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Single-Truss Tomato System — A Labor-Saving Management System for Tomato Production

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Abstract

In the single-truss system of tomato growing, the main shoot is pinched, leaving a few leaves above the first truss, and only the first truss is harvested. The objective of this system is to reduce labor requirement for training, pruning and harvesting. Workplace ergonomics is markedly improved by the use of high benches. There is no need for skillful plant operations. Soilless culture is required for the system, because several replantings are performed in a year. A “wet-sheet culture” system has been developed, in which a water-retaining sheet made of non-woven fabric is used as a growing medium. Fruit quality can be easily improved by the application of salinity stress. A large number of nursery plants are required in the single-truss system because of the dense planting and frequent replantings. Mass production of nursery plants in plug trays is recommended. In the single-truss system, no serious problems occurred even when very young plug seedlings were transplanted. An alternative way might be the use of cuttings. The roots of tomato plant cuttings emerge easily if the cuttings are placed in a medium such as rockwool. The single-truss system may be suitable for large-scale production of tomato. Continuous predictable production may be possible if the environment in the greenhouse could be adequately controlled.

Discipline: Horticulture
Additional key words: cutting, dense planting, nursery plant, salinity, year-round production

Introduction

Tomato (*Lycopersicon esculentum* Mill.) shows an indeterminate growth pattern: its shoots continue to grow endlessly, setting flower trusses at every 3 leaves. Under standard conditions of cultivation, the shoot often reaches a length of 10 to 20 m, and 25 to 30 fruit trusses can be harvested under careful crop management and environmental control. In the single-truss system of tomato growing, on the other hand, the main shoot is pinched, leaving a few leaves above the first truss, and only the first truss is harvested. Research on the single-truss cropping system was initiated in the United Kingdom in the 1960s by Cooper[1] and co-workers. Cooper invented the nutrient film technique (NFT). The objective of the single-truss system was to reduce labor requirement in tomato growing at a time when there was a shortage of workers. In Japan, Hisatomi & Fujimoto[3] evaluated the single-truss tomato system for the first time in the early 1970s. A large number of nursery plants are required in the single-truss system because of the dense planting and frequent replantings. In the 1970s, the technology for mass production of nursery plants had not been developed, and tomato plants were grown in soil culture. Therefore, the single-truss cropping system was not popular.

Recently, labor shortage in Japanese agriculture has become more acute, because growers are aging and often do not have anyone to succeed them in their businesses. Meanwhile, rapid progress has been made in the technology of soilless culture and mass production of nursery plants in plug trays. These technological advances have led researchers to re-evaluate the single-truss tomato system as a labor-saving cultural system. Studies on the single-truss tomato system are currently being conducted at several research institutes in Japan[6,16,18]. At Rutgers University in the United States, researchers have developed a

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single-truss tomato production system that uses supplementary lighting and transportable benches to achieve year-round predictable production of greenhouse tomatoes[2,7]. We have been investigating the single-truss tomato system for several years. In this paper, we outline our results and discuss the potential of the single-truss system.

Advantages of single-truss tomato system

The single-truss tomato has a very simple shape. The plant is shorter than normal, with only one truss and about 10 leaves. These characteristics give the plant several advantages over the conventional multi-truss tomato:

1) Labor requirement for training, pruning and harvesting is markedly reduced.
2) Working posture is improved by the use of elevated growing benches.
3) The process of crop management can be simplified, and since a routine can be adopted, regular workers can be employed.
4) As optimum cultural conditions can be provided for the fruits borne on the single truss, fruits with a high quality can be obtained.
5) There are very few disease and pest problems because of the short growing cycle, which reduces the need for using agrochemicals.
6) The year-round cropping schedule can be optimized to reduce seasonal labor peaks without decreasing the crop value.

Problems to be solved in the single-truss system are as follows:

1) Need for a large number of nursery plants.
2) High labor requirement, due to the frequent replantings.
3) Low fruit productivity, as there is only one truss.

