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PRACTICES

FOR INCREASING THE YIELDS OF GREENHOUSE TOMATOES

By

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Practices for Increasing the Yields of Greenhouse Tomatoes

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Yields of over 100 tons per acre of greenhouse tomatoes have been produced in experimental plantings at Michigan State University. While these are not world record yields compared to those obtained during a longer growing season in some European countries, they are far above the average. Several new practices, some of which have already been enthusiastically adopted by commercial growers in Michigan, Ohio and Indiana, have been responsible for these high yields. Growers will quickly recognize that many of the plant growing procedures which are outlined herein for the production of greenhouse tomato crops are equally beneficial for field plantings. These suggestions are intended for the beginner as well as the experienced operator. Successful greenhouse tomato production, however, usually requires a background of several years experience as well as continuous contact with the latest scientific developments.

There is a continuing market for greenhouse-grown tomatoes. Moderate increases in acreage and production in recent years reflect an expanding and profitable industry. This bulletin describes several production practices that will enable growers to increase yields of firm and high quality fruit[2].

[1]The author is indebted to his former colleague, Dr. F. G. Teubner, now associate professor of horticulture, University of Nebraska, Lincoln, Nebraska, for his assistance in many of the studies reported herein.

Many student assistants, both graduate and undergraduate, have also contributed to these studies. Those whose services in the care of greenhouse crops and record taking deserve special attention include Martha Benson, James Lone, Allen Olsen, John Gilmore, and James Anderson.

[2]Additional information on the culture of greenhouse tomatoes may be found in the following books: Bewley, W. R., 1950, *"Commercial Glasshouse Crops,"* 509 pp., Country Life Ltd., London, England; Searle, S. A., 1954, *"Plant Climate and Irrigation,"* 154 pp., Chichester Press Ltd., Chichester, England; Went, F. W., 1957, *"The Experimental Control of Plant Growth,"* 338 pp., Chronica Bontanica Co., Waltham, Mass.

Recent bulletins include: Keirns, V. F. *et al.*, 1954, Growing greenhouse tomatoes, Ohio Agr. Expt. Sta., Ext. Bul. SB-10; Porte, W. S., 1955, Commercial production of greenhouse tomatoes, U.S.D.A. Farmers Bul. No. 2082; Vincent, C. L., 1955, Growing tomatoes in greenhouses, Wash. State Agr. Expt. Sta. Cir. 276; Wiebe, J., 1959, Greenhouse vegetable production in Ontario, Ontario Dept. of Agr. Bul. 526.

Select the Proper Variety[3]

The Michigan-Ohio Hybrid is the leading and recommended red variety for greenhouse production in Michigan and adjoining areas. It is a first generation (F_1) hybrid of Michigan State forcing and the Ohio W-R Globe. Special selections of Michigan State forcing that produce a medium sized fruit are hybridized by using pollen of either the Ohio W-R 3 or the Ohio W-R 7 Globe. The resulting high yielding hybrid produces large flower clusters. It sets fruit better than either of the parents in dark cloudy weather. The mature fruits are round, firm, well colored, uniform in size, and weigh 5 to 6 ounces.

Wherever pink tomatoes are grown the Ohio W-R 7 Globe predominates. Yields, however, are slightly lower, and flower and fruit clusters smaller. Fruit setting is more difficult than with Michigan-Ohio Hybrid. The fruit are large (6 to 7 ounces) but they lack uniformity. They are often undesirably flattened rather than globe shaped.

Both the above varieties are resistant to Fusarium wilt ("yellows") but are susceptible to Verticillium wilt, leaf mold, and tobacco mosaic virus. Work is in progress to develop acceptable large fruited globe-type red and pink varieties having mosaic, Fusarium wilt, Verticillium wilt, and leaf mold resistance[4]. Several promising mosaic resistant red and pink selections are now under trial in commercial greenhouses. Varieties especially adapted for fall planting are also being developed, and some look promising. Breeding for disease resistance is a continuing, year to year program. Growers should keep in close contact with experiment stations for latest developments.

Sowing the Seeds and Germination

Seeds should be sown in flats of soil, vermiculite, or in mixtures of soil and vermiculite. The seeds are then covered with finely screened soil or vermiculite and sprinkled lightly with water. Old flats and pots and soil should be thoroughly sterilized by steam heating before using. Rapid drying of the seed can be prevented after seed-

[3]Seeds of recommended greenhouse tomato varieties are available from only a few commercial companies. Growers may direct inquiries for seed of the Michigan-Ohio Hybrid to Grand Rapids Growers, Inc., 401-433 Ionia Ave., S.W., Grand Rapids, Michigan; Joseph Harris Co., Inc., Rochester 11, N. Y.; Roy Burghart, Greenville, Michigan; or to the Gortsema Greenhouses, 421-28th St., S.E., Grand Rapids, Michigan.

Seed of the Ohio W-R 7 Globe may be procured from the Letherman Seed Co., 501 McKinley Ave., N.W., Canton 2, Ohio, and from the Cleveland Greenhouse Vegetable Growers' Cooperative Association, Schofield Building, 2014 E. 9th Street, Cleveland 15, Ohio.

[4]The greenhouse tomato variety improvement program at Mich. State Univ. is in cooperation with Dr. S. Honma, also of the department of horticulture.

ing by covering the flats with a pane of glass or by holding the temperature at about 60°F for 2 to 3 days. The seed flats can then be placed above steam pipes or in any convenient location where the temperatures are 65 to 70°F.

A helpful practice, to avoid handling of young plants and the spread of mosaic, is to seed directly into pots. The plants can then be grown without personal contact until transplanted permanently into ground beds. Direct seeding into pots also results in more rapid growth and earlier development of seedlings. Many growers, however, to conserve space and heat, prefer to seed into flats and then later "prick-off" the seedlings into pots.

Plants for the main spring crops are usually grown, till near flowering, in 4-inch clay pots. They are then spaced progressively farther apart as the plants grow. Crowding, resulting in touching or overlapping of the leaves of neighboring plants, should be avoided. This type of spacing can be most conveniently managed with clay pots.

Peat pots can also be used if they are moved only when dry. Peat pots are becoming increasingly popular for growing plants for fall crops where wide spacing before transplanting is not practiced and the plants are transplanted at a young growth stage. Since they are not re-used, storage and sterilization problems are bypassed. Open bottom containers (bands) have not been accepted. The roots are not confined and moisture levels cannot be controlled. Soil blocks are used extensively in the Leamington, Ontario area, but have not met with favor elsewhere.

