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Commercial Production of Greenhouse Tomatoes

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Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides when there is danger of drift, when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

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tention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

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NOTE: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the U.S. Department of Agriculture, consult your county agricultural agent or State Extension specialist to be sure the intended use is still registered.



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COMMERCIAL PRODUCTION OF GREENHOUSE TOMATOES^{1, 4}

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Tomato production in greenhouses is one of the most technical and intensive of agricultural enterprises. It can be very profitable if the available technical information and the many facets of the science of growing greenhouse tomatoes are thoroughly understood and practiced.

Greenhouse culture permits winter tomato production, and provides the opportunity for precise control of plant growth by regulating soil moisture, soil fertility, temperature, humidity, and other factors.

A greenhouse grower should have a thorough understanding of how the basic factors of sunlight, temperature, water, carbon dioxide, and nutrition affect plant growth. He should also learn about the diseases and pests that affect greenhouse tomatoes to be able to anticipate trouble and to control it. A successful greenhouse operator must also be a good businessman. He needs to keep accurate production records and to know marketing practices. In addition, a greenhouse grower should understand the plumbing, mechanical, electrical, and heating equipment used. Finally, and perhaps

most difficult of all, a greenhouse operator must learn to apply to practical situations the technical information available to him. This can be learned only through actual experience in greenhouse culture.

In recent years the volume of greenhouse-grown tomatoes has increased steadily in this country. The increase is attributed partly to the development of plastic and fiberglass materials that can be used in greenhouse construction. Greenhouses covered with these materials are less expensive to build than those covered with glass.

Nearly every State has some commercial greenhouse tomato production. In 1966, Ohio led with about 600 acres of tomatoes under glass or plastic. Indiana had about 100 acres; and Massachusetts, Michigan, Illinois, New York, Texas, and Missouri each had more than 25 acres. Although tomato greenhouses are widely scattered, the largest concentrations are near the following cities: Cleveland, Boston, Indianapolis, Cincinnati, Toledo, Terre Haute, Grand Rapids, Kansas City, and Rochester.

LOCATING A COMMERCIAL GREENHOUSE

Several factors should be considered when selecting a site for a greenhouse. Proximity to a good market is of prime importance. Growing tomatoes close to the market saves transportation expense and reduces transit time, thereby helping the grower to market the highest quality, vine-ripened product.

¹This Agriculture Handbook supersedes Farmers' Bulletin 2082, "Commercial Production of Greenhouse Tomatoes."

The area selected should have a high percentage of sunshine during the fall and winter days if a fall tomato crop is to be grown. It is possible, however, to grow tomatoes successfully in areas subject to much cloudy weather. A site fully exposed to sunlight, but protected from winds and storms by windbreaks, will save fuel and greenhouse maintenance costs.

Greenhouses should also be situated close to adequate supplies of fuel, good water, and

power. If natural gas is readily available at a relatively low cost, it is usually the cleanest and most economical fuel. When natural gas is not available, fuel oil, coal, or electricity must be used. Since large quantities of water are required to grow a tomato crop, an adequate supply of good-quality water is particularly important.

Greenhouses for tomato production should be built on sites with a fertile, medium-textured, well-drained soil. An area with a high water table should be avoided. The site should also have good air drainage to prevent polluted and moisture-laden air from persisting around the greenhouse. Moist air encourages the development of foliage diseases. The extent of air-pollution damage to tomatoes is not known, but an area free from smoke and gases is recommended. It is known that gases such as sulfur dioxide and carbon monoxide damage tomato plants when present in sufficient quantities.

Land for greenhouses should be carefully graded and leveled. This is important for

maintaining uniform temperature and humidity throughout the greenhouse. Pockets of cool air or high humidity may develop when the site is not level.

A plentiful supply of dependable labor is especially important, because of the large amount of hand labor required in growing greenhouse tomatoes. Also, consideration should be given to the possibility of future expansion. If expansion is anticipated or even remotely possible, adequate space should be set aside and the original house built so that additional construction is convenient.

The orientation of a greenhouse has little effect on growing tomatoes in this country. A north-south direction provides a more uniform distribution of light throughout the year and enables the construction of headhouses at the north end of the range. Greenhouses constructed in an east-west direction with the crop rows running north and south provide the best exposure to sunlight during short winter days.

TYPES OF GREENHOUSES

Greenhouses for tomato production may be covered with three basic types of material: (1) Glass; (2) soft, pliable plastic films; or (3) rigid plastic or fiberglass. Tomatoes can be grown equally well in houses covered with any of these materials, although management practices may vary somewhat. For example, plastic houses are usually more nearly airtight than glass houses, therefore, ventilation may be more critical. The relative cost of the materials, the prevailing environmental conditions, the anticipated life expectancy of the structure, and the personal preferences of the grower will determine the type of greenhouse to be constructed.

Glass

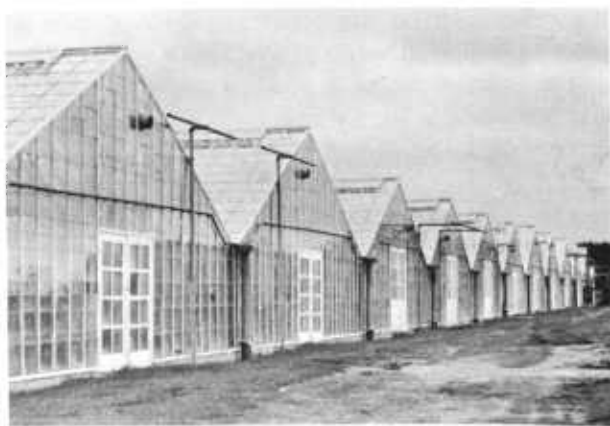
Glass-covered greenhouses are the most durable of all types. They are less subject to damage from high winds and heavy snow loads than most plastic greenhouses. Glass greenhouses are considered permanent structures with permanent walks, heating systems, and other internal features. Since they are permanent, they can be insured. In some respects,

growing tomatoes in a glass house may require less exacting management than growing them in plastic greenhouses.

High initial cost is the primary disadvantage of a glass greenhouse. Also, as permanent structures, they usually have a higher tax assessment than plastic greenhouses. Another disadvantage of glass houses is that they are subject to damage from hail or rocks. In areas where hailstorms are common, glass houses are not recommended.

Glass greenhouses for tomato production are usually constructed with truss-supported, even-spanned roofs. An example of such houses is shown in figure 1. Where more than one house is used, they may be built separate or as ridge-and-furrow houses. Ridge-and-furrow houses are two or more even-span houses built together. The inner gutters may or may not have side walls. Uneven-span and lean-to greenhouses are used occasionally.

The frame of a glass house may be constructed of wood, steel, or aluminum. Older greenhouses usually have wooden rafters and



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FIGURE 1.—A range of glass greenhouses used for tomato production.

steel purlins and posts. Aluminum has replaced steel and wood in most new greenhouses because it is lighter in weight and requires no maintenance. Wooden and steel parts require repainting about every 3 years on the outside and every 7 years on the inside. Another trend in greenhouse construction is to use wider rafter spacing and therefore wider glass panes. In older houses, 18-inch glass was standard, but 24-inch glass is now common. Wider rafter spacing allows more light to enter the greenhouse.

The size of a greenhouse may range from a few hundred square feet to more than an acre. The primary consideration should be for its proper management and the convenience of working in the house. For example, if tomato rows exceed 100 feet in length, harvesting may be inefficient because baskets of fruit must be carried long distances. The greenhouse should be 8 to 8-1/2 feet tall at the sides to allow ample growing room for tomato plants. For more specific details on greenhouse construction, one should contact a supplier of commercial greenhouses.

Internally, greenhouses are usually empty of benches or other obstructions, because tomatoes are most commonly grown in ground-level beds. In the past, raised benches were used somewhat, but their use has declined primarily for economic reasons. Ground beds can be more easily prepared with power equipment and, because tomatoes grow 6 feet or more in height, they are easier to train, prune, pollin-

ate, and harvest in ground-level beds. Certain growing techniques do require troughs or tanks, and these are described in the section on Cultural techniques.

Practically all glass greenhouses are heated by a central steam or hot-water boiler system. The steam may also be used to sterilize the plant beds, flats, and equipment. Small greenhouses, or those in areas where little heat is required, may use natural-gas or fuel-oil heaters or furnaces. With such heaters, provision must be made to circulate the warm air to maintain uniform temperature throughout the house. Fans or perforated plastic tubes running the length of the greenhouse may be used to distribute the warm air.

To prevent buildup of high humidity, which encourages disease epidemics, and to control high temperature, greenhouses must have adequate ventilation. Permanent glass houses usually have ventilators in the sides and/or ridges. Sometimes large, perforated plastic tubes like those used for distributing heat are suspended in the greenhouse and used for ventilation. A fan at one end of the tube pulls the air into the tube through the perforations and then through the length of the tube and out the end of the greenhouse.

Many greenhouses are equipped with heating and ventilation equipment designed to be controlled automatically or manually. Also, some growers devise or purchase systems with which the temperature and humidity at various points in the greenhouse can be monitored and adjusted from a single location. Such sophisticated equipment aids the grower in maintaining precise control over his crop and frees him for other tasks.

In areas where high fall and spring temperatures are common, such as the Southwest, forced cooling may be needed for satisfactory yields of high-quality fruit. The most satisfactory and economical system for cooling greenhouses is the fan-and-wet-pad system, which works by evaporative cooling. With this system, it is possible to reduce the temperature by about 80 percent of the difference between wet-bulb and dry-bulb temperature readings.

The fan-and-pad system uses a series of wood-fiber pads installed vertically on one side

of the greenhouse and large exhaust fans on the opposite side. The exhaust fans draw air through the pads, which are kept wet by continually circulating water. The moist air coming through the pads is cooled by evaporation of the water.

A common method of watering is overhead sprinkling, using a permanent system of overhead pipes and nozzles. The primary advantage of this method is that the pipes do not interfere with soil preparation, planting, and other operations. Also, large areas can be watered at one time. A serious disadvantage of overhead watering is that the plant foliage becomes wet, and this creates conditions favorable for the development of diseases such as leaf mold.

Surface or near-surface watering is also widely used. This may be done by a system of perforated pipes or hoses on the soil surface or by sprinkler pipes 6 to 12 inches above the soil surface. Such a system may be made permanent or temporary. This system has the advantage of not wetting the foliage. However, the arrangement of the pipes may interfere with soil preparation and other necessary operations. Another variation of surface watering is the use of hoses to water individual plants. This is used primarily when plants have recently been transplanted into the beds. Water-

ing with a hose involves much labor and is most practical in small greenhouses.

The least common watering system is subirrigation. Watering by this method is through a system of 3- or 4-inch drainage tiles laid end-to-end with about one-quarter inch between pieces. The tiles are buried below plow depth and spaced from 2 to 4 feet apart. The ends of the tile lines are left open so water can be conducted into them by garden hose or permanent water pipes. A disadvantage of this system is that the tiles may become clogged and no longer permit water movement through them.

Plastic Film

Greenhouses covered with plastic film can generally be constructed for one-third or less of the cost of a glass greenhouse. This makes plastic greenhouses popular with growers who are just getting established and do not have the resources necessary to construct a conventional glass house.