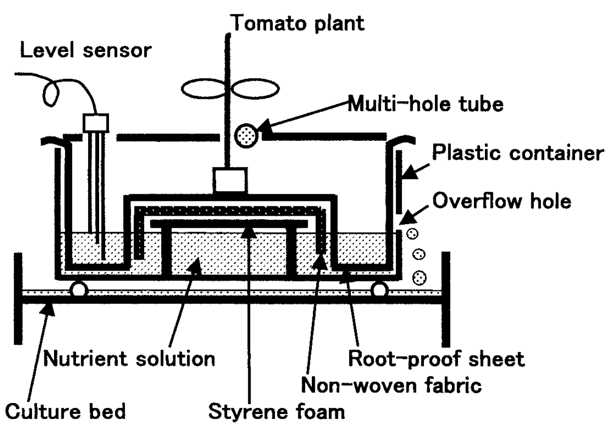

Fig. 1. Schematic diagram of the wet-sheet culture system for the cultivation of single-truss tomato

Soilless culture system

Soilless culture, often associated with NFT, rockwool, or deep flow technique, is required for the single-truss system, because several replantings are performed in a year. At present, a closed hydroponic system that uses simple and low-cost equipment is required for soilless culture. We have developed a “wet-sheet culture” system[9,15] in which a water-retaining sheet made of non-woven fabric is used as a growing medium (Fig. 1). Tomato roots develop horizontally on the wet sheets (non-woven fabric + root-proof sheet) and reach the nutrient solution wells. No aeration device is needed, as the basal parts of the root system are exposed to the atmosphere. Roots do not penetrate into the non-woven fabric, as a root-proof sheet covers it. The sheets can be easily separated from the roots after the end of cultivation and then reused. The growing bed does not need to be very strong, as only a small volume of nutrient solution is stored in it, and the grower can construct it by using styrene foam.

Nutrient solution is automatically supplied to the bed in response to the uptake of water by the roots. A level sensor controls the water level in the bed, and the electric signal is transferred to a water pump. The water content of the non-woven fabric remains constant unless the nutrient solution flows out from the bed. Surplus solution overflows through a hole in the side wall of the bed. Drainage that overflows from the beds is collected and preserved in an underground reservoir. The preserved drainage is resupplied to the growing beds and used to improve fruit quality, as described later. As a result, the plants absorb all of the drainage water and no solution is drained from the system[9].

Cultivars suitable for the single-truss system

No tomato varieties have been bred for the single-truss cropping system. Hisatomi[4] pointed out that suitable characteristics of the single-truss tomato are early ripening, small leaf, and good fruit setting. He also stated that a determinate type of tomato would be promising. We have screened tomato varieties from different viewpoints. First, we investigated varietal differences in fruit yield and quality[17]. Yield in the single-truss system was comparable to that in the conventional multi-truss one. For summer cropping of single-truss tomato, cultivars ‘Momotaro’ and ‘Palace’, which are suitable for summer–autumn growth, showed a high yield and good quality, while for winter single-truss cropping, ‘Multi-first’

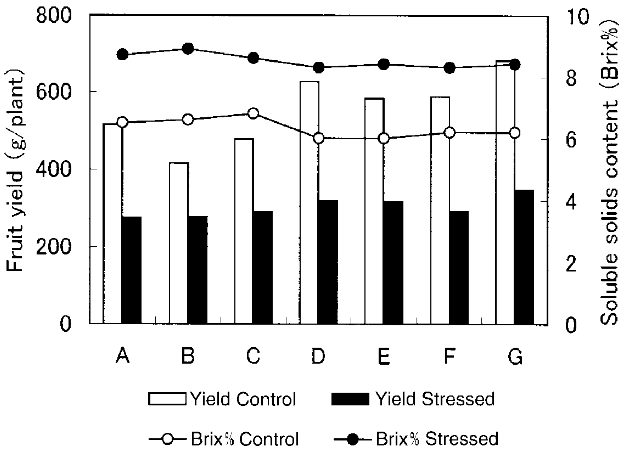

Fig. 2. Susceptibility of tomato cultivars to salinity stress in terms of effects on yield and soluble solids content of fruits

A: Momotaro, B: House Momotaro, C: Momotaro T-93, D: Supersized Serenade, E: Super First, F: First Power, G: Zuiken .

and 'Zuiken', which are suitable for winter–spring growth, were superior.

In the single-truss system, pinching of the main shoot at the early growth stage accelerates the emergence of lateral shoots. As the removal of lateral shoots is laborious and time-consuming, attempts were made to identify cultivars with fewer lateral shoots. However, these attempts were not successful. In all the cultivars examined, the lateral shoots emerged from every leaf axil after the main shoot was pinched[17].

