Development of yield and harvesting time monitoring system for tomato greenhouse production

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ABSTRACT

Tomato greenhouse growers need information about yield and harvesting time as a majority of working time to improve a yield, cultivating technique, and management of labor. We developed a tomato yield and harvesting time monitoring system for selective hand harvesting of fresh tomato. The monitoring system consists of an electronic balance, a handheld type barcode scanner, a microprocessor, and cart. Each barcode was set on each tomato plant. The monitoring system can measure and record harvested fruit weight and harvesting time, and save to mini SD card. The yield and harvesting time map were made by sheet spread software. We conducted a harvesting experiment to investigate monitoring data for 7 months, using 3 varieties. The developed monitoring system could be used in greenhouse environment without any trouble and any disturbance of harvesting work for all experimental term. By using monitoring system, we could get yield map, harvesting time map, and effect of greenhouse climate on yield and harvesting time. It is found that spatial deviation of the total harvested fruit's weight of DR03-103 was the highest. The results showed that in harvesting

of fruits of DR03-103, more labor is needed and deviation of harvesting labor is higher. The result of investigation of effect of greenhouse climate and yield indicated that when greenhouse inside temperature increased, the number of harvested fruit and harvesting time is increasing from winter to spring. It was considered it was possible for growers to use yield and harvesting time information by using monitoring system.

Keywords

Yield map, Harvesting time map, Monitoring System, Barcode, Tomato, Greenhouse

1. Introduction

Yield monitoring system is becoming important function for grain harvester through many researches since the late 1980s (Searcy et al., 1989). In Japan, several marketed type of combine harvesters have yield monitoring system which can monitor and record yield data per each field and water content of rice, wheat and barley by GPS positioning system and weighing sensor. For agricultural production, getting information and analyzing yield are important for planning next cultivation and improving productivity. Information of the harvesting time data of using machine is also important for growers. Harvesting time data can be also measured by Japanese manufacturer's combine harvester with information assistance system.

Tomato is one of the most popular vegetables in the world. Fresh tomato growers need yield and labor monitor for improvement of production and management. Yield and labor monitoring system are also needed for installation of new variety in grower's greenhouse. If grower knows characteristic of yield and labor before installation of new variety in large scale by many plants, grower's risk will be minimum and can challenge many varieties. If grower knows characteristic of yield and labor every cultivation term, grower can manage variety and labor adequately better than present cultivation.

Yield monitor attached to processing tomato harvester was developed (Pelletier and Upadhyaya, 1999). But the yield monitor for the harvester cannot apply for fresh market tomato, because they are harvested by hand and cultivated in greenhouse. About crop harvested by hand like fruit vegetable; Yield, shape and defect grade maps were obtained by the manufactured mobile fruit grading robot for sweet pepper (Qiao et al., 2005). This robot couldn't identify each plant automatically and couldn't monitor harvesting time. Mobile eggplant grading robot were manufactured for monitoring yield and quality (Chong et al., 2008). The mobile grading robot for eggplant has encoder in its wheel and could measure the travel distance, then identify each plant by the distance from the start position. For fresh tomato, especially high wire cultivation, identification of the plant position by vehicle travelling distance is very difficult, because the main stem is grown, laid down and moved along with ridge during all cultivation term continuously. Yield map by only 1 day's harvesting data has shown in previous researches for vegetable fruit. The long term experiment for yield map is needed for fruit vegetable, because fruit vegetable is not harvested once like grain. These robot is estimated expensive, heavy and large because it has many cameras, many sensors and many actuators. It was considered that it took time to measure fruit weight because of several times of handling of fruit by the robots. In practice greenhouse, fruit vegetable grower are busy during harvesting term same as fruit grower, so measurement by yield monitoring system should not be taken a lot of times (Schuller et al., 1999).

It is needed for improvement of efficiency and labor management to measure and investigate harvesting work time precisely. Because harvesting work is majority of all cultivation work for tomato production. The efficiency of a hand harvest of tomato was measured and simulated on variable route in working path and variable number of workers (Bechar et al., 2005). Total time for harvesting was measured on variable harvesting condition, but harvesting time for each plants was not measured in this research. It is desired that harvesting time and weight per each plant are measured for improvement of production and labor management because one tomato plant's effect is large in high wire system. About cut rose greenhouse production, simulation of harvesting and handling were studied for an improvement of efficiency (Van't Ooster et al., 2012). In this study, the relationship of harvest efficiency and yield was shown by simulation. It is important for growers to know detail of harvesting work efficiency for labor management and efficiency improvement.

In the Netherlands, labor management tool so called 'registration system' by IC card using RFID is used in tomato grower's greenhouse. This system can measure harvesting time of each worker for large area about several thousand m^2 of greenhouse and cannot measure harvesting time for each plant during harvesting. Weighing system with automatic guided vehicle is also used in Dutch greenhouse. This weighing system can measure total fruits weight in each container on the vehicle automatically, but it cannot measure weight of each harvested fruit for each plant.

For citrus production, low-cost yield mapping system by using GPS was manufactured and tested (Schueller et al., 1999). In this system, one container's position represented the center of production of 0.7 m^3 (approximately 400 kg) of citrus with reasonable accuracy. For tomato high wire production also, it is desired to know yield per plant with reasonable accuracy. Yield mapping and labor tracking system for citrus production was also developed for labor management (Whitney et al., 2001). By using this system, the spatial position of the container filled with fruits was measured and recorded by GPS. The number of container was also measured by truck operator for carrying harvested fruits. This system could track position of container filled with fruits as harvesting labor's position. This system cannot measure the yield and working hour per each plant.

For fruit vegetable production of hand harvesting, there is no monitoring for yield and harvesting time per plant simultaneously, while grain harvester can monitor and record yield and harvesting time. A purpose of this study is to develop a yield and harvesting work time monitoring system for fresh tomato of greenhouse production and investigate yield and harvesting time of different variety by conducting long term experiment.

2. Materials and methods

2.1. Yield and harvesting time monitoring system

A manufactured yield and harvesting time monitoring system is shown in Figure 1. The monitoring system is composed of a barcode reader (HMBC-880, Hibino intersound Co., Ltd.), an electronic balance (FG-30KBM, A & D Co., Ltd.), a microprocessor (MBED NXP LPC1768, Switchscience Co., Ltd.) and a cart. The microprocessor is connected to a barcode reader, an electronic balance and a microSD card reader. The size of the monitoring system is length 1182 mm, width 455 mm and height 930 mm. The weight of monitoring system including cart is 35 kg. The monitoring system has enough small structure for worker to harvest fruits with a cart in greenhouse path.