Plastic greenhouses usually have wooden or metal pipe frames. They may be of any of several designs (fig. 2). They are usually built as temporary structures, designed to last only a few years, and therefore maintenance costs are high. Usually, plastic greenhouses have a lower tax assessment than glass greenhouses, because they are only temporary structures.



FIGURE 2.—A small plastic greenhouse.

Plastic films suited for greenhouse construction are polyethylene, polyvinyl chloride, and polyester. Polyethylene film is the least expensive material and the least durable. When used as a greenhouse covering, it can be expected to last only one winter. Vinyl films are more expensive than polyethylene, but they may last up to 4 years. Disadvantages of vinyl materials are their attraction for dirt and dust from the air and their tendency to expand and contract with temperature changes. Polyester film is slightly more expensive than vinyl and may have a useful life of 2 to 5 years. Several State agricultural experiment stations have bulletins available that discuss in detail various plastic materials and their use in greenhouse construction.

Plastic greenhouses may be of several different designs, including A-frame, scissors-truss, truss-rafters, center-post, rigid-frame, gothic-arch, quonset, panel, ridge-and-furrow, and air-supported houses. Whichever design is used, consideration should be given to maximum light penetration, easy ventilation, and adequate heating.

On the inside, plastic greenhouses for tomato production are quite similar to glass houses. The type of heating system best suited for a greenhouse depends on the size and design of the house and the climate of the area where the greenhouse is located. The heating system must be able to maintain a minimum temperature of 60° F. on the coldest nights and must release no toxic gases into the greenhouse.

Heaters used in plastic greenhouses include temporary convection-type heaters or space heaters, unit heaters installed in the peak of the house, forced warm-air furnaces, and steam or hot-water boilers. For large greenhouses, a boiler system is probably best. However, for smaller greenhouses the first three types are usually preferred. Liquified petroleum (LP) gas, oil, or natural gas can be used as fuels for heating plastic houses. It is very im-

portant that all heaters and furnaces be vented to the outside. During combustion of the fuel, fumes are released that may injure the plants in the greenhouse.

Ventilation of plastic greenhouses may be by ridge or side ventilators, removable panels, or by exhaust fans installed in the sides or ends of the house. Designing a plastic house with ventilators complicates construction and makes the house more expensive. Thermostat-controlled fans are the easiest way to ventilate. The fans should be large enough to provide a complete exchange of air every 1 to 1-1/2 minutes, as is necessary during warm weather.

Ventilation tubes as described for glass houses are particularly good for ventilating plastic houses during cold weather. With such tubes, cold outside air is brought in through the tube suspended in the peak of the greenhouse and not directly onto the plants. The fresh air mixes with the inside air without causing cold drafts on the plants.

Watering in plastic greenhouses is generally by hose or by some temporary soil-surface system.

Rigid Vinyl or Fiberglass

Greenhouses covered with rigid panels of polyvinyl chloride (PVC) or fiberglass are satisfactory for tomato production. The durability of these materials may range from 2 to 20 years, depending on the quality. PVC panels and cheaper grades of fiberglass may discolor so badly that they no longer allow satisfactory plant growth. PVC is also quite susceptible to hail damage and should not be used in areas where hailstorms are common. A serious peril of fiberglass is its susceptibility to fire.

The rigid materials are usually used on permanent structures, and may be as expensive to build as a glass greenhouse. The frame, heating, ventilation, and watering for such a house are similar to those discussed for glass greenhouses.

CULTURAL TECHNIQUES

Ground Beds

Greenhouse tomatoes are most commonly grown in ground beds (fig. 3). Ground beds can

be easily prepared with power equipment. Since tomatoes grow 6 feet or more in height, it is easy to train, prune, pollinate, and harvest



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FIGURE 3.—Greenhouse tomato plants growing in a soil bed.

them when they are grown in ground-level beds.

The primary disadvantage of growing in ground beds is the difficulty in controlling soil-borne diseases. Even in greenhouses equipped with permanent steam tile for sterilization, it is not possible to steam deeply enough to kill all disease-producing organisms. Also, sterilizing greenhouse beds is expensive.

Production potential in ground beds is limited if a greenhouse is built on a site with poor soil. The soil should have good physical properties and an initially high level of fertility. If the greenhouse soil does not possess desirable properties, it can be improved with certain practices. Continuous efforts are necessary to maintain even an initially good soil.

A greenhouse soil for tomato production should possess good drainage and physical properties so it will retain moisture well, but will not become waterlogged and lack aeration.

Such a soil allows the good root growth that is essential for good yields.

Loam to silt-loam soils are favored over heavier or lighter soils. Loam soils retain moisture, yet drain well enough to allow good aeration. Heavy clay soils hold water too tenaciously, but sandy and gravelly soils do not hold enough water. Without proper water management, plants growing on light sandy soils may be subjected to moisture stress that may cause blossom-end rot. On the other hand, overfertilization and salt accumulation are not likely to be serious problems on light soils, since the soil can easily be leached with heavy waterings. Heavy soils require closer management of fertilization practices, since they cannot be leached readily.

Greenhouse soils lacking desirable physical properties can be improved by incorporating organic material into them, or additional soil can be brought in from the outside to build up above the natural grade. Manure, if available, is a good source of organic matter, as are the organic mulches commonly used as ground covers when growing greenhouse tomatoes. These materials are incorporated into the soil before planting and allowed to decompose. Fine-textured soils require more organic matter than coarse-textured soils to keep them loose and friable.

The depth of a greenhouse soil is important, because tomato roots may penetrate as deeply as 6 feet. When a clay hardpan lies near the surface, root growth is restricted and water drainage is prevented. A natural water table close to the surface is also undesirable. The grower can no longer control a plant's growth by adding or withholding water after its roots grow into permanent water.

The nutritional level of soil can be determined by soil tests. These should be made at regular intervals during the growth of each crop. Deficiencies are corrected by the addition of appropriate chemical fertilizers. Soils with initially high fertility levels must be fertilized periodically, because tomatoes remove large amounts of nutrients from the soil. Chemical fertilizer programs and soil testing will be discussed in more detail in the section on Plant Nutrition and Fertilization.

A greenhouse soil for tomatoes should be slightly acid, with a pH of 6.0 to 6.7. Again, a soil test is necessary to determine the acidity of the soil. If the soil is too acid and lime must be added, dolomitic limestone should be used instead of calcitic limestone to supply magnesium to the soil. Limestone should be spread before the soil is prepared and should be worked in thoroughly during preparation.

Trough Culture

Trough culture is a system of growing tomatoes in a trough containing natural soil or an artificial medium. The troughs or trenches may be scooped out of greenhouse beds or constructed with lumber and lined with plastic film.

The troughs are filled with 4 to 6 inches of soil or an artificial soil mix such as vermiculite and sphagnum peat moss, and plants are planted directly into the soil. Some plant nutrients are available from the soil initially, but most of the nutrients must be supplied periodically in water solution.

The primary advantage of trough culture is that complete sterilization is possible, therefore, fewer problems with plant diseases are encountered. The plastic film lining the troughs restricts the plant roots to the disease-free soil in the trough. Restriction of root growth also permits better management of early plant growth. Trough culture also allows for complete control of the nutrient supply to the plants and the water drainage.

A disadvantage of this system is the initial cost of constructing the troughs and periodically replacing the soil. If an artificial soil mix is used, it may be reused for several seasons if it is sterilized after each crop.

Ring Culture

Ring culture is similar to trough culture except that the plants are planted into a bottomless pot or "ring" containing soil or growing medium (fig. 4). The "ring" of soil is set on a bed or trough like those described in the previous paragraphs. Plants grown in ring culture are able to obtain nutrients and water from both the soil in the ring and the underlying soil.



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FIGURE 4.—Greenhouse tomato plants growing in ring culture.

The rings may be made of clear or black polyethylene or roofing paper. Polyethylene rings, specifically for tomato growing, can be purchased.

Ring culture has the same disadvantage of initial cost as trough culture, plus the added expense of buying the rings and the labor required to prepare them.

Hydroponics

Hydroponic culture is a system of growing plants without soil. The plant roots are anchored in sand, gravel, or some other relatively inert medium. All nutrients are supplied in water solution. Except that no soil is used, and all plant nutrients must be provided, hydroponic growing is essentially like growing by any other technique. With proper management, the yield and quality of fruit produced by hydroponics will be similar to that obtained with soil culture.

The primary advantage of hydroponic culture is that it can be used where soil is lacking or is unsuitable for plant growth. Other advantages are the exact nutritional control that is

possible and the decreased chance of encountering soilborne diseases.

The initial cost of a hydroponic greenhouse is high, because beds, tanks, and pumps are required in addition to the structure itself. Also, this equipment must be maintained. Hydro-

ponic culture does eliminate tillage and mulching, but it is still necessary to sterilize the beds and gravel. Precise control of pH and proper timing of the addition of nutrients is critical with this system and must be closely supervised and managed.

PLANT NUTRITION AND FERTILIZATION

Greenhouse growers in the past relied primarily on animal manure to supply the essential mineral elements needed for plant growth. Today growers must depend almost entirely on chemical fertilizers. Enough fertilizer must be used to provide plant nutrients for a maximum crop without carrying over excessive amounts to the next crop. Excess fertilizer in the soil can interfere with tomato plant growth and fruiting. The three major elements required for plant growth are nitrogen, phosphorus, and potassium. Other elements required in very small amounts are iron, magnesium, manganese, boron, calcium, copper, molybdenum, sulfur, chlorine, and zinc. These essential elements must be available to the plants regardless of the cultural technique being employed.

The pH or acidity of the soil, or the nutrient solution in hydroponic systems, is very important to plant growth. A pH value between 6.0 and 6.7 is considered most favorable for the growth of tomato plants. The pH values range from 0 to 14. A neutral soil has a pH of 7.0. Values below 7.0 indicate acidity, and values above 7.0 indicate alkalinity.

When soil becomes too acid, the phosphorus in it may be changed to a more insoluble form, the compounds that supply calcium and magnesium may be deficient, and the nitrogen-fixing bacteria in the soil may fail to thrive. On the other hand, when the soil is too alkaline the phosphorus changes to another insoluble form, the nitrogen-fixing bacteria do not thrive, and the compounds that supply potassium, manganese, iron, and boron form insoluble substances.

To determine the nutrient levels and the pH of soil, laboratory tests must be conducted. All State agricultural experiment stations except California and Illinois provide soil-testing services for residents of the State. Some States

also provide plant-tissue testing services. Along with the test results, interpretations of results and suggestions for corrective measures are usually provided. Many commercial laboratories and fertilizer companies also run soil and tissue tests. In addition, kits are available that allow the grower to make his own soil analysis and to analyze plant tissue for nitrogen content. These kits are simple to use and can be valuable tools if the user learns to interpret the test results correctly.

Fertilizers

A crop of tomatoes that yields 75 tons of fruit per acre can be expected to remove from the soil approximately the following amounts of nutrients per acre: Nitrogen 250 to 350 pounds; potassium 550 to 700 pounds; phosphorus 75 to 150 pounds; calcium 250 to 300 pounds; and magnesium 50 to 75 pounds. Minor elements are removed in smaller quantities.