It is well known that salinity improves the fruit quality but decreases the yield and often induces blossom end rot (BER). In the single-truss system, it is easy to subject the plants to salinity stress without inducing BER. We therefore examined the susceptibility of cultivars to salinity, in terms of changes in soluble solids content and yield of fruit[8]. In all the cultivars examined, the soluble solids content of the fruit increased by 30 to 40% by salinity at the electric conductivity (EC) 5.0 dS m^{-1}, but a decline of a similar level was also observed in fruit yield (Fig. 2). These results suggest that a high-yielding variety may be promising for the single-truss system, as it would maintain a relatively high yield even under salinity stress.

Production of nursery plants

It is necessary to prepare a large number of nursery plants in the single-truss system; several times as many plants may be needed as in the conventional multi-truss system. Momotaro costs about ¥6 per seed. If the planting density is 10,000 plants / 10 a, and there are 4.5 growing cycles a year, the total yearly seed cost will be ¥270,000. One way to reduce the seed cost is to use cuttings. The roots of tomato plant cuttings emerge easily if the cuttings are placed in a medium such as rockwool. Although there are still problems with the uniformity of seedlings and the adjustment of the cropping schedule throughout the year, the use of cuttings would be technically feasible. However, vegetative propagation of marketable seeds and commercial sale of the plant products may represent an infringement of the law. According to the law, mass propagation of such cuttings for sale by traders is prohibited, although private use of cuttings by farmers is permitted. This problem should be addressed if the single-truss cropping system is to become popular in the future.

As an alternative, we investigated an effective production system for seedlings. In tomato, if a very young seedling is transplanted to soil, it tends to grow excessively and often fails to set flower trusses. Therefore, potted plants at the flowering stage of the first truss are generally used for transplanting. However, as the raising of seedlings until the flowering stage is laborious and time-consuming, we needed to develop a procedure for using plug seedlings at transplanting. In the soilless culture of tomato, although the optimum stages for transplanting have not been determined, the transplanting procedure usually follows that used in conventional soil culture. In soilless culture, where the control of plant growth is relatively easy, no serious problems should occur, even when very young seedlings are

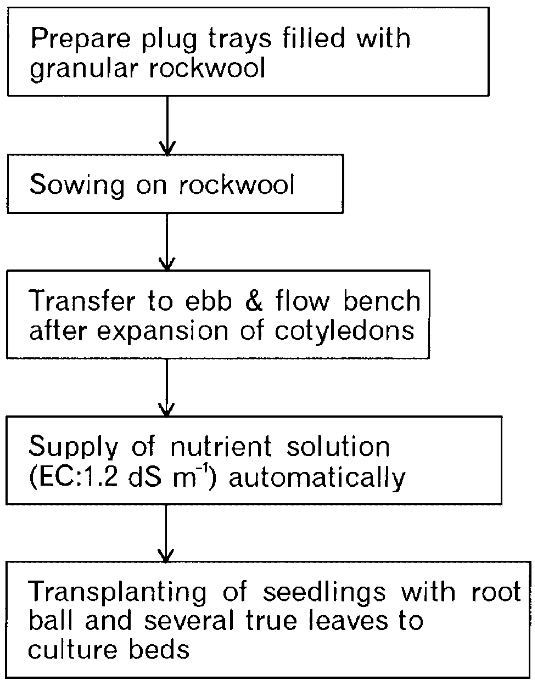

Fig. 3. Procedure for growing nursery plants in the single-truss cropping system

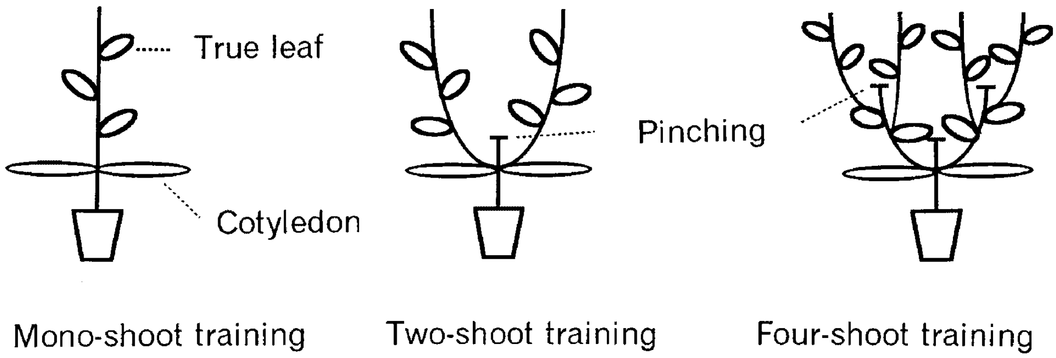

Fig. 4. Comparison of mono-shoot and multi-shoot training
The latter can be used to reduce the number of nursery plants needed in the single-truss cropping system.