2.2. Procedure for monitoring

The barcode on the main stem near truss is shown Figure 2. Flowchart for monitoring is shown Figure 3. For preparation, the barcode was printed on tag paper with adhesive tape. The barcode label with the clip for training is hung on the main stem near the harvestable fruits. The type of barcode is Code 39. The barcode was printed on waterproof paper by laser printer. For monitoring of harvesting work, firstly worker pushes start button. Next the worker harvests a fruit by hand, puts fruit in container and then push the execute button for weighing. Next, the system measures total weight of harvested fruit Wt_n g of No. n fruit including previous harvested fruits, while total weight of harvested fruit Wt_{n-1} g of No. $n-1$ fruit is memorizing in microprocessor. Next, fruit weight Wf_n g is calculated by following equation:

$$Wf_n = Wt_n - Wt_{n-1} \text{ (g)} \qquad (1)$$

where n is fruit number, F_n is fruit weight of number 'n' fruit in g, Wt_n g is total weight measured by monitoring system when number 'n' fruit is placed on balance.

Then the calculated fruit weight is memorized to the microprocessor. In case of multiple fruits of same plant, barcode was read multiple times and weighing button was also push multiple times. Harvesting time of fruit No. n was calculated time since the execute button was pushed at fruit No. $n-1$ finished harvesting until the execute button was pushed at fruit No. n finished harvesting.

The harvesting time is including walking time in greenhouse path. The harvesting time is also memorized to the microprocessor. At first harvesting tomato, starting time is time to push start button. After final tomato is harvested and end button is pushed, all data is saved to mini SD card. By using the monitoring system, harvesting time is saved automatically without disturbing harvesting work.

2.3. Greenhouse harvesting experiment

2.3.1 Experimental Greenhouse

Arrangement of greenhouse is shown in Figure 4. Tomato cultivation system in the experiment was rock wool cultivation system and high wire training system. A plant distance was 25 cm. The ridge width was 1.5 m. 36 plants of one variety were planted on same ridge. Tomato varieties used in the experiment are Momotaro York, DR03-103 and Tomimaru Mucho. Cultivation method were same in three varieties. Seeding and transplanting date of all 3 varieties were same. Pest and fertilizer management of 3 varieties were also same.

2.3.2 Harvesting method

Harvesting date in the experiment shows in Table 1. In the experiment, a skilled worker harvested selectively colored tomato fruits at 24 times from December 2014 to May 2015 within around 2 weeks' interval.

2.3.3 Investigation of yield and harvesting time

In this study, we investigated yield and harvesting time by making map. Yield map and harvesting time map were made by a spreadsheet program

(Excel 2013, Microsoft). Following other results concerning with yield and harvesting labor were calculated to consider the usage of the manufactured monitoring system as a tool for an evaluation of plant cultivation and labor management. The calculated items were total weight of fruits per plant, average weight of fruits per plant, number of fruits per plant for yield, total harvesting time per plant and average harvesting time per plant.

2.3.4 Greenhouse climate

To investigate yield and harvesting time in relation with greenhouse climate by using the monitoring system, dairy mean temperatures of greenhouse inside and outside were measured constantly during the experiment.

3. Results and discussion

3.1. Yield map

3.1.1. Total weight of harvested fruits

Yield map is shown in Figure 5. Barcode was recognized well with no miss-recognition during the experiment. Monitoring system also had no trouble during experimental under greenhouse environmental condition. The total weight of harvested fruits per plant is shown in Figure 5(a). In 4 plants of DR03-103, total weight of harvested fruit were 0 to 1 kg plant^{-1}, because they were stopped cultivation by plant disease in early cultivating term. In only 1plant of Momotaro York and Tomimaru Mucho respectively, there was total weight of harvested fruit 0 to 1 kg plant^{-1}. It is found that the number of damaged plants of DR03-103 is more than the other varieties. Grower can recognize the effect of damage of plants and spreading damage visually by using the monitoring system. In high wire system, stem extends longer than 10 m for long cultivation term of over 10 months. So cancellation of planting at early cultivation stage makes the large disadvantage in high wire cultivation in this case.

Total weight of fruits per plant indicates productivity of plant. The number of plants of high yield over 6 kg plant^{-1} were 11 (31%) in Tomimaru Mucho. It is indicated Tomimaru Mucho has higher productivity plants than the other 2 varieties. The average yield of DR03-103, Momotaro York and Tomimaru Mucho were 3.8, 4.7 and 5.5 kg plant^{-1} respectively. It was found that Tomimaru Mucho was the highest average yield in this experiments. It is considered that total weight per plant can be one of indexes for greenhouse management, because grower's income can be estimated based on total weight per plant and price of unit weight for selling tomato fruits based on weight.

The spatial deviation of the total weight of fruits indicates a stability of production. So this monitoring system is useful for greenhouse grower for installation of new variety to greenhouse, evaluation of cultivating variety and improvement of cultivation technique. The spatial deviation of the total weight of harvested fruit was caused by plant disease, plant condition, and environmental condition. By investigation of yield map, grower can know information about the effect of plant disease and other factors on yield. Because total weight of harvested fruit per plant could be known without long and heavy work by using monitoring system, it is also possible easily to investigate effect of total weight per plant on leaf picking, fruit thinning, training way and other management technics of plant.

3.1.2. Number of harvested fruits per plant

The number of harvested fruits per plant is shown in Figure 5 (b). By using monitoring system, the number of fruits per plant could be measured automatically. It is found that in DR03-103, the number of plants of more than 60 harvested fruits was the most among 3 varieties. The deviation of the number of harvested fruits of Tomimaru Mucho was the least. In case of sale based on grading of one fruit's weight, it is easy to calculate total sales amount for product by getting information of weight.

3.1.3. Average weight of harvested fruits per plant

Average weight of fruits is shown in Figure 5(c). The number of plant of less than 100 g of average weight of DR03-103 is the most. In Momotaro York and Tomimaru Mucho, the number of plant of average weight 125 to 150 g is the most. The spatial deviation of the average weight in Tomimaru Mucho is the least among 3 varieties. By using the monitoring system, uniformity of harvested fruit's weight per plant and weight distribution could be known quickly and precisely without much work for measurement of harvested fruit's weight.

3.2. Harvesting time map

3.2.1. Total harvesting time per plant

Harvesting time map is shown in Figure 6. Total harvesting time per plant is shown in Figure 6(a). In DR03-103, the number of plants harvested by total harvesting time 600 to 800 and over 800 s plant^{-1} was more than other variety. Cultivation cancelled plant in early term by plant disease, there is very few harvesting time. The spatial deviation of total harvesting time in DR03-103 was higher than those of Momotaro York and Tomimaru Mucho. The deviation of total harvesting time in Tomimaru Mucho was the least among 3 varieties. Less total harvesting time leads to save a labor cost. Less deviation of total harvesting time lead to stable labor management. So in cultivation of DR03-103, more labor per plant is needed for harvesting work and deviation of labor cost by harvesting is higher. Labor management has to be done concerned with fruit price.

3.2.2. Average harvesting time per fruit

Average harvesting time per plant is shown in Figure 6(b). Average harvesting time indicates labor's harvesting performance including walking and difficulty of harvesting. Although there was one plant harvested in harvesting time per fruit 15 to 20 s in DR03-103, most of fruits were harvested in 5 to 15 s. There is no large difference between average harvesting times per fruit in 3 varieties. It is considered the differences of fruit's size and plant's shape didn't affect to harvesting time per fruit.