Many types of fertilizers are available for greenhouse use. These include materials that contain all three of the major elements in various ratios. Examples of commonly used fertilizers are 10-52-17, 5-10-10, 10-10-10, 15-15-15, 20-20-20. In these designations, the first number indicates the percentage of nitrogen, the second of available phosphoric acid, and the third of water-soluble potassium. These fertilizers are available in both water-soluble and dry forms.

Some fertilizers supply only 1 or 2 of the major elements. Some nitrogen supplements and their grade are ammonium nitrate 33-0-0, calcium nitrate 15-0-0, sodium nitrate 15-0-0, and urea 45-0-0. Phosphorus supplements are monoammonium phosphate 11-48-0 and diammonium phosphate 21-53-0. Potassium supple-

ments are muriate of potash 0-0-60, sulfate of potash 0-0-48, and potassium nitrate 13-0-44.

The essential minor elements required are usually present in soil in sufficient quantities but may be deficient in some soils. Commercial fertilizers containing a mixture of all of the necessary trace elements are available for application to the soil or as foliar sprays. Many of the fertilizers for supplying the three major elements also have the trace elements added.

Fertilization Programs

Some growers prefer to establish a routine fertilization schedule in their greenhouses. Periodic soil or tissue analyses are made to check on the adequacy of the program. Others rely more heavily on soil and tissue tests and fertilize only when the tests indicate a need for a particular element. In these greenhouses, samples for analysis may be taken at weekly or biweekly intervals.

In developing a fertilization program, the soil type, the use of manure and mulches, and the cropping plan should be considered. A routine fertilization schedule is usually planned so that the phosphorus and potassium are applied in the summer or at the time of soil preparation. Nitrogen fertilizer is then applied only as it is needed by the growing plants. Growers who fertilize only when soil or tissue tests indicate a need for certain elements often use water-soluble fertilizers and apply them with the irrigation water. Soluble fertilizer is usually used also by hydroponic and trough-culture growers.

For a routine fertilization program, one recommended schedule for 1,000 square feet is 25 to 45 pounds of 0-20-20 applied before a fall crop and 15 to 25 pounds of 0-20-20 applied before a spring crop. Phosphorus may also be added as 46-percent triple superphosphate at a rate of 10 to 15 pounds per 1,000 square feet of bed or as 20-percent superphosphate at 25 to 30 pounds per 1,000 square feet. Potassium can be added as potassium sulfate at a rate of 20 to 25 pounds per 1,000 square feet of bed. Ammonium nitrate, sodium nitrate, calcium nitrate, and potassium nitrate are used for side-dressing to supply nitrogen throughout the season. Plant tissue tests may be used to deter-

mine when nitrogen fertilization is needed. Waiting until visual symptoms are apparent to detect deficiencies will reduce yields. It also requires experience since several elements have similar deficiency symptoms.

The number of supplemental applications of nitrogen fertilizer depends partly on the amount of organic matter in the soil. Growers who follow a schedule usually make the first application as soon as three fruit clusters have set. Usually two to three applications of 6 to 7 pounds of sodium nitrate or 3.5 pounds of ammonium nitrate per 1,000 square feet of bed are enough for a spring tomato crop. For a fall crop, one application of nitrogen fertilizer is usually enough.

One of the most common mistakes made by greenhouse growers is excessive nitrogen fertilization. This causes the plants to grow too large and vegetative, and fruit set is poor. Excess nitrogen is particularly serious during November, December, and January when the days are short and often cloudy. Excessive nitrogen may also carry over from crop to crop. Nitrogen carryover may be reduced by plowing several tons per acre of undecayed cellulose material into the soil before planting another crop. Crushed corncobs or weathered sawdust may be used for this purpose.

Deficiency Symptoms

As a supplement to soil and foliar analysis, visual recognition of deficiency symptoms may be important. Deficiency symptoms are given below for the essential elements required for plant growth:

Nitrogen.—Slow stunted growth; leaves becoming pale green, then yellow, especially the older leaves; reduced fruit size.

Phosphorus.—Slow growth; slender stems; dull purple color on leaf blades and stems, especially on the underside; delayed maturity.

Potassium.—Curling, bronzing, and dying of leaf margins, especially the older leaves; some brown spots throughout the leaves; uneven ripening of fruit, inside of fruit not solid.

Calcium.—Death of growing point and die-back of main stem; new leaves chlorotic while old leaves remain green; new growth not turgid; fruit breakdown at blossom end.

Magnesium.—Chlorosis between veins of old leaves while veins remain green; chlorotic areas turning brown and dying.

Iron.—Young leaves developing light-yellow color, first between the veins and later over the entire leaf; usually no death of tissue.

Manganese.—Chlorosis, first between veins of new leaves and then spreading to the older leaves; chlorotic areas become necrotic.

Boron.—Young bud leaves and petioles light in color, and often deformed in shape; terminal buds dying and new lateral shoots appearing; leaves tinted purple, brown, and yellow; some fruit pitted with corky areas in the skin.

Molybdenum.—Mottling of older leaves while veins remain light green; new leaves green at first but becoming mottled as they expand; leaves curling inward and dying back from the tips.

Zinc.—New leaves usually small and mottled with yellow; dead areas common.

Copper.—Leaves generally chlorotic and lacking turgidity; growth of entire plant retarded.

Sulfur.—Lower leaves thick, firm, and yellow-green in color; stems woody, elongated, and spindly.

CROPPING PLANS

Greenhouse tomato production is often combined with the production of lettuce, cucumbers, or flower crops in various sequences. The markets available and the anticipated prices of the different commodities determine the crops to grow and the growing sequence.

Six possible crop sequences used by greenhouse tomato growers are given below:

Plan 1—Spring and fall tomato crop

Tomatoes.—Seed sown October 25 to November 10; plants set in houses about January 10; vines removed July 1 to August 1.

Tomatoes.—Seed sown June 15 to July 1; plants set in houses August 1 to 15; vines removed December 15 to January 1.

Plan 2—Early-spring tomato crop

Lettuce.—Seed sown August 15 to September 10; plants set in houses September 15 to 30; crop harvested October 15 to November 15.

Tomatoes.—Seed sown September 15 to 30; plants set in houses November 15 to 30; vines removed July 1 to August 1.

Plan 3—Mid-to late-spring tomato crop

Lettuce.—Seed sown August 1 to 15; plants set in houses September 1 to 15; crop harvested November 15 to 30.

Lettuce.—Seed sown October 15 to 30; plants set in houses November 15 to 30; crop harvested February 1 to 28.

Tomatoes.—Seed sown January 1 to 15; plants set in houses March 1 to 15; vines removed July 15 to August 1.

Plan 4—Fall tomato crop

Tomatoes.—Seed sown June 15 to July 1; plants set in houses August 1 to 15; vines removed December 20 to 31.

Vegetable and Flower Plants.—January to June.

Plan 5—Fall tomato crop

Tomatoes.—Seed sown July 1 to 15; plants set in houses August 15 to 30; vines removed December 15 to 31.

Lettuce.—Seed sown November 15 to 30; plants set in houses December 15 to 31; crop harvested March 15 to 31.

Cucumbers.—Seed sown February 1 to 15; plants set in houses April 1 to 15; vines removed July 1 to 15.

Plan 6—Spring tomato crop

Tomatoes.—Seed sown December 15 to January 1; plants set in houses February 1 to 15; vines removed July 1 to 15.

Flowers.—Chrysanthemums, poinsettias, or other flower crop.

The predominant cropping plans in the large greenhouse vegetable-producing areas of Ohio and Indiana are Plans 1 and 2, in which either 2 tomato crops or a lettuce crop and a spring tomato crop are grown each year. In the Northeastern States, all of the above-mentioned cropping plans and variations of them are likely to be found. In the Southwest it is common to seed between August 1 and September 1 for Thanksgiving and Christmas harvests.

Some growers use two or more plans simultaneously. For example, a grower may use his entire growing area for tomatoes in the spring, and in the fall use part of his growing area for tomatoes and the rest for lettuce.

Since tomato plants do not fully occupy the space between rows during early stages of growth, a quick-maturing crop such as lettuce is sometimes planted between the rows. When intercropping, conditions best suited for the development of the tomatoes should be maintained, even though these conditions are not ideal for the companion crop.

The prevailing environmental conditions should be studied when considering cropping schedules. For example, in practically all areas of the United States, it is not economically feasible to produce greenhouse tomatoes for harvest during January and February. The days during the preceding months are short and sunlight is usually deficient, and these conditions result in poor fruit set, slow ripening, and poor quality. Also, the cold temperatures during these months may make fuel costs prohibitive.

Competition from field-grown tomatoes should also be considered when determining a cropping plan. The cost of producing greenhouse tomatoes makes it impractical to compete with local field-grown fruit. Also, greenhouse tomatoes for August and September harvest

are not likely to set fruit well and will be of poor quality because of the high summer temperatures at which they are grown.

Generally, when a fall crop is grown, planting should be timed so that harvest starts soon after the first killing frost or when local field tomatoes are no longer available. A spring crop should be timed so that harvest begins late in winter or early in spring and terminates when field-grown fruit become available.

Other factors to consider when selecting a cropping plan are disease control and the maximum efficiency of the labor force. If two tomato crops are grown a year, it is difficult to prevent a carryover of tobacco mosaic virus from the fall to the spring crop unless the soil is sterilized between crops, and this is expensive. Even when the main growing areas are sterilized, there is a danger of transmitting the virus from one crop to the next through the young plants being started for the second crop. Another possible disease problem is a severe botrytis infection of tomatoes when lettuce is intercropped. The disease-producing organism may build up in the dense foliage of the lettuce and move onto the adjacent tomatoes if proper precautions are not taken.

To retain competent laborers on a year-round basis, it is necessary to distribute the work load throughout the year as much as possible. If a single crop a year is to be grown, it may be difficult to retain good help.

VARIETIES OF GREENHOUSE TOMATOES

Proper selection of a tomato variety assures that the genetic potential is present for the desired yield, color, size, and quality of fruit. Also, disease losses can often be averted by growing resistant varieties.

When greenhouse tomatoes were first grown in the United States, varieties from England were used. These small-fruited, free-setting varieties included Carter's Sunrise, Sterling Castle, Comet, and Best of All. These and the varieties Potentate and Ailsa Craig, developed later, were then used extensively as parents in breeding new American greenhouse varieties.

As American consumers demanded larger fruit, and new sources of disease resistance

and other desirable traits were discovered, several varietal development programs were established. From these programs such varieties as Globe, Globe Strain A, Ohio Wilt-Resistant Globe, Michigan State Forcing, Spartan Hybrid, Michigan-Ohio Hybrid, Waltham Forcing, Improved Bay State, and Waltham Moldproof Forcing were developed. Some of these varieties are still grown, but many newer releases are now available.

In the United States, market preferences greatly influence the choice of varieties grown in different regions. In the Northeastern United States, small, 3-to 4-ounce types are most popular. In most other areas, fruits

weighing 6 to 8 ounces are preferred. Preferences for color of the ripe fruit also differ. Most northern Ohio growers produce pink-fruited tomatoes, while red-fruited varieties are grown in southern Ohio.

Desirable characteristics that a greenhouse tomato should possess include:

1. The ability to set fruit and yield well under a range of environmental conditions.
2. Resistance to diseases such as fusarium wilt, verticillium wilt, and leaf mold.
3. A low incidence of fruit cracking, blotchy ripening, and blossom-end rot.
4. Fruit with good quality, including internal and external color, flavor, firmness, and smoothness.
5. The ability to respond to fertilization and watering without overresponding.