transplanted[10]. We examined various growth media and irrigation methods for raising seedlings, and developed the procedure shown in Fig. 3. In this procedure, tomato seeds were sown on a plug tray filled with granular rockwool, then transferred to a pool-bench where the nutrient solution was supplied by sub-irrigation. With this procedure, the labor required for raising seedlings was drastically reduced, and there was no lodging of seedlings.

We also examined multi-shoot training as a way of reducing the number of nursery plants needed in the single-truss system[14]. If the main shoot is pinched at the 4- to 5-leaf stage, lateral shoots emerge from the axillae of the cotyledons and the 1st and 2nd leaves (Fig. 4). In two-shoot training, where 2 lateral shoots from the axillae of the cotyledons are allowed to grow, the yield and quality of the fruit are comparable to those under conventional mono-shoot training, although the time of flowering is retarded by 1 week. On the other hand, irregular fruits or BER are frequently observed in four-shoot training, and growth is retarded by more than 2 weeks with this system. Two-shoot training would be suitable for the single-truss system, as it can reduce the number of nursery plants needed by half.

Improvement of fruit quality by salinity

It is well known that, although water deficit or salinity improves the fruit quality of tomato, the improvement is commonly accompanied by a reduction of yield and an increase of the incidence of BER. Growers need skill to apply a constant moderate stress to tomato plants without severely reducing the marketable yield. BER usually occurs early in fruit development, when the fruit is growing rapidly and the concentration of Ca in the tissues is decreasing. Thus, if salinity could be used to decrease the uptake of water at a later stage of fruit development, the fruit quality may be improved without a marked occurrence of BER.

In the single-truss tomato, salinity stress can easily be applied to the first truss at a particular stage of fruit development. In our experiments[15], salinity stress was applied by the addition of NaCl to the nutrient solution. When EC of the solution was raised to 5.0 dS m^{-1} by the addition of NaCl at the immature green stage of the first truss, BER was not detected, even though the soluble solids content of the fruit increased remarkably compared with that of the control, which had an EC of 1.2 dS m^{-1}. We also confirmed that the response of fruits to salinity

Table 1. Effects of salinity at 2 ripening stages on fruit yield and yield components of single-truss tomato

Time of treatment	EC* (dS m^{-1})	Yield (g/plant)	Fruit weight		Soluble solids	Citrate	
			(gFW/fruit)	(gDW/fruit)	(Brix%)	(mg/100 mL)	(mg/fruit)
Immature green stage	5.0	211.4	91.9	8.8	9.0	956.2	922.3
Immature green stage	8.0	268.0	95.7	10.2	10.3	1,122.1	1,085.2
Decoloring stage	5.0	468.9	142.1	10.2	7.2	706.3	1,037.0
Decoloring stage	8.0	404.4	134.8	9.7	7.1	741.5	951.5
Control	1.2	543.9	155.4	9.5	6.1	620.1	1,027.1

*EC of the nutrient solution was adjusted by the addition of NaCl.
Figures are mean for 53–81 fruits.

differed, depending on when the stress was applied (Table 1). Next, we examined the reuse of drainage from the wet-sheet culture system[13]. The drainage was concentrated to EC 5.0 dS m^{-1} and was then resupplied to the growing beds at various fruit development stages from flowering to harvest instead of using a fresh solution. The earlier the salinity stress was applied, the lower the fruit weight and the higher the soluble solids content (Fig. 5). For example, plants in the control solution (EC 1.2 dS m^{-1}) produced fruits weighing an average of 120 g and with a Brix value of 5.5%. In contrast, plants treated at the flowering stage produced fruits weighing an average of 50 g and with a Brix value of 8.0%. When salinity was applied too early, there was a high rate of occurrence of BER (Fig. 6). Salinity treatment beginning several days before harvest markedly prevented fruit cracking (Fig. 6). Fruit cracking is frequently observed in the summer cropping of the single-truss tomato. As water uptake by roots was significantly inhibited by the salinity treatment, we considered that salinity was essentially a form of water stress, and that the resultant improvement of fruit quality and prevention of fruit cracking would be caused by the inhibition of water influx into the fruits[5].