3.2.3. Harvesting time per harvested weight

Harvesting time per harvested fruit's weight is shown in Figure 6(c). Harvesting time per harvested weight is useful on a calculation of the labor cost when fruits is graded and sold by fruit's weight. The number of plants of harvesting time 150 to 200 s and 200 to 250 s per fruit's weight of DR03-103 were the most. The spatial deviation of harvesting time harvested weight of DR03-103 was also the highest. The number of plants of harvesting time 50 to 100 s per harvested weight of Tomimaru Mucho were the most. Visually an information about harvesting could be gotten by using the monitoring system quickly and precisely without writing paper, running stopwatch and handling harvested fruit. In the experiment, it is found Tomimaru Mucho has high uniformity in harvesting time per harvested fruit's weight. So it is considered that labor cost can be estimated easily, and then grower can manage harvesting labor easily.

3.2.4. Relationship of number of harvested fruit, harvested fruit's weight and total harvesting time

Relationship of the number of harvested fruit and harvesting time is shown in Figure 7. Relationship of total harvested fruit's weight and total harvesting time is shown in Figure 8. Total harvesting time increased as the number of harvested fruits and the harvested fruit's weight increased in all varieties. The correlation coefficients of number of harvested fruits and total harvesting time are higher than those of total harvesting weight for 3 varieties. It is indicated that total harvesting time depends on the number of harvesting fruits and can be predicted by measuring the number of harvested fruits more precisely than total weight of harvested fruit. The correlation coefficients of DR03-103 in total harvesting weight is much lower than other varieties. It is considered the reason is the deviation of fruit weight of DR03-103 were much larger than the other varieties. This monitoring system is useful for the precise prediction of total harvesting time.

3.3. Relationship of greenhouse climate, yield and harvesting time

3.3.1. Daily mean temperature

Relationship of greenhouse climate and harvesting time is shown in Figure 9. The daily mean temperature at harvesting day was shown in Figure 9 (a). The first day for harvesting is December 24th in winter in Japan. Since 48th day from the first day, harvesting of February 10th, the outside temperature started rising. Then the inside temperature started also rising. By heating greenhouse inside, greenhouse inside temperature is stable in winter on December to February, until 60th day. This is normal Japanese climate and general heating way from winter to spring.

3.3.2. Greenhouse temperature and number of harvested fruits

The number of harvested fruits in relation with greenhouse climate was shown in Figure 9 (b). At 103th day, April 6th, the peak of the number of harvested fruits is found clearly in all varieties when the outside temperature was raising and then greenhouse inside temperature slightly start raising. It is considered that fruits ripened fast by greenhouse inside temperature raising then ripened fruits was increasing. It is considered that the one of the reasons is also that harvesting interval from March 24th to April 6th, was 13 days and longer than the interval in March. At the day 112th, the next harvesting day of the day 103th, the number of harvested fruit was decreasing much.

For stable production, it is desired that the deviation of the number of harvested fruit is lower. By using the monitoring system, it was found that when greenhouse inside temperature is increasing, the number of harvestable fruit is increasing. So, it is considered the prediction of number of harvested fruits is possible by measuring of greenhouse inside and outside temperature roughly. It is possible to adjust the number of harvesting and selling fruits in relation with climate by adjusting harvesting interval and harvesting fruit’s color.

3.3.3. Greenhouse temperature and total harvesting time

Total harvesting time in relation with greenhouse climate was shown in Figure 9 (c). The trend of graph of harvesting time is similar to that of the number of harvested fruits, because the harvesting time has high relationship with the number of harvested fruits. The trends of total harvesting time for 3 varieties were almost same. It was found that the peak of the total harvesting time was on 103th day of April 4th same as the number of harvested fruits. It means increasing temperature makes harvesting work busy. The harvesting time of the 103rd day was about 3 times of that of the 90th day as last harvesting day. At the 112nd day, the number of harvested fruits and the total harvesting time are decreasing a lot. To stabilize harvesting work, it is needed to adjust the number of harvestable fruit by adjusting harvesting interval as a mentioned above. Otherwise hiring labor cost increase in busy harvesting season. For tomato production, adjusting of labor is difficult, because skilled labor is desirable for plant management work and harvesting work. So it is desired that the number of harvestable fruits should be stable in all harvesting term for labor management. It is also desired that on desired date, the desired amount of harvested fruits can be harvested to get more profit of the sales among other many kind of works. By using the monitoring system, it become possible to predict the number of harvestable fruit and harvesting time roughly in accordance with greenhouse inside temperature. So by the prediction of the number of harvested fruit and harvesting time, it is possible for grower to adjust harvesting day and avoid concentration of harvesting labor.

3.3.4. Fruit weight and greenhouse climate

Average harvested fruit weight in relation with greenhouse temperature was shown in Figure 9 (d). It was found that average fruit weight in the day from 50 to 100 were lower than that in other days when the greenhouse inside and outside temperature were increasing. It is found in 3 varieties. In DR03-103, the difference of maximum average weight and minimum average weight was the highest. To know the reason, it is needed to investigate of the effect of temperature on fruit's ripening, enlargement on the number of bearing fruits by plant physiology. But by long term and repeating measurement, the changing trend of fruit weight can be known.

When the fruit's price is decided by grading the fruit's weight, information of average weight and weight distribution are important. In Japan, most of tomato fruit's price is depended on each fruit's weight, weight distribution is useful for production management. It is considered that the rough prediction will be possible by long term measurement and research of plant physiology.

4. Conclusions

We developed a yield and harvesting time monitoring system, mainly composed of the barcode reader, electric balance, and microprocessor, by identifying barcode on tomato plant and conducted harvesting experiment in tomato cultivating greenhouse of 3 varieties for 7 months from December to next June in Japanese climate, then investigated the yield and harvesting time. The developed monitoring system could be used in greenhouse environment without any trouble and any disturbance of harvesting work for whole experimental term.

By using monitoring system, we could get yield map, harvesting time map, and relationship of greenhouse climate, yield and harvesting time. In the yield map, we could get information of distribution of total harvesting weight per each plant, the number of harvested fruit per each plant and average fruit weight of each plant. The result of the yield map indicated (1) average yields and deviations of 3 varieties, (2) effect of plant disease on yield. It was considered that these results indicated the information gotten by the monitoring system is useful for improvement cultivation technique and production management, installation of new variety.

Harvesting time map indicated the amount of labor for harvesting. It was easy to get information about harvesting time per plant and recognized the deviation of harvesting time per plant in greenhouse. It is considered that by using developed monitoring system, total harvesting time per plant is useful for labor and production management. Average harvesting time per plant of 3 varieties were almost same. It is considered that labor cost can be estimated easily all around greenhouse and can manage harvesting labor easily.