Time of sowing the seed varies with locality. In western Michigan most growers sow their seed in late December and early January. Plants are ready for setting in ground beds in late February and March. Harvest begins in May and the greatest volume of fruit ripens in early July. Seed may be sown, however, from early October to February 1.

Plants from the first seedings are set into ground beds by mid-December and harvest begins in late February or early March. Seed for most early plantings, however, is sown in early November, and the plants are set in the ground beds in January. Harvest of fruit begins in early April and the largest volume of fruit ripens in late May or early June.

For spring crops in plastic greenhouses, seed may be sown as late as February 1. Seed for fall plantings is usually sown between June

25 and July 1. The harvest season for a fall crop usually extends from October 1 to December 20.

It is a very difficult and usually a non-profitable enterprise in Michigan and neighboring states to produce greenhouse tomatoes for harvest from December to April. Sunlight is extremely deficient during fruit setting and ripening, growth is slow, fruit quality is poor, and fuel costs prohibitive. Even for plantings which are seeded from October 1 to December 15, special care by experienced operators must be exercised in controlling growth during cloudy weather; fuel costs may be excessive, and heating facilities inadequate.

Some growers produce both fall and spring tomato crops. Many hazards, however, are encountered. It is difficult to prevent mosaic virus transmission from one crop to the next even though plant houses are isolated from the main growing areas. An additional mid-winter steam sterilization of the soil to reduce disease carry over is expensive. This may also release excessive quantities of nitrogen which unfavorably affect growth and fruiting. Planting schedules for both fall and spring crops are often delayed because of the short time allowed between removing one crop and planting the next.

The Cold Treatment for More Flowers

The first objective for increasing a tomato fruit crop is earlier and more prolific flowering. Of the many plants that are grown for their fruit, the tomato is one of the few in which there is a shortage of early flowers. This is particularly true of greenhouse crops. It is important that flowering and fruit setting occur abundantly and as early as possible.

Flowers are formed three to four weeks before the first flower buds are visible. For the first clusters this is within the 10-day to three-week period following the unfolding of the seed leaves (cotyledons). During this time temperature, light, and the mineral nutrient supply are very important. The position of the first flower cluster, in relation to the number of leaves on the stem, is determined within a few days after the seed leaves unfold.

Night temperatures of 52 to 54°F (in contrast to usual growing temperatures of 60 to 65°F) for the two to three weeks following cotyledon expansion benefit growth, flowering and fruiting as follows:

(1) The plants develop larger cotyledons, thicker stems, and darker green leaves with a tinge of purple on the under side.

Fig. 1. Typical compound flower cluster on a plant which may be obtained by following the recommendations outlined in this bulletin (var. Michigan-Ohio Hybrid).

(2) There are one to three fewer leaves formed before the first cluster (Table 1). Consequently, plants flower nearer the ground level.

(3) Flower numbers in the first and often in the second cluster may be doubled (Table 1). Ten to 12 flowers on branched (compound) clusters are common (Fig. 1).

TABLE 1—Effects of cold treatment of tomato seedlings and time of planting on the number of leaves before the first flower clusters and the number of flowers in the first clusters

Planting date	Leaves before 1st cluster: Continuous (60-65°F)	Leaves before 1st cluster: Cold treatment (52-54°F)	Flowers in 1st cluster: Continuous (60-65°F)	Flowers in 1st cluster: Cold treatment (52-54°F)
October 9	7.5	6.0	6.2	11.7
October 30	9.3	6.4	5.4	6.8
December 2	9.4	7.9	5.2	7.3
January 6	7.7	6.8	6.5	10.6
February 3	7.1	6.2	6.5	12.4

(4) Fruit clusters are larger, and early and total yields are increased (Table 2 and Fig. 2).

TABLE 2—Pounds of marketable fruit harvested from 8 clusters as affected by cold treatment of seedlings of Michigan-Ohio Hybrid and Ohio W-R 7 Globe tomatoes

Cluster number	Michigan-Ohio Hybrid: No cold treatment	Michigan-Ohio Hybrid: Cold treatment	Ohio W-R 7: No cold treatment	Ohio W-R 7: Cold treatment
1	2.0	2.6	2.1	2.4
2	2.2	2.6	2.3	2.4
3	1.9	2.2	2.2	2.3
4	2.1	2.7	1.9	2.1
5	1.7	2.3	1.9	1.9
6	2.0	2.4	1.9	2.1
7 & 8	3.7	4.1	3.4	3.9
Total yields (lbs/plant)	15.6	18.9[a]	15.7	17.1[a]

[a]Fruit yields significantly greater than those not given the cold treatment.

Fig. 2. Large fruit clusters, averaging in excess of 2 pounds per cluster, may be obtained by following the recommendations described in this bulletin.

Recent experiments have shown that low root (soil) temperatures are more important than top (air) temperatures in obtaining the best results from the cold treatment. When tomato plants are given the cold treatment it is important that growth be slowed but not completely stopped. Where there is no growth flower buds will not develop.

Recommendations for the cold treatment of tomato seedlings:

Two to three days after the seed leaves unfold (Fig. 1A) air and soil temperatures should be lowered to 52 to 54°F for 10 days to 3 weeks. A 10- to 12-day cold treatment is adequate during periods of good sunlight. Three weeks are usually necessary in the fall and early winter when most of the days are cloudy and plant growth is slow. The cold treatment should be started just as the first true leaves emerge (Fig. 3A), whether the seedlings are still in seed rows or pricked-off. The amount of cold during the critical 10-day to 3-week period is more important than the time of day in which it is given. Cold exposure either during the day or night, or both, is effective. Night temperatures

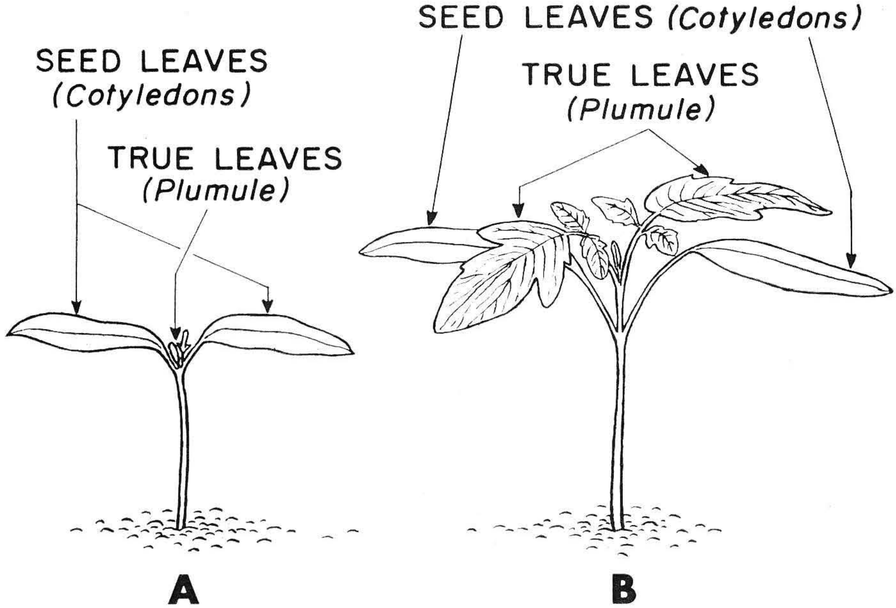

Fig. 3. Diagrams (life size) of tomato seedlings. A—(left), cold treatment for increasing flower numbers in the first cluster should begin at this stage. The cotyledons are fully expanded and the true leaves are emerging. B—(right), chemical treatment for increasing flower numbers in the first cluster should be applied at this stage. The true leaves are approximately 1 inch long.