In the single-truss system, growers can easily produce various kinds of tomato fruits with different sizes and soluble solids contents by varying the time of application of the concentrated drainage. This technique may be useful for producing tomato fruits suited to different market demands. Reuse of drainage as a means of application of salinity results in the establishment of a closed hydroponic system, where the drainage is exhausted by the plants until the end of the harvest, and where no waste solution is drained out of the greenhouse[9].

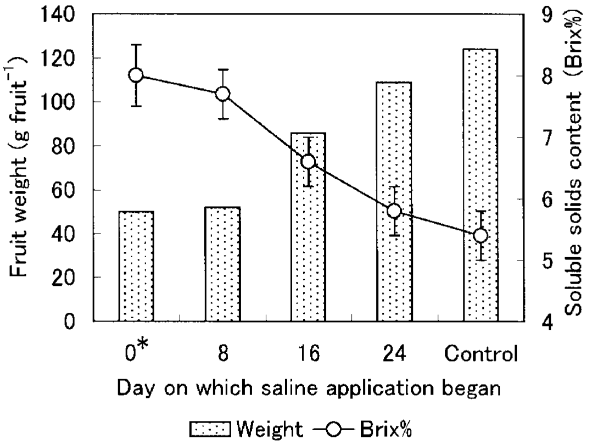

Fig. 5. Effect of starting time of application of concentrated saline drainage on fresh weight and total soluble solids content of tomato fruits (cv. Momotaro)
* Numerals indicate the days after flowering of the first truss.

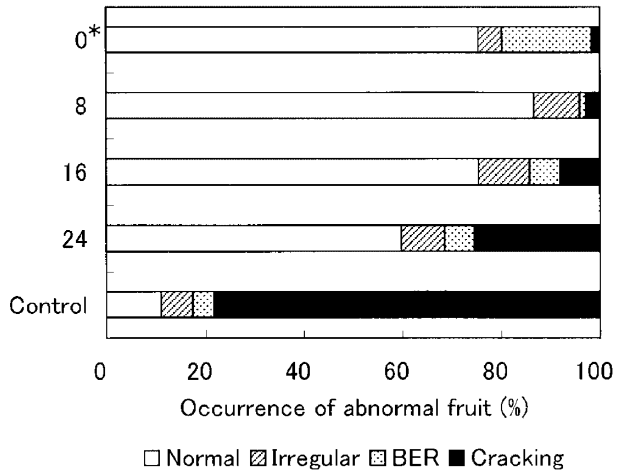

Fig. 6. Effect of starting time of application of concentrated saline drainage on the occurrence of abnormalities in fruits
* Numerals indicate the days after flowering of the first truss.

Improvement of fruit productivity

Researchers are often preoccupied by the fruit productivity of the single-truss tomato, as only 4 or 5 fruits can be harvested from one plant. This apprehension may, however, be groundless. Assuming that the planting density is 10,000 plants/10 a, there are 4.5 cropping cycles per year, and 800 g of fruits (200 g × 4 fruits) can be harvested per plant, the annual yield should amount to 36 t/10 a (10,000 plants / 10 a × 800 g/plant × 4.5 times/y = 36 t), which is far superior to the yield level of a conventional multi-truss cropping system (20–25 t/y). However, it may be difficult to produce 800 g of fruits per plant continuously throughout the year, because temperatures above 40ºC are likely to inhibit tomato growth in summer. This problem can be solved by the use of appropriate techniques for environmental control.

The optimum planting density is considered to be about 10,000 plants/10 a in the single-truss tomato system, although a density of 16,700 plants/10 a has been reported in NFT culture. Unlike in conventional soil culture, the planting density cannot be freely changed in soilless culture, owing to the restriction of bench structures. The planting density in wet-sheet culture is 10,400 plants/10 a, and in the fixed bench system, the plants spacing is 8 cm in rows 120 cm apart (Fig. 7). The spacing between the plants is too narrow compared with the distance between the rows. The leaf area index (LAI) is 5 to 6, a value which is higher than that in conventional tomato culture (LAI = 3–4). We examined the light interception characteristics of plants in the single-truss sys-