Most varieties grown have been developed specifically for greenhouse production, although some varieties developed for field production are grown in greenhouses. Both open-pollinated varieties and F_1 hybrids are grown. Since many varieties are available and new ones are developed each year, it is difficult to provide a complete listing. Some of the cur-

rently popular varieties are given in table 1, along with some of their characteristics.

Growers may keep abreast of the latest developments in greenhouse varieties through contact with their State experiment station and vegetable seed companies.

Some varieties popular in the Northeastern States are Tuckcross O, Michigan-Ohio Hybrid, Waltham Disease-Resistant Hybrid, and Veegan. In the Middle West, Michigan-Ohio Hybrid, Michigan State Forcing, Ohio WR25, Ohio WR29, and Ohio Hybrid O are the most popular varieties. Southeastern growers use Michigan-Ohio Hybrid; Michigan State Forcing; Tuckcross M, O, and V; Manapal; and Floradel. Growers in the Western and Southwestern States grow many of the same varieties grown elsewhere plus several additional. These include Tuckcross O and V; Michigan-Ohio Hybrid; Floradel; Floralou; Manapal; Pinkshipper; Spartan Red; and Spartan Pink.

Growers should be aware that all varieties cannot be treated alike. Fertilization and irrigation practices and proper spacing to attain maximum yields may vary with different varieties. Also, some varieties perform best as a fall crop while others do best in the spring.

TABLE 1.—A partial list of tomato varieties for greenhouse production

Variety name	Fruit color	Disease resistance ¹	Fruit size
Michigan State Forcing	Red	Moderate-fusarium	Medium to large.
Michigan-Ohio Hybrids	Red	Fusarium	Medium to large.
Ohio WR7	Pink	Fusarium, blotchy ripening, fruit pox	Medium to large.
Manalucie	Red	Fusarium, blossom-end rot, leaf mold	Medium to large.
Manapal	Red	Fusarium, blossom-end rot, leaf mold	Medium to large.
Tuckcross, M, O, and V	Red	Fusarium, leaf mold	Small to medium.
Spartan Red	Red	Fusarium	Medium to large.
Ohio WR29	Pink	Fusarium, blotchy ripening, fruit pox	Medium to large.
Ohio WR25	Pink	Fusarium, blotchy ripening, fruit pox	Medium to large.
Waltham Disease-Resistant Hybrid	Red	Fusarium, leaf mold	Small to medium.
Ohio Hybrid O	Pink	Fusarium, leaf mold	Medium to large.
Veegan	Red	Fusarium, leaf mold	Medium to large.

¹ At least 10 races of leaf mold exist in this country. Varieties listed as resistant may be resistant to only certain races.

STARTING THE PLANTING STOCK

Practically all greenhouse operators grow their own tomato plants from seed. The grower thus assures himself of having plants of the desired variety and at the proper stage of development when he wishes to plant the crop. Also, plants grown locally can be transplanted into the permanent beds with the least shock.

Number of Seeds and Plants Needed

Only the best seed obtainable should be used. The cost of seed is relatively small compared with the large investment in equipment and labor needed to grow a crop. The seed used should be new. It should have been stored under proper conditions to retain a high percentage of germination. The seed should be free of seedborne diseases. If F_1 hybrids are used, new seed must be purchased for each crop. It must not be saved from the preceding crop because it will not breed true.

An ounce will contain 8,000 to 10,000 well-matured tomato seeds. This number should be sufficient to produce at least 5,000 strong plants. However, it is good insurance to grow more plants than will be needed to set the available bed space. Growing additional plants costs more for supplies and labor, but may be the difference between a crop and no crop, if something should happen to part of the seedlings.

The number of plants needed depends on the amount of bed space to be allotted each plant and the total bed space to be planted. The variety being grown, season of the year, soil fertility, and importance of fruit size influence the plant spacing. Experience has shown that some varieties yield more fruit at high plant populations than other varieties. Some growers plant at a closer spacing for a fall crop to help attain a satisfactory total yield, since less fruit will be set per plant in the fall. Care must be taken that close spacing does not reduce fruit size below that demanded by the market. More fertilizer may be necessary when spacing is close. Growers space plants from 12 to 24 inches apart in the rows, with rows 3 to 4 feet apart.

A common spacing is 18 inches by 3 feet, which allows $4\frac{1}{2}$ square feet per plant or 10,890 plants per acre. For other spacings the number of plants needed can be estimated by dividing the total number of square feet of bed space to be planted by the number of square feet provided for each plant. Number of plants per acre required for various spacings is given in table 2.

TABLE 2.—*Number of plants required per acre for various plant spacings*

Plant spacing in row-inches	Row spacing in inches ¹	No. plants per acre
12	36	14,520
12	42	12,445
12	48	10,890
15	36	11,616
15	42	9,945
15	48	8,712
18	36	9,680
18	42	8,297
18	48	7,260
21	36	8,297
21	42	7,118
21	48	6,223
24	36	7,260
24	42	6,223
24	48	5,445

¹ For alternating row spacings, average the row widths and use this average for determining the number of plants required.

Time for Sowing Seed

The date for sowing seed is governed by the time desired for the first harvest. About $4\frac{1}{2}$ months from seeding to harvest should be allowed for a fall crop and $5\frac{1}{2}$ months for a spring crop. Plants grown in summer and early fall develop faster than those grown in late fall and early winter months. The location of a greenhouse also influences the time of seeding.

Demands for greenhouse tomatoes increase immediately after the outside crop has been killed by frost. This and the difficulty of obtaining a good set of fruit after the prevailing

cloudy weather that starts in November, make earlier fall plantings more profitable. Since it takes 50 to 60 days to develop tomatoes from blossom to full ripeness under late fall and winter conditions, tomato plants that are to be removed by mid-January must have all their fruit set by mid-November.

Greenhouse growers vary the time of sowing the seed for the early spring crop to fit the crop into diverse cropping systems. If a long tomato-growing season is desired, the seed must be sown early. Experiments have shown that earlier planting not only produces the largest yields, but also usually brings better prices on the early spring market. In most areas, seed for the spring crop is sown as early as October 25. The plants are set in permanent ground beds about January 10, and the harvest begins around the first of April.

It is important to use seeds free of disease-producing organisms. Treated seed should be purchased, or the seed should be treated as described in the USDA Agriculture Handbook 203, "Tomato Diseases and Their Control." Growers who save their own seed should use only ripe fruit and extract the seed with a hydrochloric acid treatment to eliminate tobacco mosaic virus on the seed surface. One fluid ounce of concentrated hydrochloric acid should be added to the seed, pulp, and juice taken from 5 pounds of fruit. The material is soaked and stirred occasionally until the seed settles to the bottom. The seed is then ready to be separated from the pulp by washing thoroughly with water.

Seeding

Two basic systems are used for starting tomato seedlings: (1) Seeding directly in small pots or growing containers; or (2) Seeding into flats and later transplanting into growing containers. The first method involves less handling of the small plants; therefore, less labor is required and there is less chance for the spread of tobacco mosaic virus. Also, the seedlings develop more rapidly because the roots are not disturbed by transplanting. Growers

who seed in flats and transplant into pots may do so because of space limitations or because they feel they obtain superior-quality plants.

The medium used for starting seedlings should permit good germination and subsequent root growth, be economical to use, be chemically and physically uniform, and be free of disease. Several materials can meet those criteria, including loam or sandy soil, sand, shredded sphagnum peat moss, vermiculite, and perlite. These materials are usually mixed together in various combinations for the best results. Some combinations used for starting tomato seedlings are:

1 part compost: 1 part sand: 2 parts topsoil.

1 part peat moss: 1 part vermiculite.

2 parts sand: 1 part peat moss.

1 part soil: 1 part peat moss: 1 part perlite or sand.

1 part compost: 1 part vermiculite.

1 part perlite: 1 part peat moss; 1 part vermiculite.

The medium used should be sterilized with heat or chemicals before the seeds are planted unless it is known to be free of disease-producing organisms. Also pots, flats, and any tools used should be sterilized. Materials and methods for sterilizing are discussed in USDA Agriculture Handbook No. 203, "Tomato Diseases and Their Control."

Direct seeding may be into 3- or 4-inch clay or peat pots or some of the newer plant-growing containers (fig. 5). The pots are spaced out and filled with the sterilized potting medium to within about 1/2 inch from the top of the pot. One to three seeds are planted 1/3 to 1/2 inch deep in the center of each pot. Seeds should be planted at a uniform depth so they will germinate evenly and result in uniform plants for transplanting into the beds. After germination, pots with more than one seedling should be thinned to a single plant.

When seeding is done in flats, seeds are sown in rows 1/2 inch deep and 2 to 3 inches apart (fig. 6). A wooden lath notched on the ends so it will make a row of the proper depth when pressed into the soil may be used. Seed should



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FIGURE 5.—Sowing tomato seeds in peat pots.

be distributed 7 to 8 per inch in the rows and covered with the germinating medium.



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FIGURE 6.—Sowing tomato seeds in a flat, a method commonly used for starting greenhouse tomatoes.

For good germination of tomato seed, the soil must be kept moist. Temperatures of 70° to 80° F. are recommended during the germination period. To help maintain proper temperature and moisture for germinating seeds, the flats or pots may be covered with panes of glass or sheets of plastic until the seedlings break through the soil surface. After germination, the soil surface should be wet only as often as necessary to keep the young plants growing. It has been shown that night temperatures of 52° to 54° F. and day temperatures of 56° to 58° F. during the 2 to 3 weeks following cotyledon expansion can result in the first cluster of fruit being formed earlier and more flowers in the first and second cluster. Following the cold treatment, temperature should be maintained between 60° to 70° F to promote stocky growth of the seedlings.

GROWING THE TRANSPLANTS

The productivity of a tomato crop is to a large extent determined by the quality of the transplants set in the beds. A grower can control the quality of his transplants by controlling temperature, water, nitrogen, carbon dioxide, and light. It is very important that these factors be kept in the proper balance.

Transplanting of young seedlings from seed flats should be done as soon as their stems have straightened and the seed leaves (cotyledons) have opened horizontally. This is usually 9 to 14 days after the seed is sown (fig. 7). The sooner the seedlings are transplanted, the more quickly they recover from the shock. When transplanting young tomato seedlings, the grower should always grasp the plant by one of the seed leaves. Slight pressure on the stems can easily injure the seedlings permanently. Seed planted directly in clay or peat pots or some other growing container do not require transplanting.

