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ORIGINAL ARTICLE

Effects of Single-Row Transplantation on Improving Strawberry Growth and Marketable Yield

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Abstract

This study shows how the growth of the top part of plants cultivated using the single-row strawberry method, with 12 cm plant spacing, as well as that of plants cultivated through conventional planting, is characterized by the presence of many leaves in the first flower cluster harvest. The leaf area and crown diameter were the largest in the 12 cm spacing method. The hight top fresh weight (59.2 g) was detected wen the 12 cm spacing method was used followed by conventional planting and, 9 cm and 6 cm spacing method. The K and Ca contents in the first flower cluster were the highest when the 12 cm spacing method (2.0% and 2.1%, respectively) and conventional planting, (0.42% and 0.86%, respectively) were used, and these values were significantly higher than the K and Ca contents obtained using the other two methods. The N, P, Mg, Fe, and B contents show no significant differences across the planting methods. The sugar content of the first flower cluster fruits was the highest when the 12 cm spacing method was used, while the sugar content of the fourth flower cluster fruits was highest after conventional planting. Firmness was the highest in the first, third, and fourth flower clusters after conventional planting, while no significant differences were observed for the 6 cm, 9 cm, and 12 cm spacing methods. A yield of 25 g or above during November to December was observed to be the highest when the 12 cm spacing method was used, while a yield of 10-16 g was the highest when both the 9 cm and 12 cm spacing methods werw used. The yield of products in January-April was the highest when the 12 cm spacing and conventional planting methods were used, and total product yield was also the highest for these methods. A significant portion of non-marketable products (39 g) was obtained when the conventional planting method was used.

Key words : Early yield, Firmness, Southward, Sugar content

1. Introduction

Strawberries have stable prices and guarantee high profits per unit area; hence, the number of farmhouses cultivating strawberries is constantly increasing (RDA, 2008). Strawberries are rich in vitamin C and contain ellagic acid, an anticancer compound(Mass et al., 1991). A regular consumption of strawberries is thought to contribute significantly to consumer health. Forcing culture has become very popular recently, due to the supply of “Seolhyang” strawberries, whose harvest begins in mid to late November, and lasts until late May, throughout the winter(Kim et al., 2011; Park et al., 2015a, 2015b). Most farmhouses have tried to improve their thermal insulation to be able to harvest strawberries in winter. Most of them have been installing single-span greenhouses, positioned towards east and west(NSES, 1998), and adopting fruit thinning

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technology to maintain plant vigor and increase marketability(Lee, 2008). Strawberry cropping in low temperatures generally does not require heating, but it largely depends on the type of insulating curtains used, and both temperature and quantity of light tend to be low, in many cases(Jun et al., 2008). Recently, strawberry cultivation has faced severe limitations due to low temperatures, in winter. Constantly low temperature has adverse effects on strawberry growth, may cause nutrient imbalances and deterioration (Park and Oh, 2000; RDA, 2013), and requires prompt intervention.

Strawberry plants located on the southern part of an east-west single-span greenhouse receive a fair amount of light during the day, and their growth is favored by the increased soil temperature, while plants on the northern part of the greenhouse suffer relative disadvantages, and are often showing deformation and poor coloring. Udagawa et al.(1989) showed cases of accelerated aging, root browning, and unstable output in strawberry forcing cultures, mostly due to low root temperature. Therefore, to resolve such issues in winter and increase product yield, farmhouses are recently adopting the single-row planting method, disposing all plants at the center of the furrow and facing flower clusters toward south. This method is believed to promote growth and increase quantity, but the results are not clearly proven, and may cause trial and error for farmhouses. The principal aim of this study is to clarify the effect of spacing on growth and product yield ability, when the single-row planting method is used in strawberry cropping when harvested in low temperatures, and to provide new data on the issue.