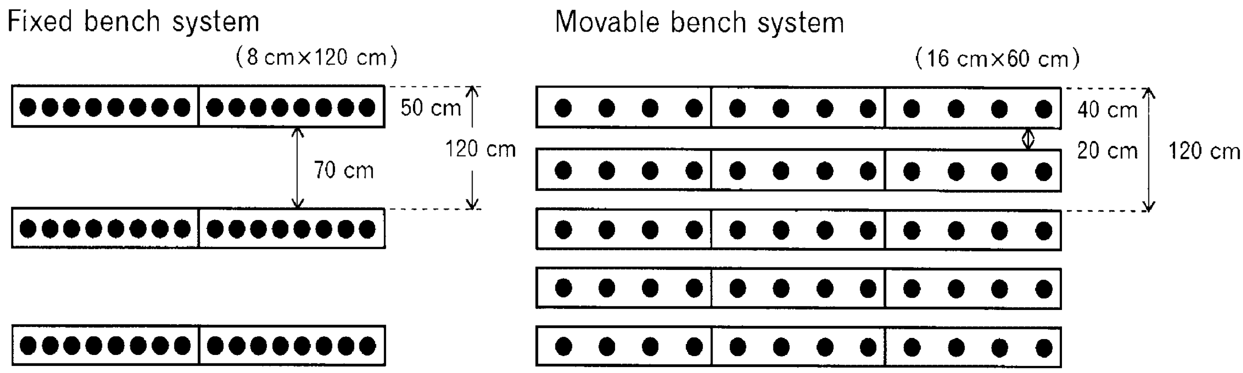

Fig. 7. Spatial arrangement of tomato plants in the fixed bench system (left) and the movable bench system (right)

tem, and found that the photosynthetic activity of the middle and lower leaves was suppressed by mutual shading of the leaves[10] (Fig. 8). We then designed a more uniform arrangement of the plants in the greenhouse by using movable benches, which could be moved to form transverse rows. In the movable system, the plants spacing was 16 cm in rows 60 cm apart (Fig. 7). When growers work on the plants they can increase the distance between benches by moving them. By changing the plant spacing like this, we were able to increase the fruit yield of Momotaro at the spring cropping to approximately 1,000 g/plant [11]. If the planting density could be further increased, the yield would still be high. To achieve this objective, plants for single-truss tomato growing should be compact and more adaptable to dense planting. We are currently examining the minimum leaf area needed for optimum fruit growth and source–sink relationships between individual leaves and the first truss, in order to identify the ideal plant type of the single-truss tomato[12].

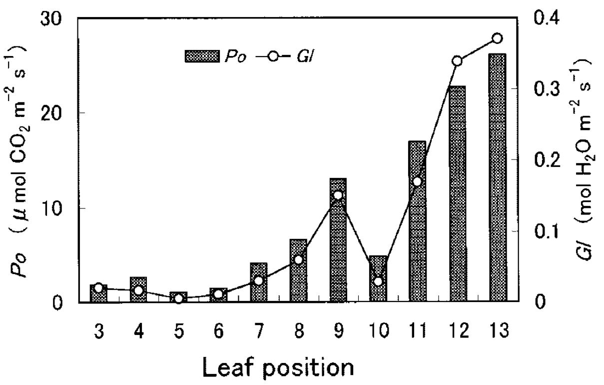

Fig. 8. Photosynthetic rate (*Po*) and stomatal conductance (*Gl*) of leaves at various positions on the main shoot of a single-truss tomato plant

Cropping schedule throughout the year

In the single-truss system, there is no distinct cropping season, and tomato plants grow continuously all the year round. The growing period from sowing to harvest varies with the season in the greenhouse if environmental control is inadequate. Fig. 9 shows the number of days required for the growth, flowering and harvest of single-truss tomato (cv. Momotaro) sown each month of the year[6]. The duration of the total growing period from sowing to harvest is relatively short (< 100 days) for the April to July cropping, while the longest (160–165 days) occurs in the September to October cropping, which indicates that the cropping schedule should be determined from this kind of growing data for each cultivar.

The major environmental factor affecting the growth rate of tomato is the air temperature in the greenhouse. Growth is fast at high summer temperatures and slow at low winter temperatures. In winter, the minimum temperature in the greenhouse is usually maintained at 12 to 13°C, which is the minimum temperature required for the normal development of tomato fruits. If the minimum temperature could be raised to 18°C, growth may be accelerated and the growing period shortened, resulting in the increase of the number of cropping cycles that could be fitted into a year. Any decisions about temperature control should be made by striking a balance between the income derived from increased yield and expenditure incurred for increased heating costs. The quality of tomato fruits is superior in winter, when the fruits develop slowly. Acceleration of fruit growth by heating may exert a negative effect on quality.