of 52 to 54°F and 54 to 56°F during the day in sunny and partly cloudy weather are recommended.

Following the cold treatment, night temperatures should be raised to 57 to 58°F. Cool daytime temperatures (58 to 60°F) should be maintained in cloudy dull weather. On bright sunny or partly cloudy days temperatures of 65 to 70°F accompanied by good ventilation are suggested (Table 3).

TABLE 3—Night and day temperature schedules, from seed germination to fruiting, for the production of a spring crop of greenhouse tomatoes

Growth stages	Sunlight conditions	Recommended temperatures in degrees Fahrenheit[a] Night	Day
Seed germination	Not critical	65 to 70	65 to 70
After cotyledon expansion (Fig. 1A) begin the "cold treatment" and continue for: 10 days to 2 weeks during	Sunny or partly cloudy days	52 to 54	54 to 58
2 to 3 weeks during	Cloudy or dull days	52 to 54	54 to 56
After the "cold treatment" and until the plants are transplanted into beds:	Sunny or partly cloudy days	57 to 58	65 to 70
	Cloudy or dull days	57 to 58	58 to 60
During flowering and fruiting when outdoor conditions permit control of greenhouse temperatures by ventilation:	Sunny or partly cloudy days	58 to 60	65 to 75
	Cloudy or dull days	57 to 58	60 to 62

[a]Air temperatures recorded at average plant level. Soil (root) temperatures may be even more critical than air temperatures during the early growth stages. For young plants root temperatures should be close to the listed air temperatures. The ranges in night and day temperatures given to accommodate slight differences among varieties. For example, the Ohio W-R 7 Globe has a slightly higher temperature requirement than the Michigan-Ohio Hybrid.

Chemical Treatment for More Flowers

Increased flower number and fruiting may also be attained by spraying plants with N-m-tolylphthalamic acid[5] during the time the flowers are formed. Treated plants produce branched and elongated clusters that have two to four times the normal number of flowers

[5]Commercially available as a 20 percent wettable powder from the Naugatuck Chemical Co., Naugatuck, Conn., as Duraset 20-W.

With the passage of the Delaney clause of the Miller bill August 7, 1959, all growth regulating chemicals including flower forming substances and fruit setting agents cannot be used after March 5, 1960, without the approval of the Food and Drug Administration. Accordingly, N-m-tolylphthalamic acid cannot be used on tomato seedlings unless it is registered with the Food and Drug Administration or an extension is granted.

(Fig. 2). Under conditions of high nutrition and adequate sunlight, phenomenally large fruit clusters may then develop (Fig. 1).

The chemical treatment can be used in place of cold treatment, such as in fall crop plantings where the cold treatment cannot be used. Increases in flower numbers may be obtained at any stage during growth. Any flower cluster may be affected if the chemical is sprayed on the plant at the proper time. The chemical treatment can be used to increase the productivity of any cluster. The "cold treatment" must be confined to the first one or two clusters.

Some growers have combined the cold and the chemical treatments. The results are roughly additive and flower and fruit numbers may be quadrupled (Figs. 1 and 2). There is little advantage, however, in combining the two. Adequate flower numbers can be obtained by either treatment.

The chemical breaks down very rapidly and leaves no residues in the sprayer, on the plant, in the fruit, or on the soil. Leaves of treated plants may droop or flag slightly for a few days. Later the stems may elongate slightly and the leaves turn a darker green. One or two large misshapen flowers or fruit may occur on sprayed plants, but these can easily be removed during pruning. There is a more serious consequence of the chemical treatment. If dosages in excess of the recommended are applied, many plants terminate ("top-off") in a flower cluster. One or more flower clusters may be skipped. Usually a strong side-shoot, however, will develop and replace the leader.

The chemical treatment increases flower numbers but does not affect early fruit set. Because of occasionally unpredictable results with the chemical treatment, most commercial growers prefer the cold treatment for promoting early flower formation. However, the potential possibilities of the chemical treatment should not be ignored.

Suggestions for the chemical treatment of tomato seedlings:

> Prepare the spray mixture just before using. Add 1 to 2 grams[6] of the commercial 20 percent wettable formulation to 1 gallon of tap water. Shake well before using. To increase flowers on the first cluster, spray when the first two true (plumule) leaves are approximately 1 inch in length (Fig. 1B). This is usually 7 to 10 days after the seed leaves have unfolded. Spray when 4 to 5 true leaves have appeared to obtain increased flower numbers on the second cluster, when 7 to 8 leaves have

[6]The services of a local druggist may be needed in weighing out these small quantities.

appeared for the third cluster, and so forth. This is because three leaves usually occur between each flower cluster. The young leaves and growing tips should be sprayed with a fine mist of the chemical solution until it begins to run off. One gallon of solution should treat 1500 to 2000 plants at the size that the first cluster is affected.

Maintain Young Plants at High Nutrient Levels for More Flowers

The best results from the cold or chemical treatment of tomato seedlings can be obtained only if soil nutrient levels are high. Potted plants and those transplanted to ground beds should be heavily fertilized. During the dark cloudy weather of late fall and early winter, growth of potted plants should be controlled by withholding water, not mineral nutrients. High nitrogen and phosphorus levels during the early seedling stages are necessary for the maximum number of flowers.

In a typical experiment, as the nitrogen was increased flower numbers were increased (Table 4). The more nitrogen the plants received, the more flowers they produced. The addition of phosphorus also increased the number of flowers in the first cluster. Cold treated plants had the most flowers at the highest levels of both nitrogen and phosphorus.