2. Materials and methods

The experiment was conducted in a plastic greenhouse (length 96 m × width 6.5 m), positioned east and west, with a latitude of 35° 12' 10.885" N and longitude of 126° 45' 27.931" E, and located in Naedae-ri, Oksan -myeon, Buyeo-gun, Chungcheongnam-do, using 1,500 kg/10a of fermented cattle slurry as base manure, two weeks before planting and cultivating, and the soil had EC of 1.0 and pH of 6.6. A furrow 120 cm wide and 35 cm high was formed in the field, and seedlings were planted on September 8, 2014, with 28.0 cm in plant length, 5 leaves per plant, 8.2 mm in crown diameter, and 15.4 g in fresh weight. The experimental seedlings have been planted in the middle of the furrow, in a single row at 6 cm, 9 cm, and 12 cm intervals, with the flower clusters facing south, and using the method of conventional planting (2 rows × 18 cm intervals, flower clusters facing south 50%: north 50%) as counterfactual, in the frame of a 10-week randomized experimental design, repeated 3 times. Rooting was promoted by shielding and sufficient ventilation after planting, and Ferticare (N-P_2O_5-K_2O=20-20-20+2MgO+6 type trace elements, Dof, Pyeongtaek, Gyeonggi) was used for fertigation, in the range of EC 0.45-0.55 $dS \cdot m^{-1}$, since the blooming period of the first flower cluster, 120-150 mL/day per stock. For growth investigation, plant bodies in the first flower cluster harvest on December 10 were collected three times, 5 stocks for each planting method, to examine plant length, number of leaves, leaf area, crown diameter, amount of chlorophyll, and top fresh weight. We also analyzed the contents of nitrogen (T-N), phosphoric acid (P), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), and boron (B) in the third leaf and stem of the new leaf. For the analysis of mineral contents, this study followed the Rural Development Administration Agricultural Science and Technology Research Analysis Standard(RDA, 2003). To examine sugar content and firmness changes, the second and third fruits of each flower cluster, from the first through fourth flower clusters, were harvested, 10 each, on December 12, February 13, March 25, and April 27, respectively, and they were measured using a glucose tester (SAM-706AC, G-won Hightech, Seoul)

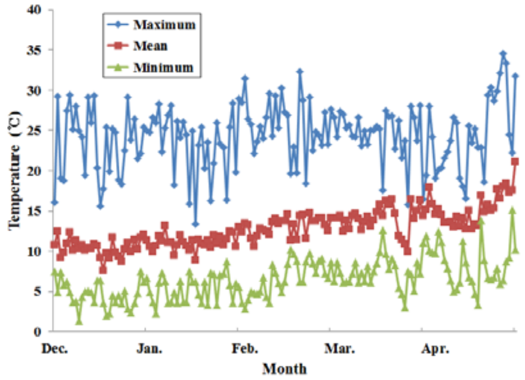

Fig. 1. Temperature change in the greenhouse from December 2014 to April 2015.

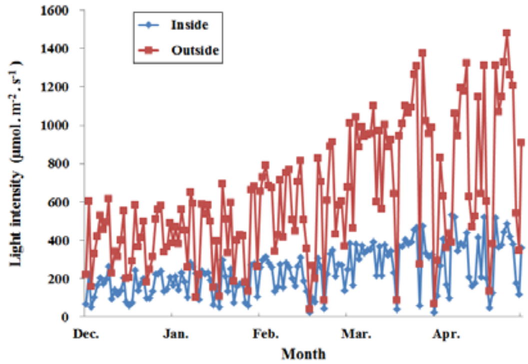

Fig. 2. Solar radiation change in the from December 2014 to April 2015. Investigation during the day: 09:00 -18:00.

and pressure tester (Sun theo tex SD-700DP, Tokyo maruichishoji Co., Ltd., Tokyo, Japan). The yield survey for each method divided the early yield, in November-December, and late yield, in January-April, into four categories: 25 g or above; 17-24 g; 10-16 g; non-marketable products. During the experiment (December 2014 to April 2015), the temperature and amount of solar radiation in the greenhouse were managed, as shown in Fig. 1 and Fig. 2. We used the SAS 9.2 (NC, USA) program to perform a Duncan's multiple range test ($P < 0.05$).

3. Results and discussion

Strawberries were planted in a single-row, with 6 cm, 9 cm, and 12 cm spacing, and in conventional planting (2 rows × 18 cm intervals), and the top part growth of these plants was investigated, by collecting the plant body in the first flower cluster harvest. Table 1 reports the characteristics of our sample. The plant length was ranging between 36.6 cm to 38.9 cm, showing similar growth for all planting methods. The number of leaves was ranging between 6.1 and 6.5 leaves for the 6 cm and 9 cm spacing planting, respectively, but it was significantly higher, with 7.3 cm and 7.2 cm, for the 12 cm spacing and conventional planting. The leaf area, which determines the plant photosynthetic capacity(Lee, 2008), was the smallest in the 6 cm spacing planting at 2.654 cm^2, followed by the 9 cm spacing, conventional, and 12