General prospects for single-truss tomato system

In the single-truss cropping system, the labor requirement for training, pruning and harvesting can be drastically reduced, and workplace ergonomics is consid-

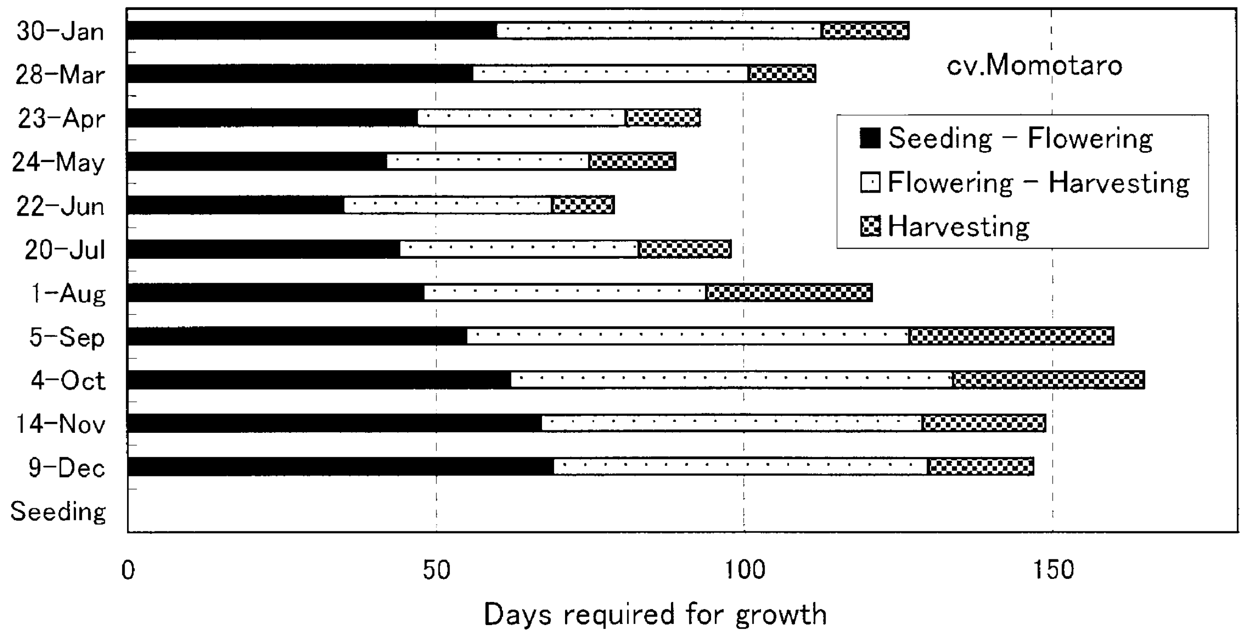

Fig. 9. Number of days required for growth, flowering, and harvest of single-truss tomato plants sown each month of the year (cv. Momotaro)

erably improved by the use of high benches. There is no need for skillful plant operations, as routine work is repeated throughout the year. These characteristics enable growers to employ regular labor for plant management. Therefore, we consider that the single-truss system is suitable for large-scale production of tomato. Continuous predictable production may be possible if the environment in the greenhouse could be controlled adequately. Presently, crop production under automated systems is restricted to leafy vegetables such as mitsuba (*Cryptotaenia*) and lettuce. Fruit crops like tomato or eggplant would not be suitable for mechanized production, because they have a longer growing period and need complicated management. Single-truss tomato cultivation, however, can be performed on transportable benches with mechanical harvest, as the plants have a shorter growing period and a compact form, and plant operations are markedly simplified.

Tomato growers may be interested in the single-truss tomato system from the viewpoint of the cultural techniques applied to produce high-quality fruit, rather than for the labor-saving characteristics. Growers want to produce fruits with a high soluble solids content that fetch high price in the market. Skill is required to produce high-quality fruits constantly without inducing BER. In the single-truss system, anyone can produce high-quality fruits easily by raising the EC of the nutrient solution. We have developed the basic techniques required for a single-truss cropping system. Hereafter, the advantages of the single-truss system should be evaluated practically by the integration of these techniques.

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