerous chemicals.

A great variety of safety devices and precautions are available to guard against failure of the pH and salinity controllers, Timers are routinely installed that can override either of the two controllers and prevent the continuous addition of fertilizer or acid to the solution for periods that exceed a normal, expected time span. Also, small tanks for the stock and acid solutions can be used, so that the crop would not be damaged, even if all their contents were added to the catchment tank; the disadvantage of this approach is that the stock solution tanks must be topped up regularly

Experiments at the Glasshouse Crops Research Institute (GCRI) in Littlehampton, England, have shown that plants grown with the NFT technique can tolerate a wide range of nutrient concentrations. For example, in one of their studies no significant loss of yield was found when the nitrogen (as NO_3^-) concentration was reduced from 320 to 10 ppm, provided that the concentrations were effectively maintained. In commercial practice, however, a high nutrient concentration is preferred because it ensures an adequate reserve of nutrients within the system. In addition, a concentrated solution is sometimes useful in controlling excessive crop growth by exerting an osmotic stress.

Some general recommendations, based on commercial experience and on research carried out at GCRI, are available on the optimum concentration of nutrients in the NFT solution; they are summarized in Table 20.

On the basis of the nutrient content of the water supply, two major recommendations are available regarding the composition of the NFT fertilizer and acid-concentrated stock solutions. The fertilizer concentrates given in Table 21 apply to areas with a moderately hard water supply, with alkalinity in excess of 100 ppm calcium carbonate equivalent.

Table 20 Target nutrient levels in NFT solution for tomato cropping

Element	Minimum* (pH 5.5, EC 1800 µS)	Optimum (pH 6.0, EC 2000-2500 µS)	Maximum (pH 6.5, EC 3500 µS)
Nitrogen nitrate (NO_3^-)	50	150-200	300
Nitrogen ammonium (NH_4^+)	5	10-15	20
Phosphorus	20	50	200
Potassium	100	300-500	800
Calcium	125	150-300	400
Magnesium	25	50	100
Iron	1.5	6	12
Manganese	0.5	1	2.5
Copper	0.05	0.1	1
Zinc	0.05	0.5	2.5
Boron	0.1	0.3-0.5	1.5
Molybdenum	0.01	0.05	0.1
Sodium	†	†	250
Chloride	†	†	400
Sulfur	–	50–200	–

* Concentrations listed as minimum should be regarded as the approximate lower limit of a preferred range; in general, these minimum values are above those at which symptoms of deficiency develop.

† As little as possible.

Where routine analysis of the nutrient solution shows that calcium has accumulated in the solution, it might be necessary to reduce the amount of calcium nitrate in stock solution 1. For each kilogram of calcium nitrate omitted from solution 1, increase the potassium nitrate by 0.86 kg, to compensate for the NO_3^- lost in the reduction of calcium nitrate; and decrease the potassium sulfate by 0.74 kg, to counterbalance the increase in potassium because more potassium nitrate was added. The water supply could contain enough calcium, i.e., more than 120 ppm, to preclude the addition of calcium nitrate.

However, in areas where the water supply has an alkalinity of less than 100 ppm calcium carbonate equivalent, the calcium nitrate in stock solution 1 must be increased. The fertilizer formula then takes a new form, as shown in Table 22.

The grouping of fertilizers and acids in Tables 21 and 22 can be altered to include some or all of the potassium nitrate in stock solution 1, which might be desirable when little calcium nitrate is used. Also, when the acid requirement is known from previous experience, a proportion of it should be included (but only as nitric) in stock solutions 1 and 2. This practice has the dual benefit of preventing precipitates in stocks 1 and 2 and allowing the nitrogen content of the nitric acid to be taken into account when formulating stock solutions. In fact, fertilizers can be grouped into stock solutions in a variety of ways, the only limitation being that calcium be kept apart from phosphate and sulfate.

The formulas in Tables 21 and 22 are a good example of how the composition of the nutrient concentrates may be varied for particular purposes. For beginners who cannot or do not wish to prepare their own stock solutions, various commercial nutrient formulations are available. Obviously, these commercial products are likely to be made for universal application and might not be the ideal choice for every crop, but they have given good general results. However, commercial growers with a significant portion of the tomato crop in NFT should make every effort to obtain basic fertilizers and mix them to provide the plants with the best nutrient mix according to the latest research findings. Table 23 constitutes the latest fertilizer feeding recommendations for NFT tomato cropping at the time of writing.