TABLE 4—Effects of nitrogen and phosphorus levels on flower numbers of the first clusters of tomato plants that received the cold treatment

Phosphorus levels—(p.p.m.)		Nitrogen levels—(p.p.m.)			Phosphorus level means
		Low (100)	Medium (200)	High (400)	
		(flower numbers in first clusters)			
Low	(15)	9.7	8.7	14.3	10.9
Medium	(30)	7.3	9.3	15.0	10.5
High	(60)	5.3	12.3	15.3	11.0
Nitrogen level means		7.4	10.1	14.9	

Ideal potted tomato plants can be grown according to the following fertilizer program. Spacing between plants should be adequate and growth controlled by withholding water. Leaves will be dark green and closely spaced, the stems thick and sturdy, and the flower buds will be early and well formed. If fertilizer is applied frequently good growth in potted plants can be maintained. This should be until the flower buds are well developed on the first cluster without undue hardening of the plants.

Recommendations for maintaining high soil nutrient levels for young tomato plants:

> As seedlings emerge in seed flats or the seed bed, water them with a solution of soluble fertilizer[7]. It should be high in phosphate with moderate levels of nitrogen and potash. Use ½-ounce per gallon when watering. When the plants are "pricked-off" into pots or beds, water once again with the above fertilizer soultion. Repeat at five to 10-day intervals until the plants are transplanted into the ground beds. When the plants are small fertilize every 10 days with ½ ounce per gallon of water. Two to three weeks before setting into ground beds fertilize every 4 or 5 days with 1 ounce of fertilizer per gallon of water. This is equal to 3 pounds in 50 gallons of water and is enough for a single watering of 1500 to 2000 potted plants.

The Effect of Sunlight Intensity and Season on Tomato Flowering

Most tomato plants for spring crops in greenhouses are started when sunlight is insufficient for best growth, flowering and fruiting. In Michigan, and adjoining areas, this period usually extends from October 15 to March 15. The effectiveness of the cold and chemical treatments and fertilizer is limited by the many dull, sunless, and short days of autumn and early winter.

Data in Table 2 show that there were more leaves and fewer flowers from seedings grown from late October through early December than from those after January 1. Tomato plants produced fewer flowers when the light intensity was low. The cold treatment for increasing flower numbers on plantings grown under low light intensities was less effective than when sunlight was plentiful. Similar results have been observed for chemical treatments and high fertility levels.

Artificial Lights

The use of artificial lights in tomato plant growing deserves mention. In some northern European countries (Denmark, England,

[7]For example: 10-52-17, 10-50-10, 15-52-9 or other fertilizers with similar analysis. These are primarily mixtures of di-ammonium phosphate and mono-potassium phosphate.

and Holland) beneficial results have been reported. High intensity mercury vapor lamps with small reflectors have proven most useful in commercial greenhouses. Greatest benefits from artificial lights are derived during the cloudy days of mid-winter where the daylight hours are considerably shorter than they are in the United States.

Small seedlings occupying a limited area are usually given 12 hours of high intensity (800 to 1,200 foot candles) artificial light daily for a three- to four-week period. There is no advantage in using low intensity (25- to 100-foot candles) incandescent lamps on tomato plants in mid-winter to extend the daylight period. Flowering is earliest if well fertilized tomato plants are grown under a 9-hour daily exposure to high light intensity (3,000 foot candles). This should be accompanied by night temperatures of 52-54°F during the critical two weeks after the cotyledons unfold.

Ground Beds Should Be Fertilized and Steam Sterilized Before Transplanting

Soils used for greenhouse tomato production should be high in organic matter. This may be accomplished by an annual application of the equivalent of 100 yards (tons) of manure per acre.

If manure is not available, or if soluble salts are high, growers should work large quantities of organic matter into the soil from the mulches used on the previous crop. An annual application of 1,000 or 2,000 pounds of a commercial fertilizer such as 0-20-20 or 0-20-0 (superphosphate) is usually needed. The 1,000-pound per acre application is usually adequate for soils in old greenhouses, while 2,000 pounds may be desirable in new greenhouses.

Most growers in the Grand Rapids, Michigan, area will also benefit from an annual application of 100 to 200 pounds of manganese sulphate per acre. This is especially true where the soil pH is 6.8 or above. All of the above fertilizers should be tilled into the soil before transplanting the crop.

Steam sterilization of the soil once a year is necessary for sustained high production of greenhouse tomatoes. This should be from permanently installed underground tile or their equivalent. Steaming of the soil should be thorough, and of sufficient duration to kill all weed seeds, insects, nematodes, and disease organisms. Serious losses from *Verticillium* and *Fusarium* wilts and mosaic virus to many plantings can be avoided by proper sterilization of the soil before planting. Soil steaming should follow the addition of manure and precede planting by at least six weeks. This allows the soil to cool and dry. Toxic levels of ammonia and manganese formed from heating the soil can also escape or be broken down.

Pre-Transplanting Handling of Plants and Transplanting into Ground Beds

Every means should be employed in tomato plant growing for maximum utilization of the available sunlight for flower formation. The cold treatment should be followed by night temperatures no higher than 57 to 58°F. Day temperatures should not exceed 65 to 70°F on sunny or partly cloudy days, and 58 to 60°F on cloudy days (Table 1). Plants should be held as dry as possible without wilting, and fertility levels kept high by periodic watering with soluble fertilizers high in phosphate.

Good growth without excessive elongation should be maintained. The width of the potted plants should at all times be equal to or even greater than the height (Fig. 4). The cotyledons should be large, the stem thick, and the leaves dark green and spaced close together[8]. When the leaves of potted plants begin to touch they should be progressively spaced farther apart.

This is especially important during the 2 to 3 weeks prior to transplanting into the ground beds. Plants should be transplanted when the first flower buds become prominent. This is a week to 10 days before they open (Fig. 4, right). If high fertility levels are maintained and watering and spacing are carefully controlled, plants may be held in pots until they flower. During the late fall and winter this will be 60 to 70 days after seeding. At no time should nutrients be withheld to suppress growth.

Soil in the ground beds at the time of transplanting should be dry or only slightly moist. The soil temperature should also be close to the desired air temperature. If a watering solution is used at transplanting, the usual 1-ounce per gallon of an all-soluble fertilizer high in phosphate is added. Plants should then be spot watered as needed for several weeks after transplanting. Once established they should go for several weeks without a general irrigation.

[8]Several new chemicals, such as (2-chloroethyl)trimethylammonium chloride, recently discovered and under test at Michigan State University, greatly aid in producing this type of growth. Both early and total yields of winter and spring crops have been increased by periodic watering of young potted plants with solutions containing a few parts per million of the chemical. These growth substances are available only for experimental use. Growers should not use them on plants for commercial plantings until additional research has been conducted, and until approval has been granted by the Food and Drug Administration.