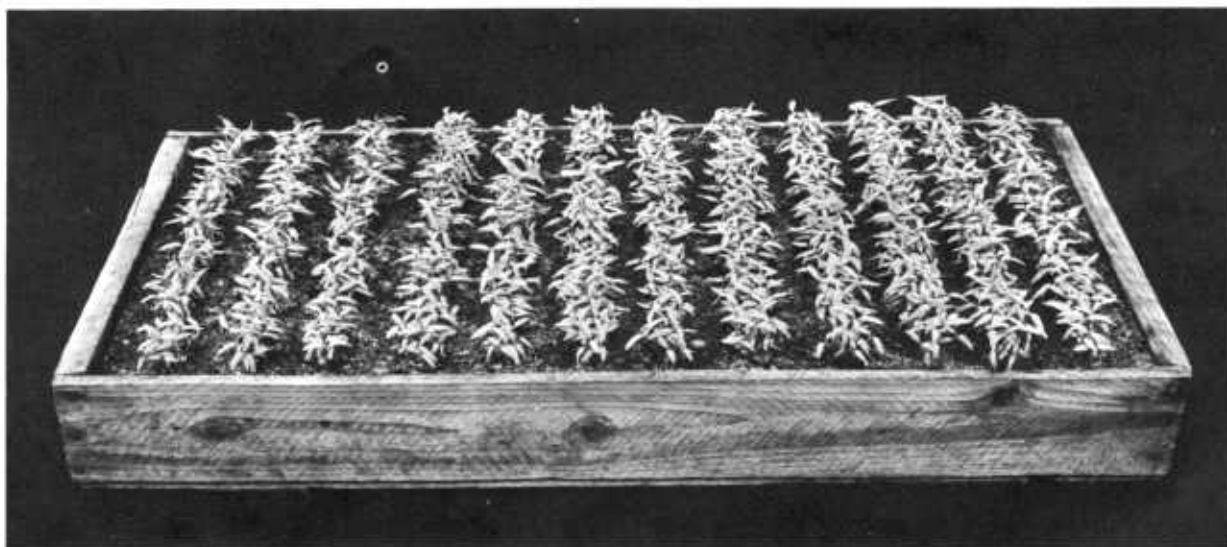
It should be a routine practice for all persons to wash their hands in strong soap and water before handling young tomato plants to avoid infecting them with mosaic viruses. Workers should not be allowed to use tobacco in any form while working around the plants. After smoking or handling tobacco, workers

should always wash their hands again before starting back to work. Also, only clean clothing, including shoes, should be worn by workers.

Plants obviously infected with a mosaic virus should be pulled and destroyed immediately. The workers' hands and any equipment that come in contact with the plants should then be washed thoroughly.

Since the plants for the spring crop must be grown during the shortest and cloudiest days of the year, it is important to provide the best possible conditions for their proper development. The soil in which the plants are grown should be well-aerated and high in phosphate and potash, but low in nitrate nitrogen.

High nitrate content of the soil with abundant moisture during short days will cause plants to grow soft and spindling. Under these conditions the first flower buds often fail to develop properly and produce no viable pollen. The buds frequently drop off and delay fruit setting for weeks. Plants grown slowly in soil low in available nitrogen with moderate soil moisture will grow into a fruitful condition during the winter. With some of the small-fruited varieties, it is not so important to keep the available nitrogen in the soil at such a low



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FIGURE 7.—A flat of tomato seedlings at the proper stage for transplanting.

level. These varieties set fruit quite readily even when the days are short and there is considerable cloudy weather. Where more nitrogen can be made available during this period, the plants develop and mature more quickly.

When plants are grown in summer for early fall planting, the days are long and usually bright. These conditions encourage high production of carbohydrates (sugar, starch, and cellulose), and hence plants need larger amounts of nitrogen during summer. The plants tend to become nitrogen-starved, so more nitrates must be supplied to maintain good growth.

To obtain normal growth and fruiting of tomato plants a balance between the amount of nitrogen available to the tomato plants and the rate of carbohydrates manufactured in these plants must be maintained. The successful tomato grower learns to recognize this growth relationship and to know what to do to keep the carbohydrate-nitrogen ratio in proper proportion.

While the transplants are growing, the night temperature should be kept as close to 60° F. as is practical, with day temperatures maintained between 60° and 70°. The transplants should be watered only as often as is required to keep them growing continually. Watering should be done early in the morning so the foliage will dry rapidly and prevent disease epidemics. If the transplants cannot be set in the ground bed on schedule, water can be withheld to slow down growth.

Eight to ten weeks after seed germination the plants should be 8 to 10 inches tall, with strong roots, and with the first fruit buds partly developed (fig. 8). They may be somewhat deficient in nitrogen, as indicated by a light yellow-green color of leaves and by a purple tinge of stems and petioles. Plants at this stage should be firm but not hard and woody. The plants should be set in the ground beds at this time. If they are held much longer, the root systems will become potbound and plant growth will be stunted. Good transplants ready to be set in the beds should be as wide as they are tall.

If the plants should become too hardened before transplanting, an ounce of sodium or



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FIGURE 8.—A good tomato plant ready to be set in a greenhouse bed.

ammonium nitrate per gallon of water will stimulate renewed growth. Complete water-soluble starter fertilizers are also available that furnish the plants better balanced nutrition. A good starter solution may be made by dissolving 3 pounds of 10-52-17 fertilizer in 50 gallons of water. A half pint of this solution per plant is usually ample to stimulate renewed growth. It is best to pour the fertilizer solution directly into each pot a day or two before plants are to be transplanted out in the greenhouse beds. The starter fertilizer will give the plants a quicker start, thus hastening the first harvest.

Research has shown that young tomato plants respond more to carbon dioxide enrichment than older plants do. Therefore, enrichment of the atmosphere with carbon dioxide during the growth of the transplants is an effective means of accelerating their growth rate and increasing the eventual yield of fruit. A more thorough discussion is given in the section on Carbon dioxide enrichment.

Although most growers in the United States do not presently supply artificial light to transplants during their growth, tests show that supplemental artificial light during normal daylight hours can increase the eventual fruit

yields significantly. High-intensity lamps supplying at least 500 ft.-c. at the leaf surface should be used. Artificial light in combination

with carbon dioxide enrichment offers a promising prospect for increasing the quality of tomato transplants.

PREPARING FOR PLANTING

The first step in preparing the greenhouse bed for a new crop is to dispose of all debris of the preceding crop. Before the old vines are removed, all insects on them should be destroyed to prevent their reentry into the greenhouse. Old vines should then be moved several hundred yards from the greenhouse and destroyed. When plants are piled near the greenhouse, spores of disease-producing fungi may blow back into the house.

After the bed is cleaned, the first consideration should be sterilization of the soil to kill all potential tomato pests in it. Sterilization, if done effectively, will destroy weed seeds, insects, nematodes, and disease-producing fungi, bacteria, and viruses.

Many growers sterilize twice a year or before every crop. Other growers prefer to sterilize only once a year. The cost of sterilization, the possible benefits to be derived, and the cropping plan being used must be considered when deciding whether to sterilize once or twice a year.

The two general methods for sterilizing greenhouse beds are through the use of heat or chemicals. In large permanent establishments, steam is generally used for sterilization because these houses are heated with steam. Houses not equipped for steam heating must be sterilized with chemicals.

For steam sterilization, steam is diverted from the boiler and forced through a permanent system of 3- or 4-inch tile buried about 15 inches deep in rows 18 to 24 inches apart. The lines are all connected at one end by elbows and tees. At the other end a header made of 2½- or 3-inch pipe delivers the steam to the tile lines.

The tile should be laid so that about ¼ inch is left between them at joints. This allows room for the tile to swell when wet and for steam to escape into the soil. It is best if the tiles are laid with a slight grade away from

the header to prevent water from collecting at the header.

The time required to sterilize plant beds varies with the size of the steam line, the steam pressure, and the soil type. It is generally recommended that the soil be heated to 180° F. and held at this temperature for 4 hours. Thus if 4 hours are required to heat the soil to 180°, the total sterilization time will be 8 hours.

To retain the heat in the soil during sterilization and insure uniform heating throughout, it is necessary to cover the soil during the heating process. Polyethylene film, black building paper, synthetic rubber sheets, or specially made cloth covers may be used.

Before sterilization, the soil should be cultivated and well pulverized. Best results are obtained when the soil moisture is such to allow for good cultivation.

Pathogenic fungi, bacteria, nematodes, and weed seeds in soil can be controlled by chemicals. Some available chemicals control all kinds of organisms; others control only one or various combinations. For a thorough discussion on soil sterilization with chemicals, see USDA Agriculture Handbook No. 203, "Tomato Diseases and Their Control."

After sterilization, extreme care must be taken to prevent recontamination of the soil. Since no competing organisms remain in the soil after sterilization, the growth of a pathogen reintroduced into the soil goes unchecked. To help prevent recontamination, all hand and power tools should be sterilized before being used. Also, walkways in the greenhouse should be sterilized, and workers should not be allowed to move from unsterilized to sterilized areas without having clean clothing and clean shoes.

After the soil has been sterilized and allowed to lie idle for 2 weeks or more, any lime or fertilizer to be applied should be broadcast onto the soil surface. Amount and types of materials used are discussed in the section on

Plant nutrition and fertilization. The fertilizer, lime, and any mulch from the preceding crop is then worked into the soil as it is prepared for planting.

Many types of equipment are available for preparing the soil. Rotary soil pulverizers are widely used and do an excellent job of preparing a deep, fluffy soil bed in one operation. Many large growers use tractor-driven rotovators (fig. 9), but small growers may use smaller, self-propelled cultivating equipment.

In soils that contain little organic matter, particles tend to cement together again after the plants have been set and the soil has been watered several times. This deprives the roots of oxygen and moisture, as well as making root penetration more difficult. As a result many roots die, the plants grow more slowly and yield less fruit.

An unfavorable physical condition of the soil can be improved by incorporating an abundance of organic material into it. Organic materials are often applied in summer just before planting the fall tomato crop, rather than in the winter preceding the spring crop. Heavy soils require more organic matter than light



FIGURE 9.—Tractor and rotovator for preparing soil beds in a large greenhouse.

soils to keep them loose and friable. Sources of organic matter will be discussed in the section on Mulching.

After cultivation, the beds are usually marked to indicate precisely where the plants will be planted. In large houses, furrows about 6 inches deep are often made with a small tractor.

PLANTING

Houses should be warmed thoroughly before the plants are set during winter weather. To encourage prompt growth of plants, some growers introduce steam into the tile used for steaming the soil, until the soil temperature is raised to 70° F. Warmed water is also used sometimes at transplanting time to help the plants start growing more quickly. If soft vegetative plants have to be used for winter planting, starter fertilizers and extra heat should be omitted.

The sequence of planting operations varies according to the grower's plans. Many growers set the plants in place but leave them in the pots a week or two longer so they reach the right bud stage before setting in the ground bed.

It is very important, except when growing free-setting varieties, to have the first bud cluster at the proper stage of development be-

fore planting so the blossoms will open normally and set fruit. The grower must not allow the plants to take root in the soil beneath them if a mulch has been spread and they are sitting on the mulch. If the roots are allowed to penetrate into the bed soil, the nitrogen and moisture available many cause the plants to become succulent and vegetative, leading to failure to develop normal blossoms.

Most growers water the potted plants thoroughly the day before they are to be planted in the permanent beds. If the plants are in clay pots, they are then easily removed without disturbing the root by inverting the plant and jarring it out of the pot.

The plants are set in holes or trenches, 1 to 2 inches deeper than they were in the growing container. If peat pots are used, it is important that the pot be set deeply enough that the top is covered with soil and does not act as a wick

to dry out the plant roots. After the plants have been set, the mulching material should be leveled around them, if it has already been spread. The plants should also be watered enough to settle the soil around the roots and to provide sufficient moisture for good growth.

A common practice is to apply a soluble starter fertilizer with the first watering or two. Three pounds of 10-52-17 per 50 gallons

of water is adequate. One-half to one quart should be applied around each plant.