By the investigation of the relationship of the number of harvested fruits and total harvesting time, correlation coefficients of number of harvested fruits and total harvesting time are higher than those of total harvesting weight. Total harvesting time can be predicted by measuring number of harvested fruits more precisely than total weight of harvested fruit. The monitoring system is useful for the precise prediction.

The result of investigation of relationship of greenhouse climate and yield indicated that when greenhouse inside temperature is increasing, the number of harvested fruit is increasing from winter to spring. It is possible to adjust the number of harvesting and selling fruits in relation with climate by adjusting harvesting interval. The result of investigation of relationship of greenhouse temperature and harvesting time indicated that inside temperature is increasing, the number of harvesting time also is increasing from winter to spring. By using this monitoring system, it is possible to predict the number of fruit and harvesting time roughly in accordance with greenhouse inside temperature. By prediction of the number of fruit and harvesting time, it is possible for grower to adjust harvesting day and avoid concentration of harvesting labor.

It is considered that the monitoring system will be available for other fruit vegetable easily and even tree fruit. In case of tree fruit, it is possible to hung on branch, then production of each branch can be measured and recorded. In this study, we used the spread sheet program for displaying some maps. In future, improvement of user interface is needed to develop for the monitoring system’s commercialization.

Acknowledgments

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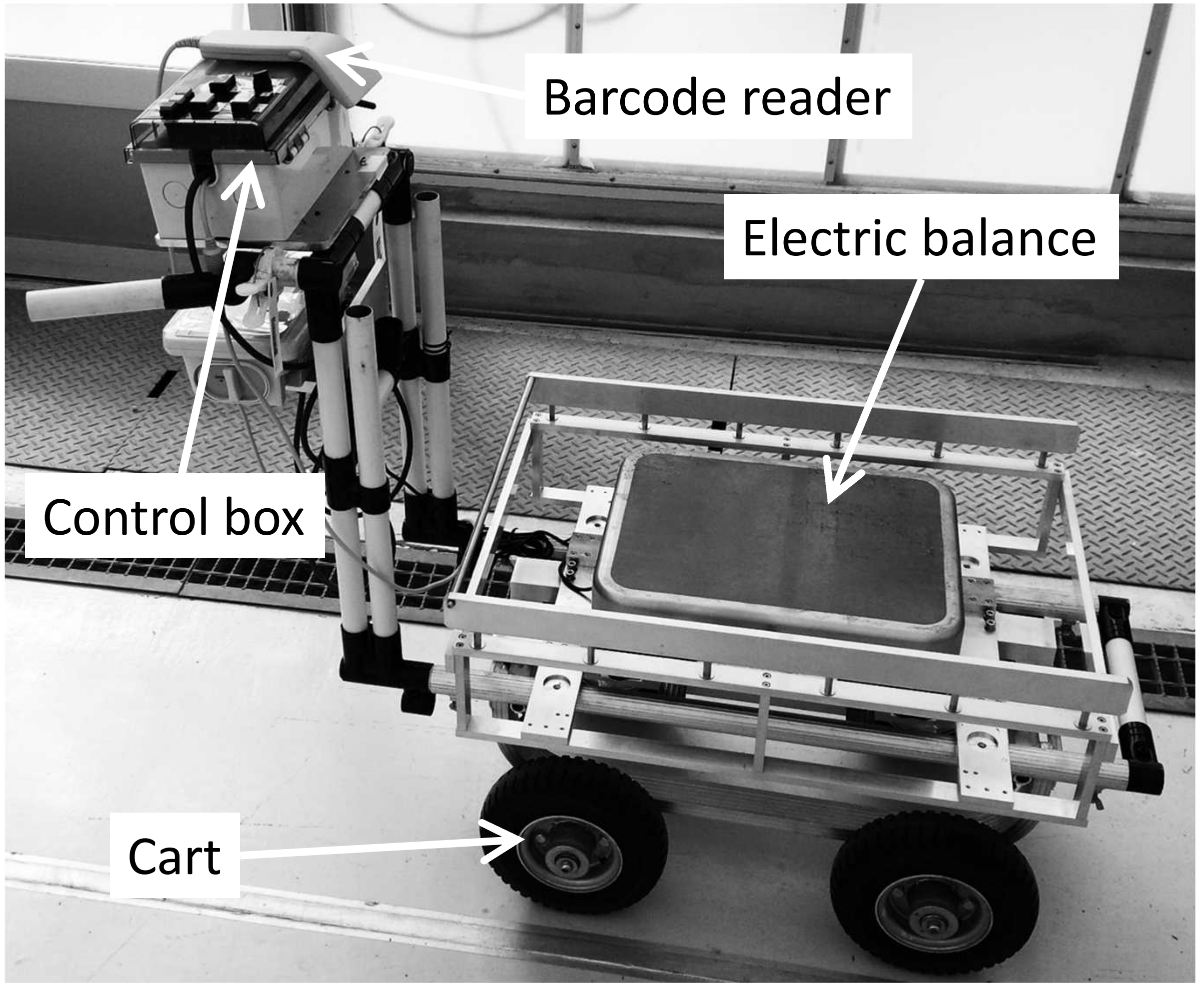