Table 21 Fertilizer formulation for use with NFT in hard-water areas*

Stock solution 1 (1000 L total volume)	Stock solution 2 (1000 L total volume)	Stock solution 3 (1000 L total volume)
50 kg calcium nitrate	80 kg potassium nitrate 40 kg potassium sulfate 60 kg magnesium sulfate 0.6 kg ammonium nitrate 3.0 kg iron chelate (15% iron) 0.4 kg manganese sulfate 0.2 kg boric acid 80 g copper sulfate 40 g zinc sulfate 10 g ammonium molybdate	54 L nitric acid (67%) 24 L phosphoric acid (85%)

[*] No phosphatic fertilizer has been included other than the phosphoric acid in stock solution 3. Where the water is not particularly hard and the acid requirement, is correspondingly low, include 1.5 kg of monopotassium phosphate in stock solution 2 while decreasing the amount of potassium sulfate from 4.0 to 3.0 kg.

Note: Assuminga dilution ratio of 1:100 for stocksolutions 1 and 2, the theoretical nutrient, concentrations in the circulating diluted NFT solution are as follows, in parts per million:

Nitrogen”	192
Phosphorus?	
Potassium	490
Magnesium	59
Calcium*	85
Iron	4.5
Manganese	1
Boron	0.4
Copper	0.2
Zinc	0.09
Molybdenum	0.5

[*] Additional nitrogen is supplied by the nitric acid of stock solution 3.

[†] Some phosphorus is supplied by the phosphoric acid of stock solution 3.

[‡] The calcium content of the water supply has not been taken into account,

Table 22 Fertilizer formulation for use with NFT in soft-water areas

Stock solution 1 (1000 L total volume)	Stock solution 2” (1000 L total volume)	Stock solution 3 (1000 L total volume)
7.5 kg calcium nitrate	90.0 kg potassium nitrate	7.9 L nitric acid (85%)
	30.0 kg monopotassium phosphate	
	60.0 kg magnesium sulfate	
	3.0 kg iron chelate (15% Fe)	
	0.4 kg manganese sulfate	
	0.24 kg boric acid	
	80 g copper sulfate	
	40 g zinc sulfate	
	10 g ammonium molybdate	

* It may be necessary to slightly acidify stock solution 2 with a small amount of nitric acid (20 mL) to prevent salt precipitation, e.g., magnesium phosphate.

Note: Assuming a dilution ratio of 1:100 for stock solutions 1 and 2, the theoretical nutrient, concentrations in the circulating, diluted, NFT solution are as follows, in parts per million:

Nitrogen”	214
Phosphorus	68
Potassium	434
Magnesium	59
Calcium‡	128
Iron	4.5
Manganese	0.4
Boron	0.2
Copper	0.09
Zinc	0.09
Molybdenum	0.09

* Additional nitrogen is supplied by the nitric acid of stock solution 3; however, the amount, is small because the amount of acid needed to control the pH of soft, water is far less than that required for hard water.

‡ The calcium content of the water supply has not been taken into account,.

Table 23 Recommended nutrient solution for tomatoes in NFT (amount of fertilizer per 1000 L of stock solution)

Stock solution 1 (1000 L total volume)	Stock solution 2 (1000 L total volume)
99.0 kg calcium nitrate	49.7 kg magnesium sulfate
65.8 kg potassium nitrate	27.2 kg monopotassium phosphate
	3.0 kg iron chelate (13% iron)
	0.5 kg manganese sulfate
	180.0 g boric acid
	30.0 g copper sulfate
	35.0 g zinc sulfate
	8.0 g ammonium molybdate

- Prepare the final solution by adding equal volumes of both stock solutions in water until a recommended final solution EC of 2200 µS/cm is achieved; adjust the pH to 6.2 by adding phosphoric (low-light conditions) or nitric (high-light conditions) acid. Ideally, stock solutions are mixed and pH is adjusted automatically by electrical conductivity and pH controllers.
- When starting a new crop, begin with an EC of 1500 µS/cm and gradually increase to 2200 µS/cm over a week.
- A background EC of 300-600 µS/cm from the water supply is assumed.