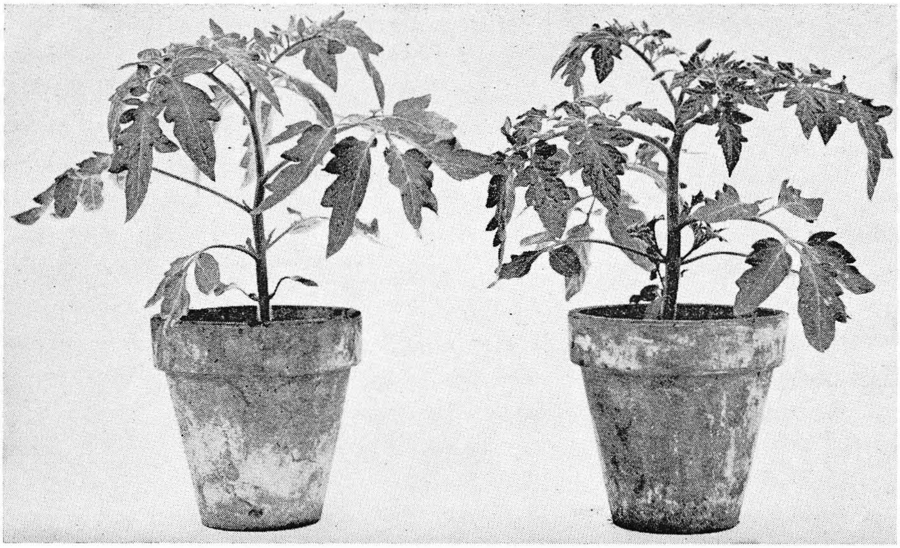

Fig. 4. The width of potted plants should at all times be equal to or even greater than the height, the stems thick, and leaves dark green and spaced close together. Flower buds should also be prominent such as on the plant on the right at the time of transplanting into ground beds. Plant on right treated with (2-chloroethyl)trimethyl-ammonium chloride, control on left. Plants in 4-inch clay pots.

Mid-winter plantings at Michigan State University, on a heavy loam soil, are not given a general irrigation until eight to 10 weeks after transplanting. Percentages of available soil moisture during this period range from 10 to 20 per cent at a depth of 6 inches. Twelve inches below the soil surface the percentage of available moisture is 30 to 60 percent. No general irrigation program is started until moisture levels are below 20 percent in the first 12 inches of soil[9].

A unique irrigating and fertilizing practice has proven ideal for some experimental plantings, and is now being adopted by some commercial growers. Each row of plants is set in a depression or furrow about 4 inches deep and 10 inches wide. All irrigation water and soluble fertilizer, throughout the season, is added in the furrow along the plant rows. In this system only the soil in the depression along the plant row is watered. The surface soil between the rows is heavily mulched with straw and always dry.

Spacing and Training

There is no agreement among growers as to the most desirable distance between rows or plants in the row. Usually 8,500 to 9,000

[9]Determined by use of the Bouyoucous soil moisture meter and gypsum soil blocks. Available from Industrial Instruments, Inc., 89 Commerce Road, Cedar Grove, New Jersey.

plants per acre are used for fall and early spring plantings. Late spring plantings will vary from 9,300 to 10,000 plants per acre. Excellent results have been obtained by spacing plants 15 inches apart in 42-inch rows. This spacing will give approximately 10,000 plants per acre.

The use of a wide-paned glass is highly recommended where new greenhouse units are to be constructed or old ones reconditioned. Glass sash 20 inches in width or wider in modern greenhouses greatly increases the amount of sunlight transmitted into the houses. More plants per acre can thus be planted and yields increased accordingly.

Plants are usually trained to a single stem. All sideshoots should be removed at least weekly. The plants are occasionally supported by stakes but usually by baler or binder twine. One end of the twine is tied with a small non-slip loop to the base of the plant. The other is attached to a wire supported 6 to 8 feet above the plant row. The string is then wound around the plant once or twice for each fruit cluster. An extra length of twine is allowed for loosening and lowering the plants periodically late in the fruiting season when the tips of the vines reach the wire to which the twine is attached. Flowering, fruit setting, and fruit ripening occur on all successive clusters at about the same height with this method of training. This aids greatly in pruning, pollination, and harvesting.

Alternate training methods late in the growing season include running the vines horizontally along the wires to which the twine is attached or training them overhead and across the rows.

Pollination

High yields of greenhouse tomatoes can be produced only if the flowers set fruit. The first flower clusters on each plant should be vibrated daily with an electrically operated vibrator[10]. Pollen is shed most abundantly on bright sunny days between 10 a.m. and 4:00 p.m. Wind machines, air jets, and other gadgets have not proven completely satisfactory for pollination. Tapping or jarring the wires is effective only on flower clusters which set fruit during May and June and are three to four feet above the ground level.

Regular vibrating for pollination, pruning and training are necessary in greenhouse tomato production. These practices, however, often result in rapid transmission of mosaic virus diseases from infected to healthy plants. When growers discover infected plants these should

[10]Invented by R. Zinn, 25 West Schaaf Road, Cleveland 31, Ohio. Available from Vernon Kraushaar, 400 Tuxedo Ave., Cleveland 31, Ohio.

be handled only after healthy plants have been cared for. Separate equipment should also be used.

Fruit Setting Chemicals

Many chemicals sprayed onto tomato blossoms will cause the fruit to grow without pollination. At one time fruit setting chemicals were widely used in many commercial greenhouse plantings. The practice, however, was quickly discontinued and even outlawed by some co-operative marketing groups. Indiscriminate use of chemical sprays by many growers and their failure to use good accompanying cultural practices resulted in soft and misshapen fruit of poor color and storage quality. Chemical growth substances have been used to an advantage where their application was restricted to the first flower clusters. They may also be used to supplement but not replace regular vibration of the flowers for pollination. The tendency has been, however, for growers when they use chemical sprays to rely on them exclusively. Other practices to insure good fruit set were neglected. If chemical sprays for fruit setting are applied to the later forming flower clusters and the fruit ripens in hot weather, the chemically set fruit is often of inferior quality.

In view of the many hazards involved where fruit quality may be impaired, chemical sprays for improving fruit setting of greenhouse tomatoes are not generally recommended. Furthermore, all functional flowers that a tomato plant produces can usually be induced to set fruit by use of the electric vibrator described above, if the cultural practices outlined in this bulletin are followed[11].