Table 1. Top part growth in the first flower cluster harvest, by planting method[z]

Planting method	Plant height (cm)	Number of leaves	Leaf area (cm^2/plant)	Crown diameter (mm)	Chlorophyll contents (SPAD)	Fresh weight (g/plant)
6 cm	38.9±1.8 a[y]	6.1±0.2 b	2,654±5.3 d	12.0±0.5 c	47.7±3.5 a	39.5±0.8 c
9 cm	38.2±1.1 a	6.5±0.3 b	3,023±5.5 c	13.1±0.7 b	45.8±3.3 a	45.7±0.7 b
12 cm	38.8±1.3 a	7.3±0.1 a	3,811±4.1 a	13.9±0.6 a	46.0±2.5 a	59.2±1.1 a
Control	36.6±0.8 a	7.2±0.2 a	3,370±3.8 b	13.2±0.5 b	46.8±4.0 a	53.1±1.0 ab

[Z]Investigation date: December 10, 2014

[y]Means within a column followed by the same letter are not significantly different by Duncan's multiple range test (P<0.05)

Table 2. Mineral content of the top part plant body in the first flower cluster harvest, by planting method[z]

Planting method	T-N	P	K	Ca	Mg	Fe	B
	-------------(%)-------------					----(mg·kg^{-1})----	
6 cm	2.3±0.12 a[y]	0.42±0.07 a	1.6±0.10 b	0.43±0.09 b	0.41±0.09 a	110±5.1 a	33±2.2 a
9 cm	2.4±0.15 a	0.40±0.09 a	1.7±0.09 b	0.52±0.11 b	0.45±0.11 a	112±4.8 a	35±1.9 a
12 cm	2.4±0.10 a	0.45±0.11 a	2.1±0.11 a	0.84±0.15 a	0.34±0.08 a	108±4.3 a	35±2.4 a
Control	2.3±0.09 a	0.51±0.10 a	2.0±0.13 a	0.86±0.16 a	0.37±0.06 a	113±5.3 a	34±2.0 **a**

[z]Investigation date: December 10, 2014

[y]Means within a column followed by the same letter are not significantly different by Duncan's multiple range test (P<0.05)

cm spacing planting methods. The crown diameter was also the smallest in the 6 cm spacing planting, with 12.0 mm, followed by the 9 cm spacing and conventional planting, with 13.1 mm and 13.2 mm, respectively, and the 12 cm spacing planting, with 13.9 mm. The chlorophyll contents, indirectly measured through the SPAD value, showed no significant difference among planting methods. The top fresh weight was the biggest in the 12 cm spacing planting, with 59.2 g, and, as for the single-row planting, the weight decreases with the spacing interval. Strawberry forcing culture requires sufficient growth before budding(Jang et al., 2009; Lee, 2008), and using the growth of the top part of the first flower cluster harvest in this experiment may affect our estimates of productivity and yields.

The N and P contents of the top part of a plant body, based on the dry weight in the first flower cluster harvest, were 2.3-2.4% and 0.4-0.51%, respectively, showing similar patterns across methods. The Mg content, that plays a significant role in the core of the atom of chlorophyll molecules (Marschner, 1995), was 0.31-0.44%, showing no clear pattern across planting methods.

The K and Ca contents were 1.9% and 2.0%, and 0.84% and 0.86%, respectively, for the 12 cm spacing and conventional planting, higher than for the 6 cm and 9 cm spacing planting methods.

Bould et al.(1983) showed that the K content enabling normal growth for dry matter of strawberries is 1.0-2.0%, while Choi et al.(2000) stated that it is 1.08-1.60% for the "Yeobong" strawberry. Jeong et al.(2001) showed that the limit concentration for Ca deficiency symptoms in strawberries is 0.41%, and that, if an absorption inhibiting environ-ment is established around the roots, the Ca content of growing points or new leaves decreases rapidly. We find that the average mineral contents of plants, across all methods, lie in the optimum range of contents for the plant body of a "Maehyang" strawberry, described by Jeong(2007) as N 0.97-1.18%, P 0.3-0.75%, K 1.9-2.8%, Ca 1.6-2.25%, and Mg 0.3-0.65%. However, we found that the Ca content was low, in our sample. The 6 cm and 9 cm spacing planting methods showed low K and Ca contents, and the top part growth was also poor, suggesting that these methods may have negatively affected plant growth, inducing nutritional competition among entities, due to the high number of plants per unit area(Takeuchi and Sasaki, 2008). Fe and B contents showed no significant differences across methods, while Fe, a key mineral for the soil(Singer and Munns, 2002), showed increased absorption in the plant body.