Fig. 1 Yield and harvesting time monitoring system on cart

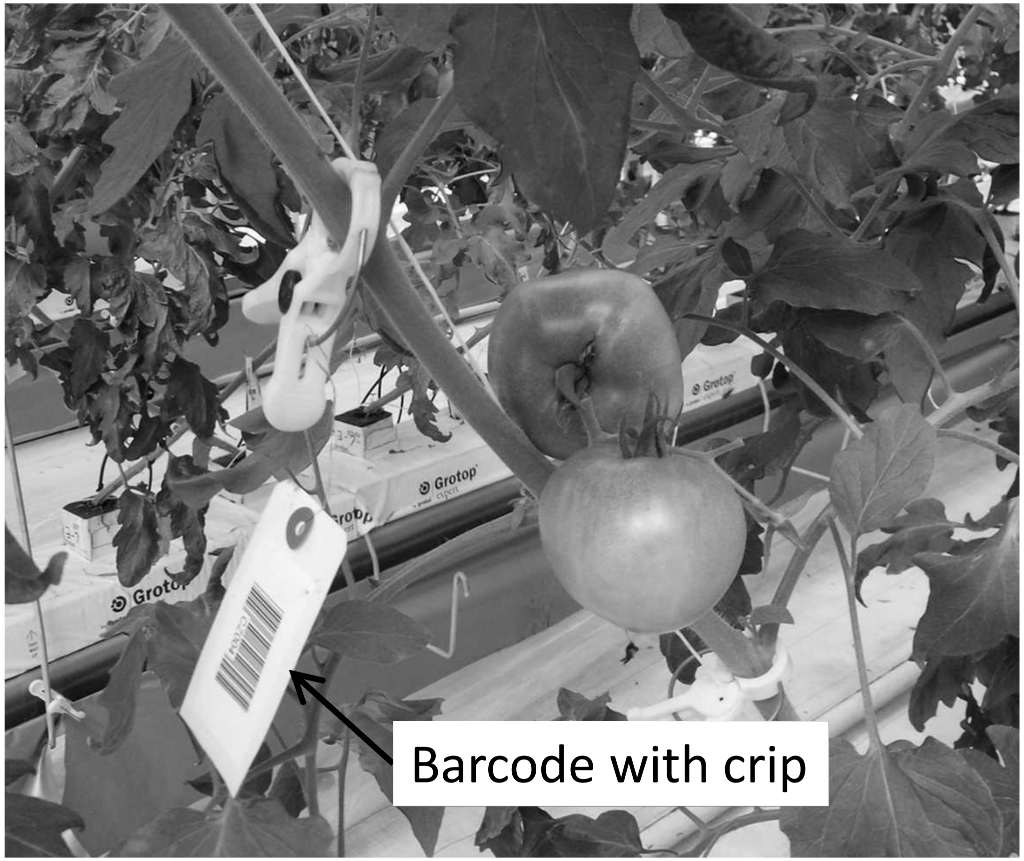


Fig.2 Barcode and truss

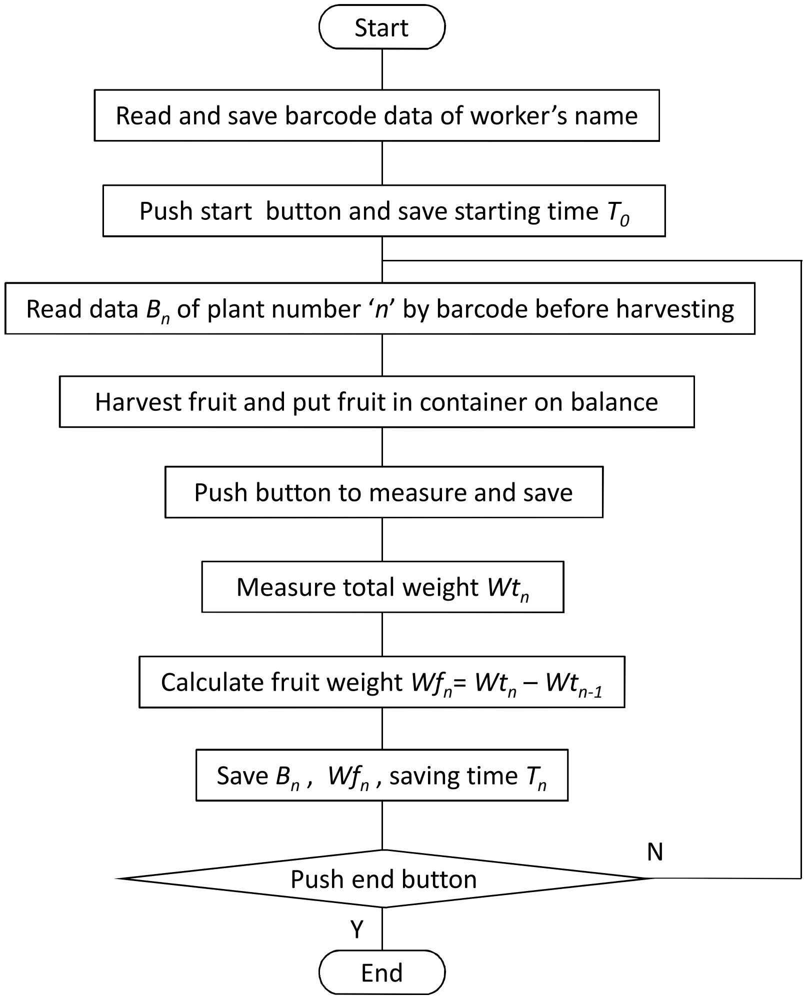


Fig.3 Flow of measuring and saving of yield and harvesting time

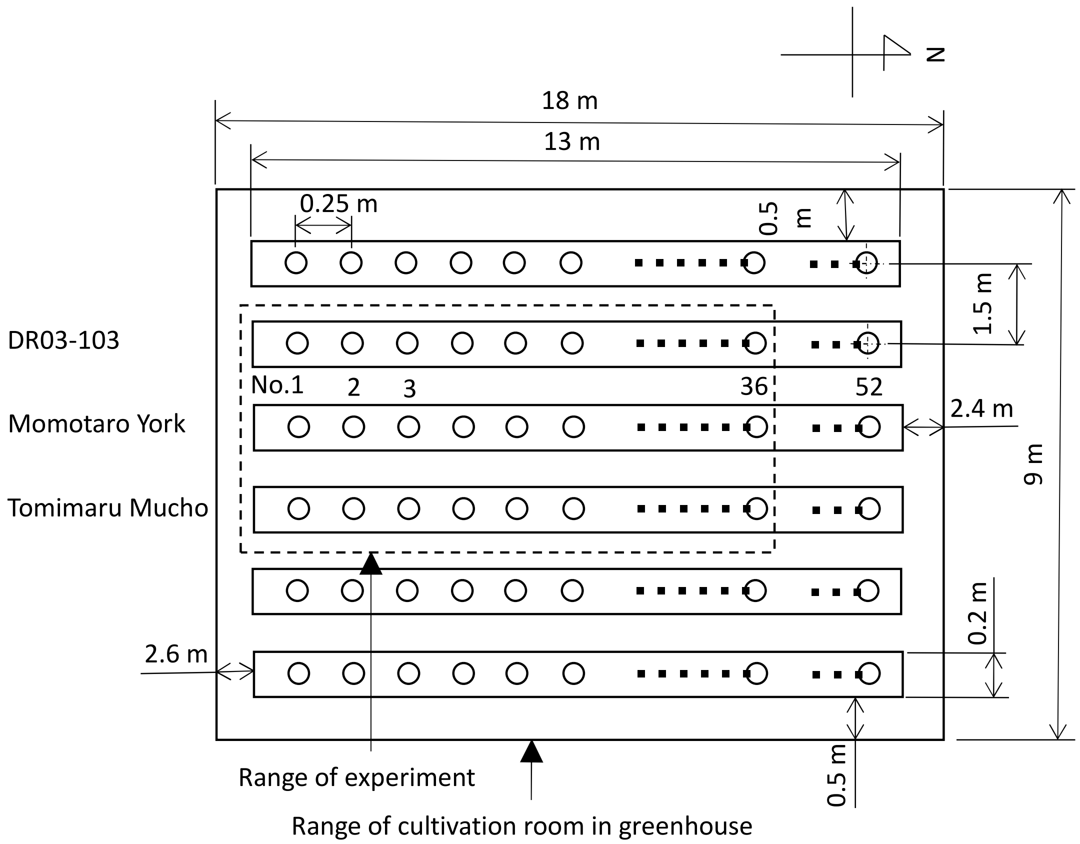