Tomato plants should be handled as little as possible to avoid the spreading of virus diseases through the plants. When they must be handled, the operator's hands, clothing, and tools should be washed free of any possible virus contamination before touching any tomato plants. Also, smoking should not be allowed in the greenhouse.

MULCHING

A common practice in greenhouse tomato production is to use an organic mulch. Mulches serve the following purposes: (1) To help maintain more uniform soil moisture, thereby lessening fruit cracking; (2) to add organic matter to the soil; (3) to reduce soil compaction and thereby improve soil aeration and root growth; (4) to protect the fruit of the first cluster from touching the soil and becoming infected with soil rots; (5) to reduce the amount of spattering of water drops from the soil onto the lower leaves, thereby reducing the spread of diseases; and (6) to liberate carbon dioxide during their decomposition.

A number of materials are satisfactory for mulching greenhouse tomatoes. Some of the most commonly used mulching materials are wheat straw, peanut hulls, ground corncobs, and manure. Other materials used include alfalfa, red clover, wheat and rye straw, various

types of hay, sawdust, wood chips, pine needles, sphagnum peat, rice hulls, and sugarcane bagasse.

The choice of mulch depends on the cost and availability of the material, its ability to prevent soil compaction, its decomposition rate, its effect on the nutritional balance of the soil, its freedom from potentially harmful chemicals such as herbicides, and the possibility that it may carry a disease-producing organism into the greenhouse.

The mulch may be applied after the soil has been sterilized and cultivated just before planting, or it may be applied after the transplants have been set in the ground beds. The mulch should be spread over the entire soil surface to a depth of 2 to 3 inches. Approximate amounts required per acre are 6 to 8 tons of wheat straw or similar materials, 12 to 14 tons peanut hulls, and 10 to 12 tons ground corncobs.

TEMPERATURE AND HUMIDITY CONTROL

One of the most effective means of controlling plant growth is through regulating the greenhouse temperature. Respiration, or the process through which living plants constantly use food, varies considerably with temperature. Likewise, photosynthesis, or the process of manufacturing food during the daylight hours, is controlled by temperature.

The rate of photosynthesis is determined also by the amount of light available, so temperature must be coordinated with light conditions. On bright days when light does not limit

photosynthesis, the greenhouse temperature may be higher than on dull days. When light is limiting, a high temperature may increase the respiration rate until the amount of food consumed by the plant is equal to or greater than that produced by photosynthesis. Night temperature must be low enough to insure that the food manufactured during the day is not entirely used up.

As stated in the section on Seeding, the temperature for tomato seed germination should be 70° to 80° F. After germination a temper-

ature range of 60° to 70° F. is best for growing the planting stock, except for a cold treatment of seedlings.

After plants are in the beds and growing, the night temperature should be held between 60° and 65° F. Day temperatures of from 70° to 75° F. should be maintained on bright days. The temperature may range as high as 80° on clear days without adversely affecting the development of the crop. On cloudy days the temperature should be kept 65° to 68° F. When this temperature schedule is maintained, fruit buds should develop normally, and the fruits should be smooth and of high quality. In no case should the night temperature drop below 58° during fruit bud development, as this may cause poorly formed blossoms that will abort, or misshapen tomatoes of poor quality.

If carbon dioxide enrichment is used, research has shown that slightly higher temperatures should be maintained. On sunny days the temperature may range up to 85° F. and on cloudy days up to 75° or 80° F.

Greenhouse temperature is regulated by controlling the source of the heat, the ventilators, or an evaporative cooling system. Environmental conditions influence the frequency with which adjustments must be made. However, temperature should usually be checked at hourly intervals. On clear, sunny days the direct rays of the sun raise the temperature inside greenhouses very rapidly. During daylight hours when the temperature of the greenhouse reaches 70° to 72° F. all heat should be shut off and the ventilators opened to prevent the temperature from going higher.

Automatic thermostat-controlled steam valves or heaters and ventilators make temperature control much easier (fig. 10). An alarm system that warns of temperature extremes is also very useful.

Shading with an external application of whitewash or similar compound is used on glass greenhouses to control temperature. The white coating reflects the sun's rays and reduces their penetration into the greenhouse. The time of application and removal of the shading compound varies with the amount of sunshine received and the conditions of a given season. Generally, glass greenhouses should be



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FIGURE 10.—Equipment for automatically controlling greenhouse ventilators.

shaded about the time of transplanting to the groundbed when a fall crop is grown. As the days become shorter and the sun's rays more indirect, the shading should be removed around the middle of October. For a spring crop, an application of shading is usually required about the middle of April.

Ventilation is important, not only for maintaining temperature control but also to remove stale, moisture-laden air and replace it with fresh air. The introduction of fresh air and consequently carbon dioxide is particularly important if carbon dioxide enrichment is not used. The relative humidity inside the greenhouses should always be kept below 90 percent to keep under control the leaf mold disease that is so destructive to greenhouse tomato plants. If the humidity of a house is allowed to go over 90 percent for 1 day, leaf mold infections may result.

No rigid rules can be laid down for ventilating. Usually the ventilators are closed at night during cold weather when heat must be kept on in the houses. Even then, it may be necessary to "crack" (slightly raise) the top ventilators to maintain enough exchange of air to prevent the humidity from building up. In plastic greenhouses where exhaust fans are used to ventilate, it may be necessary to run the heaters and fans simultaneously to allow

ventilation and at the same time to prevent the temperature from dropping too low.

Heating and ventilation should be regulated, if possible, so the atmosphere of the house is kept in circulation. Outside air may enter the greenhouse through opened side ventilators and be warmed as it moves through the greenhouse, picking up excess moisture and carrying it out through the top ventilators. This is especially helpful in controlling leaf mold. The most dangerous times are during relatively

mild weather in fall and spring when proper night temperatures may be maintained without any heat in the greenhouse by keeping the ventilators closed. This is likely to create a combination of conditions inside the houses that will start an epidemic of leaf mold raging through the plants. A grower should never be tempted at such times to save the small amount of fuel needed to provide a little heat and sufficient ventilation in the houses.

TRAINING AND PRUNING

Greenhouse tomato plants are usually supported by stout wires (Number 9-11) running parallel to the soil surface, 6 to 8 feet above it. The wires are directly over the plants and are attached to the greenhouse frame. Individual tomato plants are then supported by sisal, hemp, or synthetic twine tied to the overhead wire with the other end tied loosely around the stem of the plant near the ground (fig. 11). As the plant grows, it is wound loosely around the string, always in the same direction. The string should be kept under the point of leaf attachment to the main stem. In this way, the leaves will not be broken and the plant will be supported at the base of the leaf petioles so it will not slip down the string. Do not attempt to wrap higher than 6 inches below the tip of the plant, as the stem is likely to snap off if wound around the string all the way to the top. Fruit clusters should be trained under leaves so they are protected from sunscald.

With crops that will be harvested over a long period of time, it is a common practice to lower the vines after the first clusters are harvested. This makes it easier to prune, pollinate, and harvest the top of the plant. Fruit on the first cluster generally ripens when the sixth or seventh cluster is setting fruit. So that the vines can be lowered later, the pieces of supporting twine are cut 3 to 4 feet longer than would otherwise be necessary. The vines are lowered at the desired time by loosening the twine and retying it nearer its end.

Occasionally late in the growing season growers train the vines along the overhead supporting wires or across the rows, but this is

generally not recommended because it cuts down on the sunlight reaching the leaves. Others train the plants over the wires so the weight of the plant and the fruit bend the plant toward the ground.



BN-36539

FIGURE 11.—Tomato plant growing in a straw-mulched bed, tied with twine and pruned to a single stem.

Light wooden or metal stakes are sometimes used to support tomato plants (fig. 12). They are pushed into the soil near the plant and, if overhead wires are present, the stakes may be tied to them. To support the plant to the stake, soft twine can be tied tightly around the stake 2 to 3 inches above a leaf petiole, then looped under the base of the petiole and tied with a square knot. Plant ties, made of tape with wire reinforcing, may also be used to support plants to stakes.

The single-stem system of pruning and training is almost universally used by greenhouse growers, although a few train plants to two or three stems. Pruning is accomplished by removing the small lateral shoots that appear at the point where the leaf stem joins the main stem (fig. 13). Fruit buds appear on the opposite side of the main stem, usually above or below the points where the leaves are attached.

Pruning should be done at least once a week, because the lateral shoots can be easily re-

moved when they are still small without making large wounds. The shoots may be broken off by hand or cut with small clippers. Pruning by hand is usually preferred because it results in less spread of plant viruses. When pruning by hand, grasp the shoot to be removed with the thumb and forefinger and bend it sharply to one side, then snap it off with a sharp bend and pull in the opposite direction. The reversal of direction becomes increasingly important when the shoot is large, to avoid injuring the leaf axil or the main stem. Since the hand touches only the shoot being removed, there should be no spread of virus diseases from plant to plant.

Even when a serious effort is made to avoid touching virus-infected plants, workers' hands and clothing are bound to contact the virus if it is present in the greenhouse. Therefore, it is advisable that workers wash their hands with soap and water after working with each row or use disposable plastic gloves when handling the plants. Clean clothing should also be pro-



FIGURE 12.—Tomato plants growing in a small plastic greenhouse and supported by wooden stakes.

BN-36542



BN-36537

FIGURE 13.—Pruning a lateral shoot from a greenhouse tomato plant.

vided for the greenhouse workers at least twice a week. The clothing should be washed in detergent and hot water. If clippers or knives are used to prune, these tools should be periodically dipped in a 3-percent solution of trisodium phosphate. Trisodium phosphate is a household cleaner that can be purchased at most hardware or paint stores.

After plants have reached the maximum

height desired, the terminal growing point should be removed. The time for this is determined by the height of the greenhouse or by the number of fruit that can be matured before it becomes necessary to remove the plants to start a new crop. Generally plants are topped about 45 days before harvesting is expected to stop. Normally a fall crop will be topped after 6 to 7 clusters of fruit have set per plant. A spring crop will not be topped until about 13 clusters have been set. Topping plants diverts all the food manufactured to the development of fruit already growing on the plants. To allow proper development of the last cluster of fruit set, two leaves should be kept above the top flower cluster.

As the lower clusters of fruit approach maturity, it may be desirable to prune off part of the lower leaves if they are yellowing. This allows for easier harvesting of the lower fruit clusters and helps to control leaf mold by permitting better air circulation. It may also make watering easier, especially when automatic equipment on the soil surface is used. Unnecessary pruning of leaves should be avoided because all organic food for fruit development must come from the leaves. To yield well, the plants need a maximum of functioning leaf surface.

As plants are pruned during the season, watch for deformed or rough fruit. Such fruit will be salable only as culls, so they should be removed as soon as they are detected. All food produced by the plant can then be used to mature the remaining fruit on the plant.

WATERING

Adequate soil moisture is essential for obtaining good yields of high-quality tomatoes. Overwatering can result in excess vegetative growth at the expense of fruitfulness. By carefully controlling soil moisture, a grower can maintain control of his plants. For example, withholding water can slow excessive vegetative growth when high temperature and low light conditions favor it. To maintain control of plants growing in soil beds, they should not be allowed to root deep enough to reach permanent water.