Watering and Fertilizing Spring Crops

Top yields of high quality greenhouse tomatoes cannot be obtained if fruiting plants become deficient in moisture or mineral nutrients. Long sustained production is accomplished only by timely watering and generous feeding with soluble mixtures of nitrogen, phosphorus, and potash in proper proportions. One of the best methods of adding soluble plant food is in the irrigation water. Fertilizer salts that contain no chlorides, sodium, or sulfates are recommended. These include di-ammonium phosphate, mono-potassium phosphate, ammonium nitrate, potassium nitrate, and urea.

[11]Chemical spray solutions that may be used as a supplement to pollination for stimulation of fruit setting in greenhouse tomatoes are available from Holwerda greenhouses, 612-38th St., S.E., Grand Rapids, Michigan, and from several commercial chemical companies. In view, however, of the Delaney clause of the Miller bill already referred to, fruit setting sprays should be discontinued on commercial plantings until their use has been cleared by the Food and Drug Administration.

The use of these fertilizers will avoid the dangers of salt accumulation in the soil (Table 5). A satisfactory fertilizer and irrigation program should produce thick-stemmed tomato plants. Leaves should be dark green, flower clusters large, and fruit clusters closely spaced (Figs. 5 and 6). A properly nourished plant should display stem growth ½-inch thick at a point 6 to 8 inches below the growing tip (Fig. 5).

Four or five large clusters of fruit exert a great demand for all available food reserves in the tomato plant. If nutrients or soil moisture are in short supply, newly developing flowers will not set fruit. The diameter of the new stem growth becomes smaller and flower number is reduced. One or more clusters of fruit may be partially or completely lost before the competition for nutrients is relieved by removal

Fig. 5. Tomato plants should display stem growth ½-inch thick at a point 6 to 8 inches below the growing tip. Plants should be thick-stemmed, with large flower clusters and closely spaced fruit clusters. Experimental spring planting, Michigan State University, March 4, 1959.

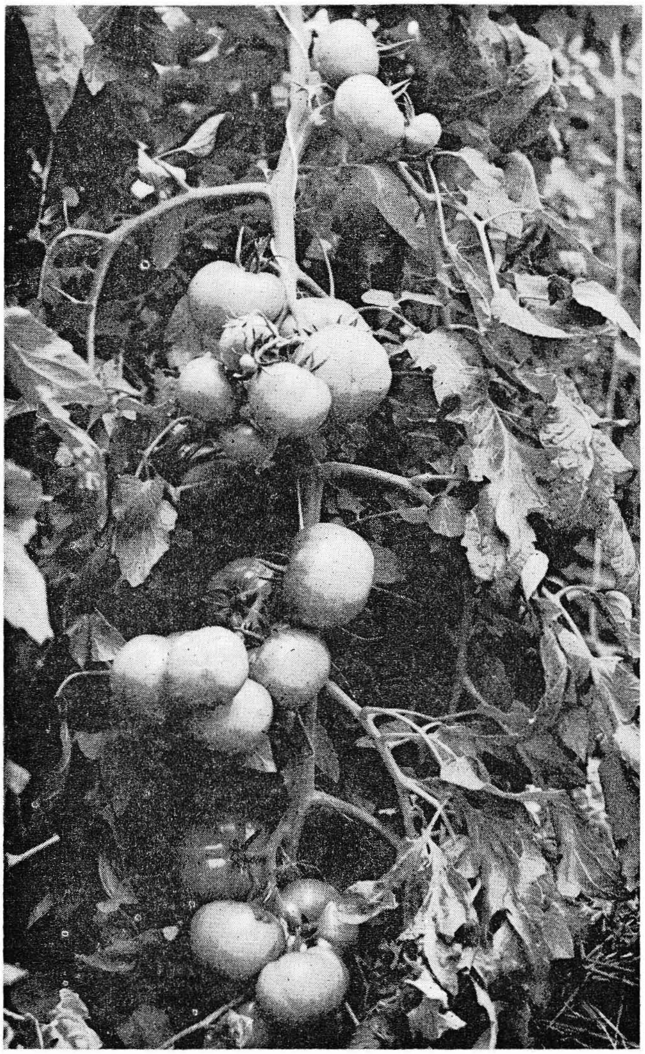

Fig. 6. Four or five large, closely spaced clusters of fruit exert a great demand for all available food reserves in the tomato plant. Adequate fertility and soil moisture supplied at this stage and thereafter to maintain growth and fruiting resulted in excess of 2 pounds of fruit per cluster for 12 clusters, and total yields exceeding 100 tons per acre. Experimental spring planting, Michigan State University, April 8, 1959.

of the ripening fruit from the bottom clusters. This results in greatly reduced yields and a short supply of fruit during critical periods of the harvest season.

TABLE 5—Changes in nutrient levels of greenhouse soils during growth of a late spring tomato crop with and without fertilizer added during the growth of the crop (Spring 1958)[a]

Date of sampling	No fertilizer added during growth of the crop					Fertilizer added during growth of the crop				
	pH	Soluble salts[b] ("K" value)	Pounds per acre N	P	K	pH	Soluble salts[b] ("K" value)	Pounds per acre N	P	K
March 21	7.3	77	44	136	410	7.3	78	44	146	425
April 21	7.6	60	39	145	605	6.9	70	44	225	720
May 22	7.5	19	11	190	117	6.6	60	44	450	450
June 21	7.8	20	2	123	176	6.7	70	88	420	1500
July 21	7.7	18	5	141	175	7.1	40	44	420	1300

[a]These studies conducted in cooperation with Dr. R. E. Lucas, department of soil science, Michigan State University.
Soil nutrients determined by the Spurway "active" method.

[b]"K" value for soluble salts equals conductivity in mhos x 10^{-5}, for a 1 to 2 soil-water extraction.

TABLE 6—Fertilizer program for greenhouse tomatoes that received preplanting and supplemental fertilizer applications—early spring experimental crop, East Lansing, Michigan, 1959 (November 7, 1958 to July 15, 1959)

Date of application	Pounds per acre N	P_2O_5	K_2O	Pounds of fertilizers applied per acre during growth of the crop: Diammonium phosphate plus monopotassium phosphate[c]	Potassium nitrate	Ammonium nitrate
Preplanting						
Manure[a]	1,000	500	1,000	—	—	—
0-20-20[b]	—	300	300	—	—	—
During Growth						
March 27-April 9	92	208	244	400	400	—
April 10-April 23	69	156	183	300	300	—
April 24-May 7	118	78	157	150	300	200
May 8-May 21	39	—	132	—	300	—
May 22-June 4	103	—	132	—	300	200
June 5-June 12	103	—	132	—	300	200
Total for the crop	1,524	1,242	2,280	850	1,900	600

[a]The equivalent of 100 tons of manure added per acre. Nitrogen valued at 10, phosphate at 5 and potash at 10 pounds per ton.