Fig. 4 Greenhouse arrangement

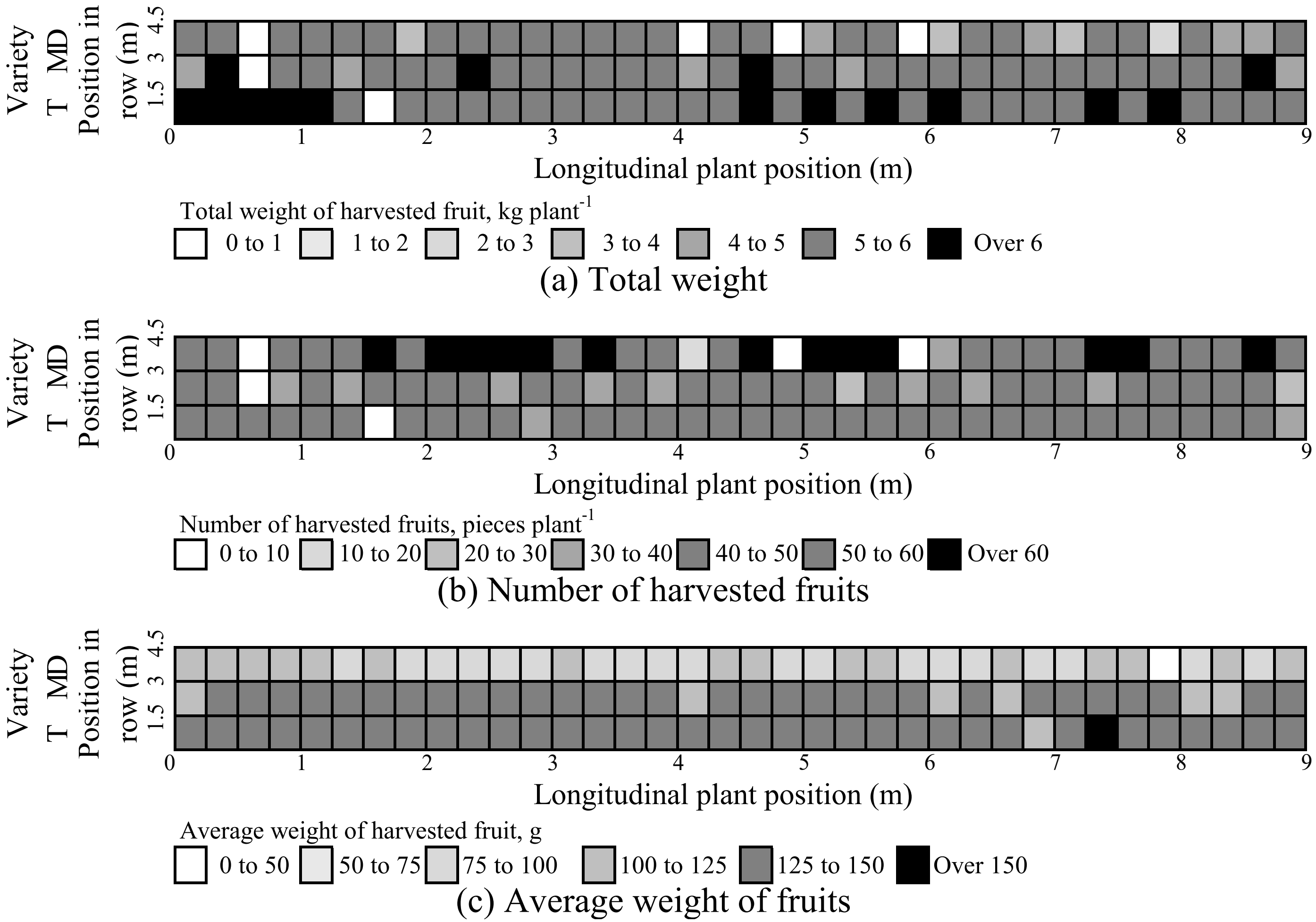


Fig. 5 Yield map: (a)Total weight of harvested fruits; (b)Number of harvested fruits; and (c)Average weight of fruits, where D: DR03-103, M: Momotaro York, T: Tomimaru Mucho