The cultural technique employed and the soil

type greatly affect the frequency of watering. The soil in a ground bed can hold large amounts of water, thus plants in soil beds usually do not require frequent watering. Tomatoes grown in trough culture, ring culture, or hydroponics are in a limited amount of growing medium and require more frequent watering. The water-holding capacity of soil depends greatly on the soil type. Heavy clay soils hold much more water than light sandy soils.

During periods of intense sunlight, plants use more water in carbohydrate manufacture, they lose more water from their leaves by transpira-

tion, and evaporation from the soil surface is higher. High relative humidity reduces the amount of moisture lost from plants and soil.

The primary factor determining watering frequency is the stage of maturity of the plants. A crop may be ruined by too much water when the plants are first set out. Later in the season when the plants have matured and are laden with growing fruit, much more water is required by each plant, so overwatering is quite unlikely. For a spring crop, too much soil moisture in January and February, or during cloudy periods, tends to promote vegetative growth and reduce fruitfulness. Some growers water with a hose for 4 to 6 weeks after setting the plants or until after the first clusters of fruit have begun to enlarge, taking care to wet the soil just down to the root zone. Until the second or third fruit clusters have set, some growers prefer to water the spring crop only when plants show signs of wilting. Sometimes a spring crop will grow for 6 weeks or longer with only spot watering before a general watering becomes necessary.

As the season advances, the lengthening days and more intense sunlight promote more normal flowers with abundant pollen and faster fruit development. By mid-season,

ground beds are watered about once or twice a week. From 1 to 1½ acre-inches equivalent of water is usually applied each time to satisfy the needs of the crop.

A fall crop should be watered frequently in August and September when the plants are young. Watering is reduced greatly in October and usually discontinued completely by the middle of November. It is important that the vegetative growth of a fall crop be terminated at the proper time to enable the limited carbohydrates being produced to go into the development and ripening of the fruit that are already set.

Generally, best growth and yield of tomatoes are obtained when soil moisture is maintained fairly uniform. This requires frequent watering and much labor, unless an automatic system is used.

Watering from overhead should be early in the day and on sunny days so the foliage will dry as rapidly as possible. Diseases are likely to get started if tomato plants remain wet for long periods.

Growers can use a soil auger or spade to check the moisture content of the soil. They should learn to recognize the moisture content of their particular soil by its appearance and by squeezing it in the hand.

CARBON DIOXIDE ENRICHMENT

One of the requirements for the growth of green plants is the presence of carbon dioxide (CO₂). This gas is necessary for photosynthesis, one of the fundamental processes in higher plants. Photosynthesis is the process of combining CO₂ and water in plant leaves in the presence of sunlight to form carbohydrates. These carbohydrates are the source of energy used by plants in growing.

Light, temperature, and CO₂ may all limit the rate of photosynthesis and carbohydrate production in plants. Research has shown that adding CO₂ to the atmosphere of a closed greenhouse can increase tomato yields by increasing both fruit size and number of fruit when the other factors are not limiting. The addition of CO₂ can also result in earlier-maturing tomatoes.

Carbon dioxide is normally present in the at-

mosphere at a concentration of approximately 0.03 percent, or 300 parts CO₂ per million parts air. Concentrations of 1000 to 1500 parts CO₂ per million parts of air in tomato-producing greenhouses usually give the best results.

CO₂ dissipates rapidly if ventilators are opened or if the greenhouse is not tightly constructed. For fall crops, the early stages of plant growth come during the warm months of summer and fall when ventilation of the greenhouse is necessary. A spring crop, however, makes its early growth during January and February, when proper temperature and humidity can be maintained without ventilation. As a result, yield increases are usually greater for spring crops than for fall crops. Care must be taken not to permit temperatures to rise above 80° F., or fruit set and fruit size may be adversely affected. Also, soil moisture and

plant nutrition must be controlled precisely when CO_2 is used, since plants become more vigorous and the tissue more succulent.

Research has shown that young plants are particularly sensitive to CO_2 enrichment. In proper balance with the other factors influencing growth, extra CO_2 can stimulate growth of newly germinated seedlings and shorten the time required to grow the transplants.

Liquid CO_2 and combustion of organic fuels are the sources of CO_2 used in greenhouses. The latter is most often used, because it is cheaper to manufacture CO_2 , even though the equipment for combustion is more expensive initially than the equipment for using the liquid form. When CO_2 is manufactured by combustion, care must be taken to prevent the possibility of injury to the crop from toxic substances such as carbon monoxide, sulfur dioxide, and others. The proper selection of burner and fuel can prevent such losses.

Some CO_2 generators introduce the gas directly into the greenhouse, and other larger units located outdoors or in a headhouse distribute the gas through a series of plastic or metal ducts (figs. 14, 15, 16). After CO_2 is introduced into the greenhouse, it will rapidly diffuse throughout.



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FIGURE 15.—Plastic tube for distributing carbon dioxide.



BN-36527

FIGURE 14.—Carbon dioxide generator for a large greenhouse.



BN-36532

FIGURE 16.—Carbon dioxide generator for small greenhouse.

POLLINATION

Pollination is the transfer of pollen from the stamens or male flower organs to the stigma or female organ (fig. 17). Pollen is shed from the inner side of the stamens of fully opened tomato flowers. Those pollen grains reaching the sticky, moist stigmatic surface adhere. If conditions are favorable, the pollen grain germinates and sends a tube down the style and into the ovary, where it unites with a ovule. The contents of the pollen tube and ovule then fuse, and fertilization is accomplished.

Tomatoes growing outdoors are pollinated naturally by air movement that shakes the flowers enough to dislodge the pollen and distribute it evenly over the stigmatic surface. Because there is little air movement in a greenhouse, tomatoes grown indoors usually require artificial pollination to set a good yield of fruit. The general shape, size, and smoothness of the fruit is largely determined by the thoroughness of the pollination. Since a single pollen grain is required to fertilize each seed in the tomato, many are required to fertilize each fruit. When all the seeds are fertilized, the tomato will enlarge uniformly; but incomplete fertilization will result in misshapen fruit. This is a common cause of low-grade fruit.

The time necessary for a ripe tomato to develop from a fertilized flower varies with the season. In winter it usually takes about 60 days; in early spring about 55 days; starting in June, 40 to 45 days.

Artificial pollination of greenhouse tomatoes is generally done mechanically. Chemical treatments may be used as a supplement when mechanical pollination alone will not result in satisfactory fruit set.

Mechanical Methods

Pollination should begin as soon as the first flowers are fully opened and continue as long as there are flowers or until the number of fruit have set that the grower desires. Ideally, pollination should be done every sunny day, but if this is not possible, it should be done at least every other day. Cool, cloudy weather can prevent pollen from being shed, so pollination may not be as effective on these days. Pollen is

more likely to be shed if pollination is performed between 9:00 a.m. and 3:00 p.m. Shedding pollen can be easily seen falling from the flower.

An efficient method of pollinating is to use an electric vibrator that operates from an ordinary electrical outlet or a dry-cell battery (fig. 18). The electrical current rapidly vibrates a wire loop or straight piece of wire. The wire is placed in contact with each flower cluster that has fully opened flowers. Since tomato flowers usually hang downward, the vibration shakes the pollen loose and it falls onto the stigma. The vibrator may be moved from one flower cluster to another as rapidly as possible.

Tomato fruits usually set without much difficulty on the first blossom clusters of the fall crop and the later blossom clusters of the spring crop because of the more nearly ideal environmental conditions. Under these circumstances, simpler methods of assisting flower fertilization may be satisfactory. One method commonly used is to walk between plant rows, tapping each overhead wire sharply with a stick. The vibrations travel along each wire in both directions so the flowers of plants in adjoining rows are also jarred. Thus, the blossoms of all plants are repeatedly shaken as the operator taps each wire again when he walks between the next two rows of plants. Some growers prefer to jar each plant directly by

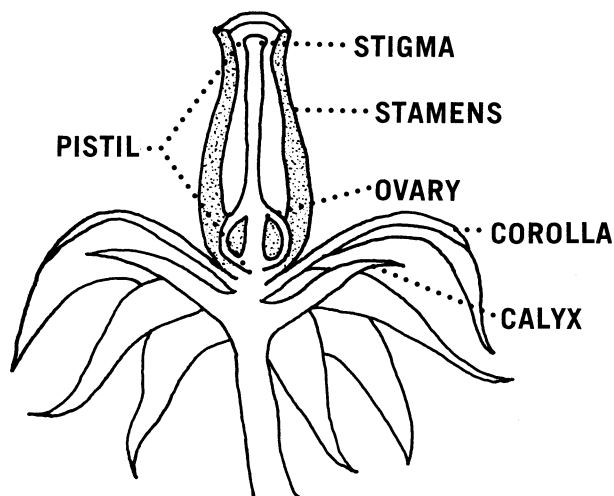


FIGURE 17.—Parts of a tomato flower.

tapping it with a rubber-covered stick. This method is effective, but there is the danger of bruising the plants or the growing fruits.

Air blowers have also been used for pollinating greenhouse tomatoes. A blower is moved between rows and a stream of air is directed at the flower clusters. Care must be taken to avoid damaging flowers by holding the nozzle of the blower too close when the air is moving at a high rate of speed.

Light, temperature, and humidity affect pollination. Cool, cloudy weather may prevent the production of pollen. Even if pollen is shed on cloudy days, it has been shown that pollen germinates best in sunlight. Optimum temperatures discussed in the section on temperature and humidity control will allow good pollination.

High humidity is usually associated with dull, cloudy days. Excessive humidity may prevent dehiscence of pollen from the anthers even though ample pollen is produced. Also, very low humidity may result in poor fertilization by causing the pollen to dry out and therefore be less vigorous.

The humidity in a greenhouse can be lowered by increasing the heat for about 2 hours before pollinating and maintaining it until pollination is completed. In areas of the country where high temperature and low humidity is a problem, a pad-and-fan cooling system is helpful.

Chemical Treatments

Hormonelike chemicals are available to supplement pollination. These materials should be used only when greenhouse conditions are too adverse for pollination alone to be effective in setting fruit.

The fruits of some varieties set by chemical treatments grow soft and do not keep well. Buyers can sometimes distinguish treated fruits from untreated by the remains of the blossom caught under the sepals of the treated fruits, and they are likely to discriminate against them. The firm, smaller fruited varieties, grown in the northeast and north-central regions, seem to be less subject to softening by treatment with hormonelike chemicals, and the treated fruits are marketed satisfactorily.



BN-36525

FIGURE 18.—Pollinating tomato flowers with an electric vibrator.

When chemical treatment is used, the flower clusters should be sprayed with the hormone only after several flowers have opened. Treating immature flowers results in a poor set of relatively small-sized fruit. In the bud stage of a flower, both the pollen and the ovules are adversely affected. A hormone spray should be directed so as to avoid as much as possible spraying the immature terminal vegetative parts of the plant, which tend to develop abnormally when thus treated. Hormone treatments are most satisfactory when applied to the face of the flower.

All chemicals used for stimulating fruit setting must be approved by the United States Department of Agriculture and The Food and Drug Administration before their commercial use with greenhouse tomatoes if the fruit is to be shipped in interstate commerce. Do not use chemicals on the basis that it may have been legal to use them prior to January 1, 1970. The grower may determine if the material he plans to use has been cleared by contacting his State Agricultural Experiment Station.