[b]The equivalent of 1500 pounds of 0-20-20 fertilizer applied per acre.

[c]Equal parts by weight.

Fertilizing schedules for early and late spring crops of greenhouse tomatoes are outlined (Tables 6 and 7). An irrigation program for an early spring crop is shown in Table 8. Such frequent irrigations may necessitate the furrow system where the water is confined to the plant row. Or irrigation pipes may be lowered to near the ground level to avoid excessive moisture on the foliage during the late fruiting period.

These schedules have given high sustained production through 8 fruit clusters for a late spring crop (Table 3), and through 12 clusters (Table 9) for an early spring crop. High yields were maintained through 12 clusters with desirable fruit numbers and size. Yields of almost 19 pounds per plant (88 tons per acre) were obtained for a late spring crop in 1958. Close to 25 pounds per plant (over 100 tons per acre) were harvested for an early spring crop in 1959 with the fertilizer schedules given in Tables 6 and 7.

TABLE 7—Fertilizer program for greenhouse tomatoes that received preplanting and supplemental fertilizer applications—late spring experimental crop, East Lansing, Michigan, 1958 (December 23, 1957 to July 17, 1958)

Date of application	Pounds per acre			Pounds of fertilizers applied per acre during growth of the crop	
	N	P_2O_5	K_2O	Diammonium phosphate plus monopotassium phosphate[c]	Potassium nitrate
Preplanting					
Manure[a]	1,000	500	1,000	—	—
0-20-20[b]	—	300	300	—	—
During Growth					
April 21-May 4	20	104	34	200	—
May 5-May 18	80	416	136	800	—
May 19-June 1	92	208	244	400	400
June 2-June 15	92	208	244	400	400
June 16-June 29	98	104	298	200	600
June 30-July 11	52	—	176	—	400
Total for the crops	1,434	1,840	2,432	2,000	1,800

[a]The equivalent of 100 tons of manure added per acre. Nitrogen valued at 10, phosphate at 5 and potash at 10 pounds per ton.

[b]The equivalent of 1500 pounds of 0-20-20 fertilizer applied per acre.

[c]Equal parts by weight.

TABLE 8—Irrigation program for an early spring crop of greenhouse tomatoes[a]

Week	Number of applica-tions	Gallons per plant	Inches per week
March 23-27	1	2	0.74
March 30-April 3	1	1	0.37
April 6-10	1	1	0.37
April 13-17	2	2	0.74
April 20-24	2	2	0.74
April 27-May 1	3	3	1.11
May 4- 8	3	5	1.85
May 11-15	3	5	1.85
May 18-22	3	6	2.22
May 25-29	3	6	2.22
June 1- 5	3	6	2.22
June 8-12	3	6	2.22
June 15-19	3	6	2.22
June 22-26	3	6	2.22
June 29-July 3	3	6	2.22
July 6-10	3	6	2.22
July 13-17	3	6	2.22

[a]Crop seeded November 7, 1958, transplanted to ground bed January 10 and harvest terminated July 15, 1959.

TABLE 9—Pounds of marketable fruit, numbers of fruit, and size of fruit of 12 clusters of the Michigan-Ohio Hybrid and Ohio W-R 7 Globe tomatoes grown according to procedures outlined in this report (Early spring crop, 1959)

Cluster number	Michigan-Ohio Hybrid			Ohio W-R 7 Globe		
	Lbs. of fruit per cluster	No. of fruit per cluster	Size of fruit in ounces	Lbs. of fruit per cluster	No. of fruit per cluster	Size of fruit in ounces
1	1.4	4.2	5.5	1.2	2.7	7.0
2	2.2	5.4	6.8	2.3	4.4	8.2
3	2.2	6.3	5.7	2.3	5.9	6.4
4	2.0	6.6	4.7	2.3	6.1	6.5
5	2.3	6.7	5.6	2.3	5.4	6.9
6	2.5	6.7	6.3	2.4	5.8	6.8
7	2.6	7.4	5.7	2.2	5.8	6.6
8	2.4	7.3	5.6	1.9	5.0	6.4
9	1.9	5.7	5.4	1.7	4.2	5.5
10	1.7	4.9	5.5	1.4	4.0	6.3
11	1.6	4.8	5.4	1.4	3.6	5.4
12	1.8	4.7	6.1	1.5	3.9	6.5
Totals or means	24.6	5.9	5.7	22.9	4.7	6.5

Recommendations for fertilizing a spring crop of greenhouse tomatoes:

1—From transplanting until plants have 10 to 15 fruit set, use a mixture of di-ammonium phosphate and mono-potassium phosphate. Just before or with the first irrigation, apply 150 pounds per acre. Repeat the application when the plants are watered at 10-day to two-week intervals.

2—After 10 to 15 fruit have set and until 4 or 5 good clusters have set, use both the di-ammonium and the mono-potassium phosphate mixture and potassium nitrate. Seventy-five to 100 pounds per acre of each is applied at seven- to ten-day intervals.

3—After four or five fruit clusters have set and until the plants are topped[12], discontinue the phosphate mixture and use potassium nitrate and ammonium nitrate or urea. Fifty to 100 pounds per acre of each may be applied at weekly intervals. The amount should depend on sunlight, results of soil tests for nitrate nitrogen, plant vigor, and heaviness of fruiting. Where high potash fertilization is practiced magnesium deficiencies resulting in light green or yellow spots on the leaves may appear. If so, add magnesium sulfate at the rate of 300 to 500 pounds per acre. Dolomitic limestone may be used on slightly acid soils.

If the above program is carefully followed for spring crops, high early and total yields can be expected (Tables 3 and 9). Sustained yields of 1½ to 2 pounds of fruit for each cluster can be produced (Fig. 6). For an early spring crop having 12 to 14 clusters per plant this should give 20 to 25 pounds of fruit per plant. Late spring crops having 8 to 10 clusters per plant should produce 15 to 18 pounds per plant.

The above amounts of fertilizer will more than meet minimum requirements. They are recommended because the cost of fertilizer is a small percentage of the total production cost. Growers of greenhouse tomatoes should not risk a nutrient deficiency. The amounts recommended will not cause an accumulation of salts nor will they reduce yields.

Acceptable soil nutrient levels of nitrogen (N), phosphorus (P), and potassium (K) are given in Table 10. The soluble salt reading ("K value") should be below 150, and the pH between 6.0 and 7.0.

[12]Growing tips removed two leaves above the last flower cluster.