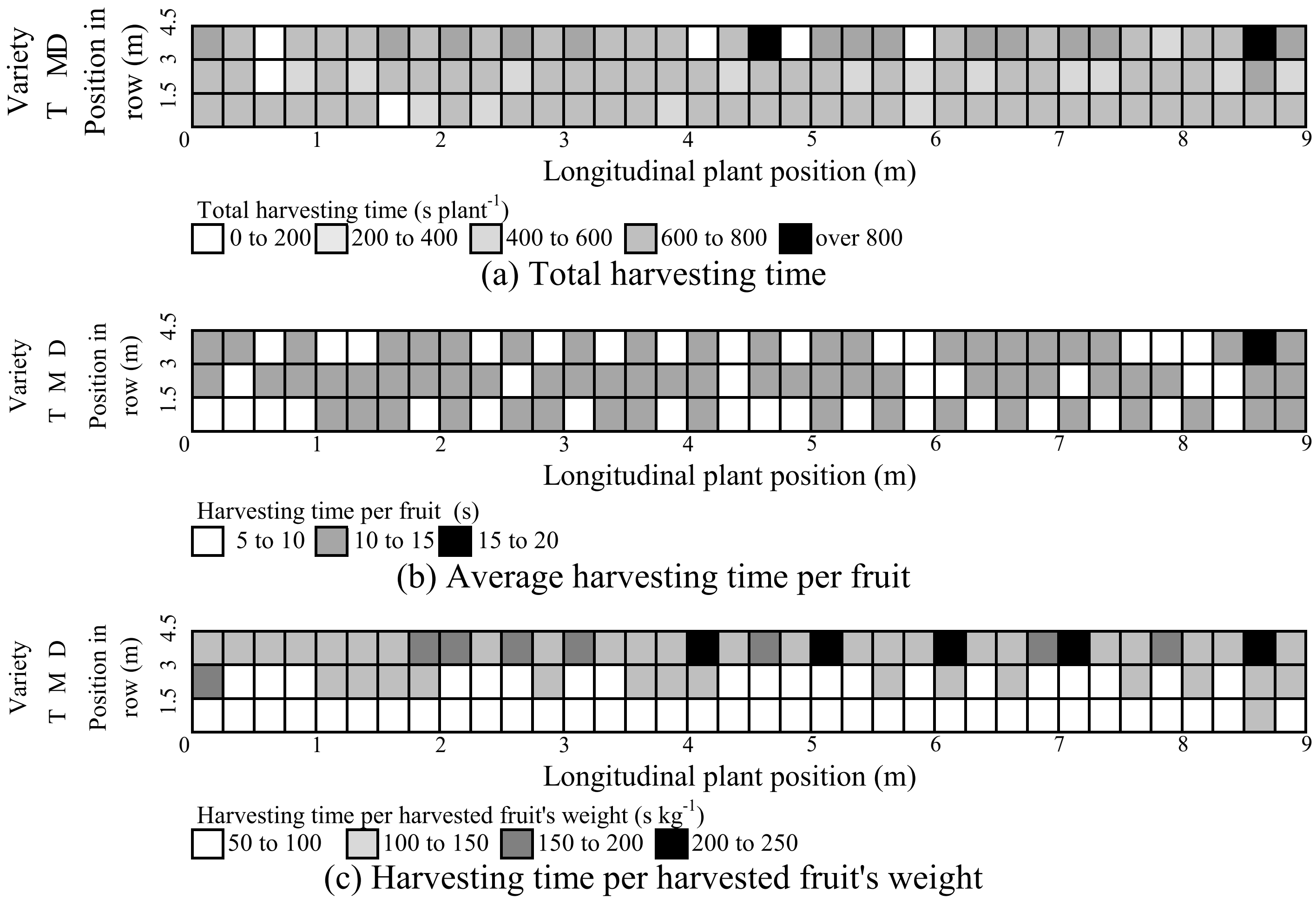
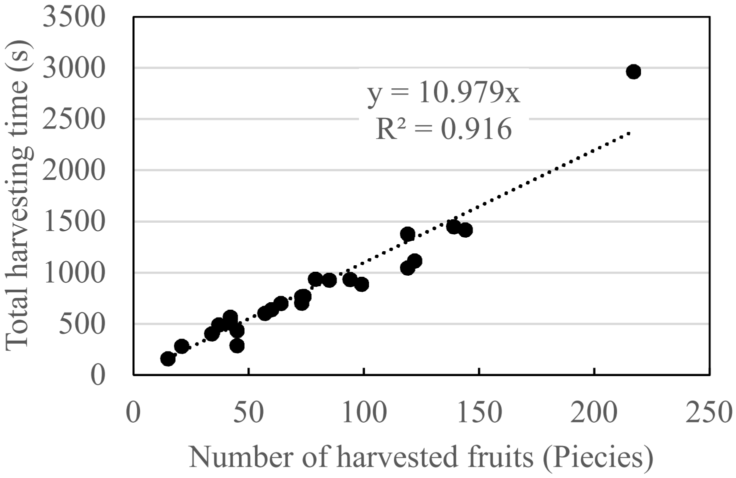
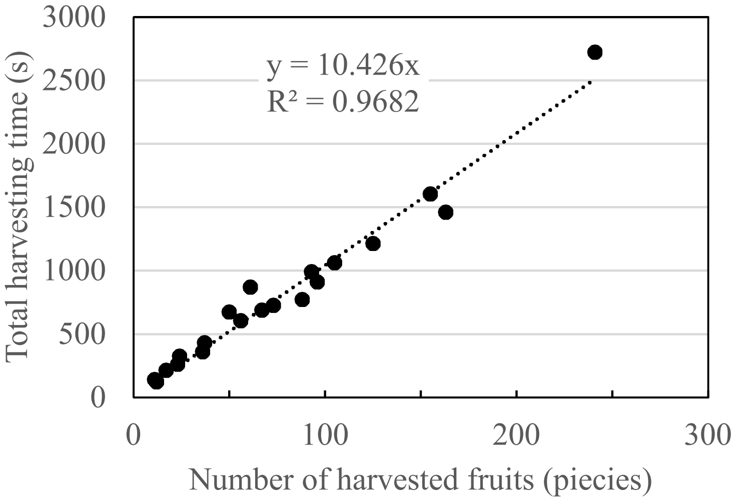


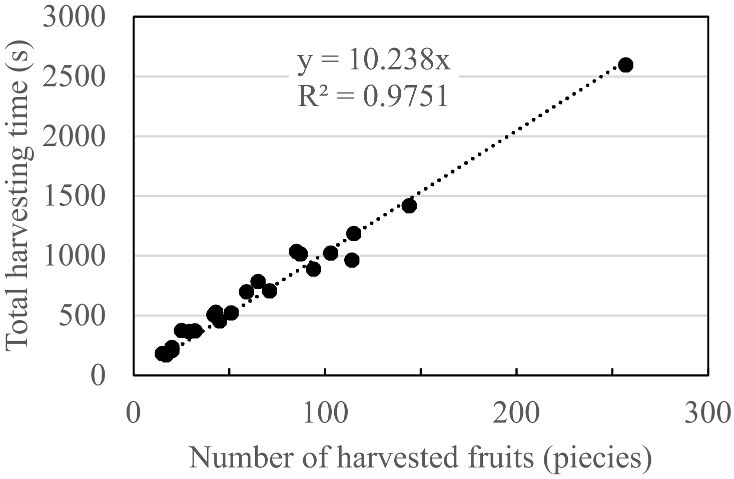
Fig. 6 Harvesting time map: (a)Total harvesting time; (b)Average harvesting time per fruit; and (c)Harvesting time per harvested fruit's weight, where D: DR03-103, M: Momotaro York, T: Tomimaru Mucho