DISEASES

Disease control is essential to profitable greenhouse tomato production, but it requires constant watchfulness. Because of the close spacing and frequent handling of plants, the opportunities for spread of disease-producing fungi, bacteria, and viruses are somewhat greater than with tomatoes in the field. Also, the closed environment is often conducive to the rapid development and spread of diseases. On the other hand, soil sterilization and control of temperature and humidity afford means of disease prevention and control that are not possible when plants are grown outdoors.

Diseases such as fusarium wilt, verticillium wilt, leaf mold, mosaic, and root knot occur

frequently in greenhouses. Regular practices of sanitation are needed to prevent serious losses unless resistant varieties are grown. Sanitation also reduces losses from diseases such as stem rot, botrytis rot, streak, spotted wilt, late blight, and bacterial canker. These occur less frequently, but occasionally they cause severe damage. Good cultural practices will usually prevent serious losses from nonparasitic diseases such as blossom-end rot, blotchy ripening, and puffiness. All these diseases and others that affect tomatoes are fully described in USDA Agriculture Handbook No. 203, "Tomato Diseases and Their Control."

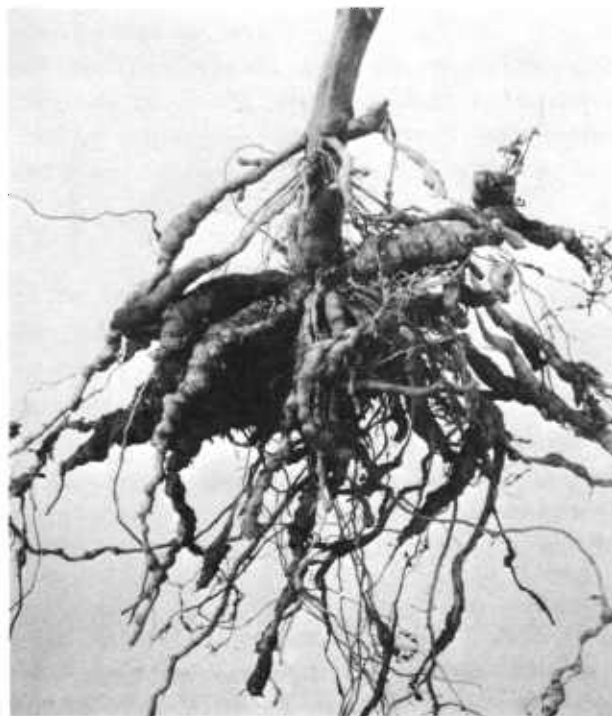
NEMATODES²

Tomatoes are subject to the attack of many types of nematodes. These are minute, round worms not visible to the naked eye. Roots of the tomato plant may be attacked by the types that live within, such as the root-knot nematodes³ and lesion nematodes;⁴ or by the kinds that feed on the plant but do not entirely enter the roots, such as the spiral nematodes⁵ and stubby-root nematodes.⁶ The root-knot nematodes, however, appear to cause the most damage.

Nematode damage on tomato plants is difficult to recognize, because nematodes do not produce specific aboveground symptoms. Retarded growth, unhealthy appearance, wilting during the hot part of the day or during dry weather, or yellowing and stunting of the whole plant may indicate the presence of large numbers of nematodes on the roots. Roots of plants suspected of being infected with nematodes should be examined.

The root-knot nematodes are the easiest to

recognize. They induce the formation of galls, irregular knots, and swellings of the roots. On the tomato plant these galls may be small and hardly noticeable or large and irregular as shown (fig. 19). When numerous, such nema-



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FIGURE 19.—Tomato plant infected with root-knot nematodes.

² Prepared by Joseph M. Good, Nematologist, Crops Research Division.

³ *Meloidogyne* spp., formerly called *Heterodera marioni* (Cornu) Goodey, but now known to comprise a group of many species.

⁴ Lesion nematodes = *Pratylenchus* spp.

⁵ Spiral nematodes = *Helicotylenchus* spp. and *Rotylenchus* spp.

⁶ Stubby-root nematodes = *Trichodorus* spp.

todes as the spiral, lesion, or stubby-root nematodes may cause stunted, short, or sloughed-off roots.

Light, sandy soils are preferred by nematodes. Heavy soils also may be infested, but in these the spread is much slower. Nematodes, once established in a soil, are difficult to eradicate; therefore, every effort should be made to prevent their introduction and establishment in the greenhouse. Unfortunately, man himself is the most effective distributor by transfer of infected root crops and seedlings and by unclean implements. It is important, therefore, to examine carefully the roots of tomato seedlings and transplants. Discard and destroy plants with decaying and diseased roots, par-

ticularly those that have galls and swellings. To produce clean tomato seedlings, it is best to grow them in steam-sterilized soil, in soil treated with a fumigant, in vermiculite, or in peat moss.

If tomatoes must be planted in soil known to be infested with root-knot or other nematode pests, sterilization of the soil with steam or with one of the newer soil fumigants or nematicides is strongly recommended.

Details of application procedures for soil fumigants and precautions on their use may be obtained from manufacturers and distributors of the fumigants, from State agricultural experiment stations, or from the United States Department of Agriculture.⁷

INSECTS

A number of insects, mites, and related species may be serious pests of greenhouse tomatoes. Malathion or parathion greenhouse aerosols will control aphids, whiteflies, mealybugs, spider mites, armyworms, the cabbage looper, cutworms, and thrips. Parathion aerosols will also control the tomato fruitworm, leaf miners, and the tomato pinworm. Be sure to follow the precautions and directions given on the container label. Some of these insects may be serious problems in early fall or late spring when

populations build up outdoors and move in through open ventilators.

As with diseases, soil sterilization and regular sanitation practices do much to prevent serious insect problems. In combating greenhouse insects it is always easier to practice preventive measures than to allow the insects to become established and have to resort to retaliatory measures. For information on specific control measures, consult your Agricultural Experiment Station or your County Extension Agent.

YIELDS

It is difficult to estimate the yield that can be expected from greenhouse tomatoes, because management plays such an important part in the success of the crop. The grower's attention to detail in maintaining optimum growing conditions and the prevailing weather conditions throughout the season are reflected in the yield of marketable fruit harvested.

Yields for fall and spring crops vary greatly. A yield of 6 to 10 pounds of fruit per plant can realistically be expected for a fall crop, while 10 to 20 pounds of fruit per plant can be expected for a spring crop. When two crops are grown per year, a total yield of 24 to 28 pounds per plant-growing site is considered excellent. This would equal more than 100 tons per acre per year.

HARVESTING

It is important that tomatoes remain on the vines as long as possible for them to be of the

highest quality. Tomatoes continue to increase in size and weight after they first begin to show red color. Sugars and acids, which are important flavor components, are also translocated into the fruit until they are fully colored.

⁷ U.S. Department of Agriculture, Agriculture Handbook No. 286, "Chemical control of plant-parasitic nematodes."

The proximity to the market usually influences the stage of maturity at which greenhouse tomatoes are harvested. Fruits grown for local markets may be allowed to remain on the plants until they are near the full red color. It may be necessary to pick tomatoes to be shipped to distant markets as early as the "breaker stage" or when the fruits first show color on the blossom end. Plants are usually harvested 2 to 3 times a week.

Greenhouse-grown tomatoes are usually harvested with the pedicel and green sepals or calyx left on (fig. 20). This distinguishes greenhouse tomatoes from field-grown fruits. So that the calyx remains, the fruits may be snapped from the plants or clipped with small shears. When the fruits are snapped off the vines, the remaining stem is usually clipped back close to the fruit so no stem protrudes to puncture other fruit during harvesting, grading, or shipping. Clippers with short, rounded blades are recommended so that the fruit is not punctured.

Care must be taken not to bruise tomatoes during harvest. The fruit should be grasped

with the palm of the hand and not squeezed with the thumb or fingers. The harvested fruit should be laid in the picking container and not dropped. Bruises on harvested fruit may not be apparent immediately, but they may show up later and render the fruit unsalable.

Fruit may be harvested into small cardboard or wooden baskets or plastic buckets. Many growers use devices such as shown in fig. 21 to reduce the amount of walking and carrying of loaded picking containers. Some picking carts are designed for movement between the tomato rows while others are for use only on concrete walks. In large greenhouses, small carts like that shown are moved between the rows. The filled baskets are transferred to larger hand trucks on the main walks for transporting into packing rooms.

To maintain the high quality of the product, harvested fruit should be moved from the greenhouse to the packing shed as soon as possible. The internal temperature of fruit allowed to remain in the greenhouse increases as the greenhouse temperature increases. Also, harvested tomatoes respire and release energy as heat, so the internal temperature of the fruit may reach 95° F. The higher the fruit temperature becomes, the more rapid the breakdown of the tissues.



BN-36535

FIGURE 20.—Tomato with sepals or calyx remaining attached.



BN-36533

FIGURE 21.—Cart used to assist in harvesting greenhouse tomatoes.

GRADING, PACKING, AND MARKETING

The grading, packing, and marketing of the harvested fruit culminates a large investment in time and money required to produce a crop. During these steps, proper handling of the fruit is very important to retain its quality.

To slow down respiration reactions that break down the sugars in the fruit, tomatoes should be cooled to 55° F. rapidly after they are harvested. This is especially important if the fruit is to be held 8 hours or more before marketing. Optimum storage conditions for tomatoes are temperatures between 55° and 60° F. and 85 to 90 percent relative humidity.

Tomatoes may be sorted, graded, and packed at individual establishments or at a central location shared with other growers. Federal grade standards established by the United States Department of Agriculture usually are the basis for the sale and purchase of greenhouse tomatoes. The grades are based on quality and condition of the fruit. Although size is not a part of grade, the size may be specified in accordance with one of the following classifications, "Small" (under 3 1/2 ounces), "Medium" (from 3 1/2 to 9 ounces), or "Large" (over 9 ounces). Complete information on greenhouse tomato standards may be obtained by writing to the Fresh Products Standardization and Inspection Branch, Fruit and Vegetable Division, Consumer and Marketing Service, U.S. Department of Agriculture, Washington, D.C. 20250.

Greenhouse tomatoes are marketed in various types of packages. The most common package is a cardboard basket holding 8 pounds of fruit (fig. 22). Other packages used include larger cardboard baskets and various sizes of wooden baskets. Some growers pack greenhouse tomatoes in small cardboard and cellophane containers.

Growers often wrap individual fruit in tis-



BN-36534

FIGURE 22.—Greenhouse tomatoes packed in an 8-pound fiberboard basket.

sue paper printed with the words "Greenhouse Tomatoes" and perhaps their brand name. Individually wrapped fruit reduces the spread of diseases in shipping boxes and baskets and identifies the product as being greenhouse-grown. Another method used to identify greenhouse-grown fruit is to attach a decal or pressure-sensitive label to each fruit.

Several diseases or disorders may affect harvested fruit. These diseases may lower the market value of the crop or render it worthless. Agriculture Handbook No. 28, "Market Diseases of Tomatoes, Peppers, and Eggplants," contains complete information on the subject.

Marketing may be directly to the retailer or through a wholesaler. The volume of fruit produced and location of the greenhouse influence the marketing procedures. A grower who markets directly must assume some of the duties normally handled by the wholesaler. Regardless of the marketing procedure, premium prices are paid for greenhouse tomatoes when they are of high quality.