Fig. 3 shows the changes in sugar content and firmness of the first to fourth flower clusters, by

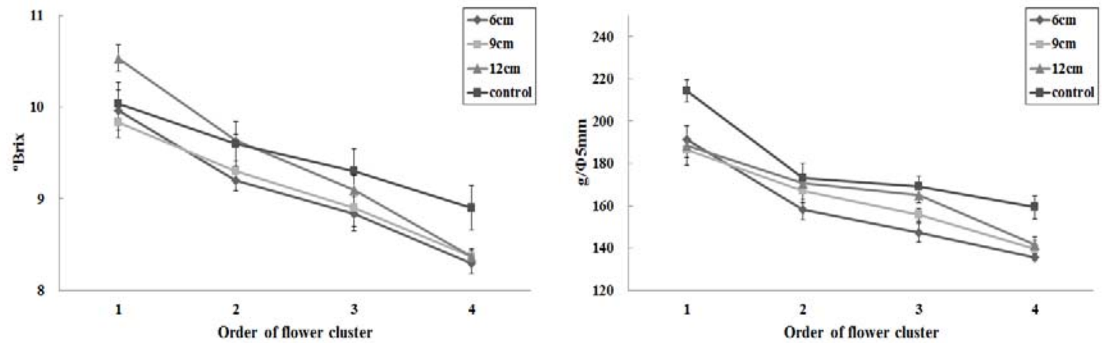

Fig. 3. Changes and investigation period of sugar content and firmness, in the first to fourth flower clusters harvest. The vertical bars represent the mean of the three replications ± standard error. Period: first flower cluster (December 12); second flower cluster (February 13); third flower cluster (March 25); fourth flower cluster (April 27).

planting method. The first flower cluster's sugar content was 10.5 °Brix in the 12 cm spacing planting, significantly higher than the average range of 9.8-10.0 °Brix in the other planting methods. The sugar content of the fruit became lower towards the end of the harvest period, due to reduction of assimilates and to n utritional competition(Lee et al., 2006), while there was no significant difference across methods in the second and third flower cluster harvest. The sugar content of the fourth flower cluster harvest was 8.3-8.4 °Brix for the 6 cm, 9 cm, and 12 cm spacing planting, but it was significantly higher, with 9.0 °Brix, for conventional planting. Firmness also showed a pattern that tended to decrease towards the end of the harvest period, and conventional planting showed the highest firmness, with 220, 177, and 164 g/ϕ5 mm for the first, third, and fourth flower clusters, respectively, while there was no clear pattern in the 6 cm, 9 cm, and 12 cm spacing planting. The environmental factor that mostly affects the yield in the strawberry thickening stage, as well as fruit quality, such as sugar content, is light, in winter, followed by temperature, when luminosity is high(El-Gizawy and Abdallah, 1993). If temperature rises, the fruit is colored before sugar is accumulated, leaving the fruit smaller, reducing its sugar content, and decreasing vase life, due to increased water-soluble pectin(Kumakura and Shishido, 1994; Sjulin and Robbins, 1987). In line with the findings of the studies mentioned, the 12 cm spacing planting strawberries, with the highest sugar content in the first flower cluster, in winter, had relatively favorable temperature and light conditions, showing the best top part growth, such as the leaf area, and a significant increase in their sugar content. Conventional planting showed the highest sugar content in the fourth flower cluster, and firmness was also high throughout the entire harvest period, except for the second flower cluster. This may be because fruits located on the northern side take longer to mature in relatively low temperature, as there is an increase in dry matter accumulation(Jang et al., 1999). Conventional planting would require further research on coloration and maturing period of the fruits on the northern side of the greenhouse, for each harvest period, compared to the fruits on the southern side. The yield of 25 g or above in November-December was the highest in the 12 cm spacing planting, while it was 40 g and 42 g in the 9 cm spacing and conventional planting, respectively, and 36 g in the 6 cm planting (Table 3). The yield of 17 -24 g showed no significant difference