As a general rule the tomato plant's requirement for nitrogen increases with increasing sunlight and longer days. For potassium the need increases with decreasing sunlight and shorter days. Thus, nitrogen is often in short supply for spring crops, while potassium may be the critical nutrient in the fall.

TABLE 10—Range of acceptable levels of nutrients in soils for greenhouse tomato production using the Spurway soil test method[a]

Nutrient	Pounds per acre
Nitrogen as nitrate—N	25 - 100
Phosphorus	150 - 500
Potassium	300 - 1,000

[a]Spurway, C. H. and K. Lawton, 1949. Soil Testing. Mich. Agr. Expt. Sta. Tech. Bul. 132.

The final index of fertilizer need, however, is the plant. Thickness of the stem near the growing tip, the vigor and number of the newly developing flowers, the degree of fruit setting, and leaf size and color should be watched closely. These features in combination with the results of periodic soil tests[13], and consideration of the season of the year and the amount of prevailing sunlight serve as the final guides for using fertilizer and water.

Watering and Fertilizing Fall Crops

The climatic pattern during the growth of fall tomato crops, in Michigan and adjoining areas, is opposite to that for spring crops. Growers should water and fertilize the young plants frequently during August and early September when temperatures are high and sunlight is adequate. By October 15 to 20 plants should be topped[12], and fruit setting terminated. This is because fruit which is set after October 20 will not likely mature by the time the crop is removed in December. Watering and fertilizing is also greatly reduced during October, and is usually discontinued completely by mid-November. Timely termination of vegetative growth and watering is essential in the growth of fall crops. This enables the tomato plant to use the limited carbo-

[13]Many growers have found the Hoffer soil probe a convenient tool for taking soil samples, checking subsurface moisture levels, and observing the condition of the subsoil. The Hoffer probe is manufactured by the Blano Corporation, Xenia, Ohio.

hydrates that are produced under conditions of insufficient sunlight for fruit production.

An excellent fertilizer for a fall crop is potassium nitrate. It may be added liberally (100 to 200 pounds per acre per week) during late August and through September. If soil tests show a need for phosphorus, equal amounts of di-ammonium phosphate and mono-potassium phosphate may also be used. High potash levels during the fall and early winter will improve fruit quality. The tomato plant will also utilize the available sunlight more efficiently. As with spring crops the needs for fertilizer and water usually occur together. Fall crops seldom benefit from fertilizer applied after October 15.

Mulch for Top Yields of High Quality Fruit

Manure as the source of organic matter for greenhouse tomato soils is often expensive. It may also add greatly to the accumulation of soluble salts. The proper use of mulches will alleviate the problem of soluble salt accumulation, supply the necessary organic matter, and give greater control over soil nutrient levels during crop growth.

There are many other benefits from mulching greenhouse tomatoes. More uniform soil moisture is maintained. This results in less fruit cracking. Root extension is favored since roots penetrate the surface soil under the mulch and even the lower layers of the mulch itself. Soil aeration is improved and there is less soil compaction. Fruit on the lower clusters are protected from spattering of soil particles during irrigation. The heavy first fruit clusters are also supported by the mulch and protected from direct contact with the soil.

It is recommended that growers mulch with 2 to 4 inches of straw, hay, peanut hulls or other suitable material. Fifteen to 20 tons per acre may be required and they should be the type that are easily worked into the soil and broken down by soil organisms. Mulches should be free from weed seeds, and toxic chemicals such as those used in weed control.

Some growers specialize in tomatoes as a single annual spring crop. The ground beds are steam sterilized in late August. They are then planted to rye or ryegrass. This green manure crop is then worked into the soil shortly before the new tomato crop is to be transplanted. By this procedure the excess nitrogen released by sterilization is temporarily reduced and bound in organic form, and the soil organic matter is increased.

Maintain Proper Temperatures and Ventilate

Spring tomato crops should be maintained at night temperatures of 57 to 58°F during cloudy weather. Temperatures lower than 57°F will result in poor setting and fruit color. Day temperatures in cloudy weather should not exceed 60 to 62°F. This is especially important early in the season when a lack of sunlight limits growth. Daytime temperatures of 62 to 65°F for short periods on cloudy days may be desirable to aid pollination. During sunny days night temperatures of 58 to 60°F are suggested. Even with bright sunlight, if outdoor temperatures permit, day temperatures in the greenhouse should not exceed 65 to 75°F (Table 1).

Temperature has little effect on photosynthesis. Respiration, however, is increased 2 to 3 times for each 10 degrees (centigrade) rise in temperature. Thus, carbohydrate production is not appreciably increased by high temperatures even during bright sunny days. Losses, however, through respiration are doubled or tripled for each 10 degrees temperature increase. Maximum carbohydrate accumulation for fruit production occurs with greenhouse tomatoes under the relatively cool conditions outlined above. This can usually be managed by adequate and timely ventilation.

Ventilation is important for disease control and air exchange. The relative humidity should always be below 90 percent. Moisture should never be allowed to condense on leaf surfaces. Heating and ventilating at the same time may appear wasteful of fuel. It is necessary, however, for disease control, and the extra expenditure for fuel is one of the best investments a grower can make.

The most dangerous periods are during mild but muggy weather in fall and spring when growing temperatures could be maintained without heating if the ventilators were closed. This is a hazardous practice. Successful growers use heat on spring crops until early August, and begin heating fall crops long before it is necessary to maintain proper temperatures for growth. Some heating late at night and during the early morning is necessary, even with mild outdoor conditions during the summer months. This raises the temperature, which lowers the relative humidity and improves air circulation.

Plastic Houses for Fall and Spring Crops

The same recommended practices for successful production of tomatoes in glass greenhouses can be used for plants grown in plastic greenhouses. While permanent glasshouse installations are superior

Fig. 7. These large closely spaced fruit clusters were produced on a fall crop by transplanting the plants in an open frame in mid-August, and covering with plastic in late September. The chemical treatment, as outlined in this bulletin, was applied to increase flower numbers in the first three clusters. Experimental fall planting, Michigan State University, November 7, 1958.

Fruit should begin to ripen by May 25 or June 1. Shortly thereafter the plastic or sections of it could be removed. As with fall crops, ventilation, disease control, and pollination may be greatly simplified during part of the growth and fruiting period by partial or complete removal of the plastic.[14]

[14]For additional information on the construction of plastic greenhouses and their use for tomato production contact the Agr. Expt. Sta., Mich. State Univ., East Lansing, Mich.; Agr. Expt. Sta., University of Kentucky, Lexington 29, Kentucky; Agr. Expt. Sta., Mississippi State College, State College, Mississippi, or your local state agricultural experiment station.

10M—6-60—SP