(a) DR03-103

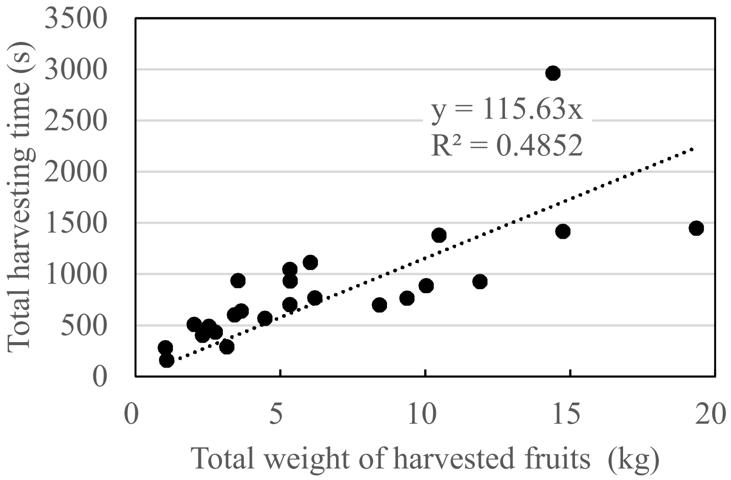


(b) Momotaro York

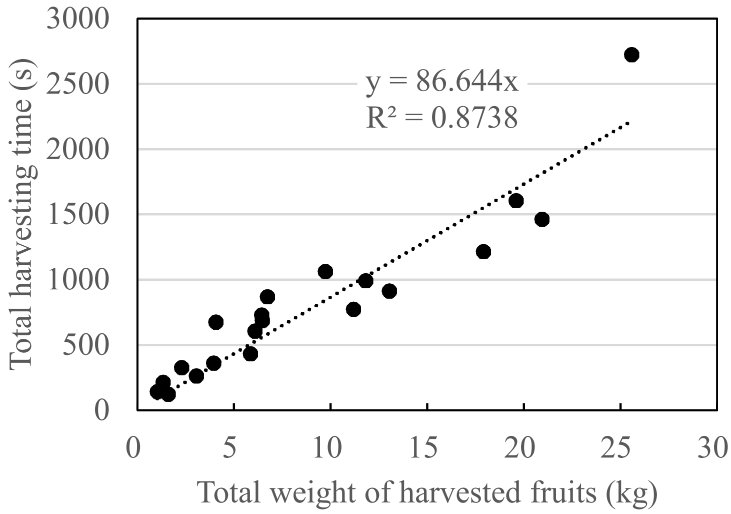


(c) Tomimaru Mucho

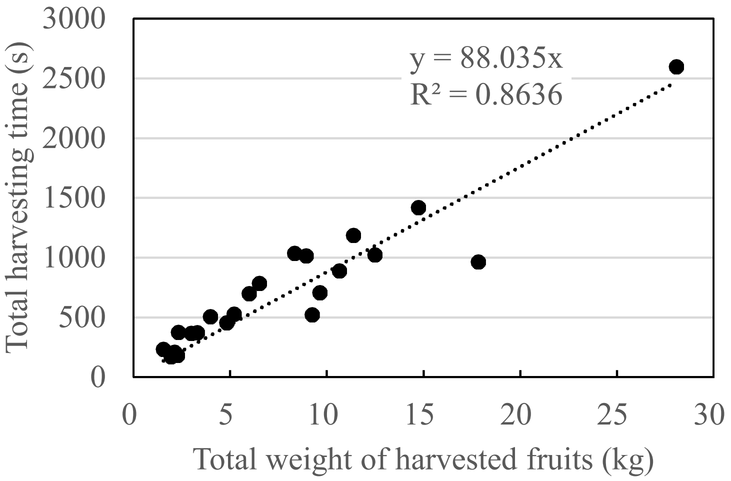
Fig.7 Relationship of numbar of harvested fruits and harvesting time of; (a) DR03-103; (b) Momotaro York; and (c) Tomimaru Mucho



(a) DR03-103

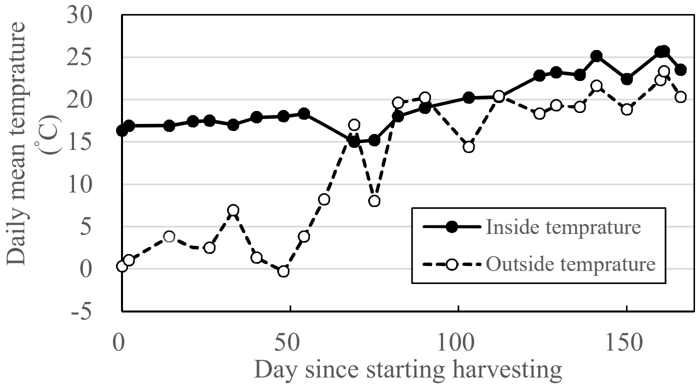


(b) Momotaro York

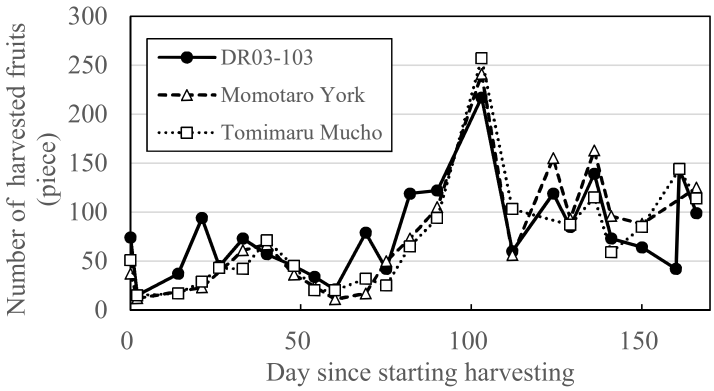


(c) Tomimaru Mucho

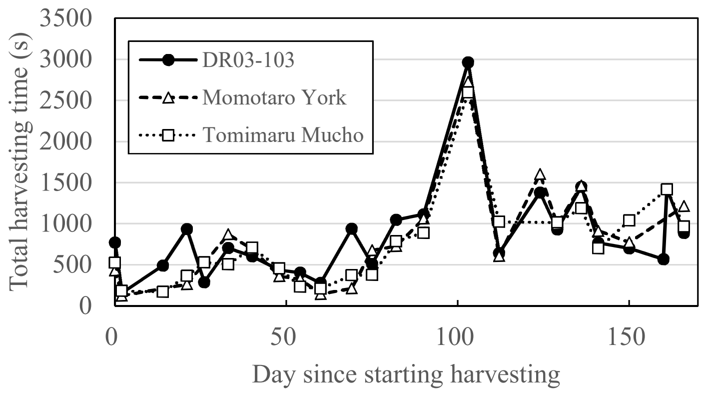
Fig.8 Relationship of total harvesting weight and harvesting time of; (a) DR03-103; (b) Momotaro York; and (c) Tomimaru Mucho



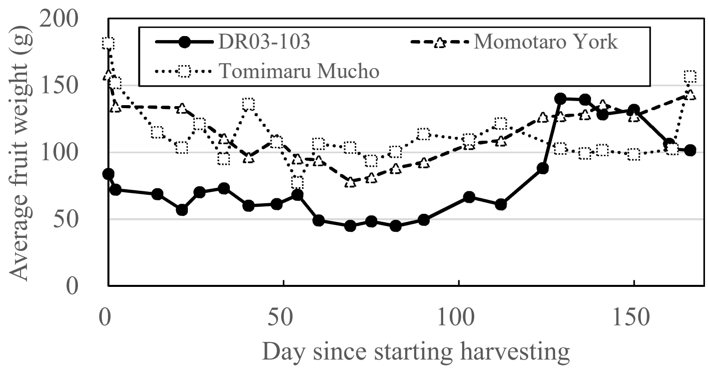
(a) Daily mean temprature



(b) Number of harvested fruits



(c) Total harvesting time



(d) Harvested fruit weight

Fig. 9 Greenhouse climate and harvesting time; (a) Daily mean temprature; (b) Number of harvested fruits; (c) Total harvesting time; and (d) Harvested fruit weight:

Table 1 Harvesting date for experiment

No.	Date	Day after 1st fruit harvesting (day)	Harvesting Interval (day)
1	Dec .24, 2014	0	−
2	Dec. 26	2	2
3	Jan. 7, 2015	14	12
4	Jan .14	21	7
5	Jan. 19	26	5
6	Jan .26	33	7
7	Feb. 2	40	7
8	Feb. 10	48	8
9	Feb. 16	54	6
10	Feb. 23	60	6
11	Mar. 3	69	9
12	Mar 9.	75	6
13	Mar. 16	82	7
14	Mar. 24	90	8
15	Apr. 6	103	13
16	Apr. 15	112	9
17	Apr. 27	124	12
18	May 1	129	5
19	May 8	136	7
20	May 13	141	5
21	May 22	150	9
22	Jun. 1	160	10
23	Jun. 2	161	1
24	Jun. 8	166	5