Table 3. Product yield ability in the harvest period, by planting method

Planting method	Yield and marketability[z]							Total yield (g)
	Nov.-Dec.			Jan.-Apr			Non-marketables	
	25 g <	17～24 g	10～16 g	25 g <	17～24 g	10～16 g		
6 cm	36±1.1 b[y]	60±1.8 a	25±1.0 b	165±2.3 c	136±2.0 b	75±0.9 b	27±0.5 b	497±3.4 c
9 cm	42±1.7 ab	63±2.3 a	28±1.0 a	194±2.4 b	145±1.8 b	86±1.0 b	25±0.6 b	558±3.6 b
12 cm	46±1.3 a	65±2.0 a	30±1.2 a	249±3.1 a	170±1.5 a	105±1.0 a	22±0.5 b	665±3.9 a
Control	40±1.5 ab	68±2.2 a	24±1.1 b	234±2.8 a	166±1.8 a	109±1.2 a	39±0.7 a	641±3.8 a

[z]Yield in November-December 2014 and January-April 2015

[y]Means within a column followed by the same letter are not significantly different by Duncan's multiple range test (P<0.05)

across planting methods, and that of 10-16 g was the highest in the 9 cm and 12 cm spacing planting. The yield in November-December was relatively high in the 9 cm and 12 cm spacing planting, and, in terms of early yield, the single-row planting can be considered beneficial. In particular, for the 12 spacing cm planting, the cause for excellent top part growth in the first flower cluster harvest may have positively affect the yield, as well(Choi, 2007; Park et al., 2015a). The yield of 25 g or above in January-April was 249 g and 234 g in the 12 cm spacing and conventional planting, respectively, significantly larger than 145 g and 136 g in the 9 cm and 6 cm spacing planting methods. The yield of 17-24 g and 10-16 g was also high in the 12 cm spacing and conventional planting. Strawberries are harvested for approximately 6 months, and towards the end of the harvest period, the yield is greatly affected by reduced assimilates and acceleration of aging(Udagawa et al., 1989; Lee et al., 2006). With regard to these reports, in the 6 cm and 9 cm spacing planting, excessive nutritional competition among entities may have been the main cause of the reduced yield, in the end of the harvest period. Total yield during the harvest period was the greatest, with 665 g and 641 g, in the 12 cm spacing and conventional planting, respectively, followed by 558 g in the 9 cm and 497 g in the 6 cm spacing planting methods. However, the yield of non-marketable products was 39 g in conventional planting, significantly larger than the 6 cm, 9 cm, and 12 cm spacing planting. This is closely related to the fact that lower temperatures and scarce light are likely to lead to a deterioration of strawberry quality(Jun et al., 2008; RDA, 2013), and further research on the issue would be needed.

4. Conclusion

The aim of this study is to analyze the effects of single-row strawberry planting on harvest growth and product yield. We showed no significant difference across methods in the plant length of the first flower cluster harvest, while the 12 cm spacing planting method and the conventional planting showed the largest number of leaves, and leaf area and crown diameter were the highest in the 12 cm spacing planting method. Top fresh weight was heaviest, with 59.2 g in the 12 cm spacing planting, followed by conventional planting, 9 cm, and 6 cm spacing planting method. The K and Ca contents of the first flower cluster harvest were 2.0% and 2.1%, respectively, and 0.42% and 0.86%, respectively, for the 12 cm spacing planting method and conventional planting, and were higher than in the other two planting methods. In contrast, we found no significant difference in the N, P, Mg, Fe, and B contents of plants across planting methods. The sugar content of the first flower cluster fruit was high in the 12 cm spacing planting, while that of the fourth flower cluster fruit was high in conventional planting. Firmness was high in the first, third, and fourth flower clusters for conventional planting, while we found no significant difference among the 6 cm, 9 cm, and 12 cm spacing planting methods. A yield of 25 g or above in November-December was highest in the 12 cm spacing planting, while a yield of 10-16 g was the highest in the 9 cm and 12 cm spacing planting. The yield of products in January-April was the highest in the 12 cm spacing planting method and conventional planting, and the total product yield was also the highest in these two methods. We found several non-marketable products (39 g) in conventional planting.

Single-row 12 cm spacing planting was the most desirable method for increasing product yield, in November-December. There is scope for further research to clarify the impact of light, temperature conditions, fruit maturing period, and fruit thinning on product yield, across planting methods.

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