A comparison of Vertical and Conventional Cultivation, Planting Distances and Growing Medium in the Growth and Yield of Three Varieties of Strawberry

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Abstract. This study is conducted in the unheated greenhouse of the Department of Horticulture and Landscape- College of Agriculture – Tikrit University during the two seasons 2019-2020. It aims at comparing between vertical and terrestrial cultivation and cultivation distances in growth and yield of three cultivars of strawberry. The study includes three factors. The first factor is the method of cultivation which includes two methods of cultivation, terrestrial cultivation and vertical cultivation in pipes. The second factor is planting distances which include three distances, 15, 20 and 25 cm between one plant and another. The third factor related to varieties and includes three, namely Camarosa, Ventana and Sweet Charlie. The experiment is implemented by randomized complete block design according to the split-split Plot Design system, with three replications, each replicate containing 9 experimental units with a length of 2 meters, the cultivation method was set in the main plots and the planting distances in the sub-plots, while the cultivars took the sub-sub-plots. The results have shown the superiority of the terrestrial cultivation treatment over the vertical cultivation in each of the number of leaves, the content of the leaves from chlorophyll, the average number of fruits, the weight of the fruit and the yield of the greenhouse, which reached to 13.74 leaves of plant⁻¹, 49.25 SPAD, 15.71 fruit plant⁻¹, 15.28 gm, and 238.5 gm plant⁻¹, respectively. The Sweet Charlie variety outperformed in the average number of leaves, leaf content of chlorophyll, fruit weight and greenhouse yield, with 15.97 leaves plant⁻¹, 50.47 SPAD, 15.39 gm and 231.5 gm plant⁻¹, respectively. The distance 25 cm between one plant and another outperformed in the above-mentioned characteristics, which reached to 13.97 leaves plant⁻¹, 49.98 SPAD, 15.25 fruits plant⁻¹ and 212.3 gm plant⁻¹, respectively.

1. Introduction

Strawberry is a perennial herbaceous plant that is considered as one of the fruits that yields small fruits and is widespread in the world. Its name is derived from Fragaria ananassa Duch. from the Latin word fragrans. It is named in English Strawberry, in French Fraise, and in Italian Fragola, from which the name was derived in Egypt as Farawla (strawberry). In Syria it is called strawberry or Feraiz. In Turkey, it is called Chillaik, from which the name is taken in Iraq as Chillaik [1, 2]. Its cultivation is currently spread in more than 63 countries, and the global production of strawberry in 2012 is about 4516,810 tons, and the cultivated areas in the world are about 241,109 hectares. The United States of America ranks first in the list of strawberry-producing countries, with a production reaching 1,366,850 tons, which is more than a quarter of the world's production. Egypt comes in fifth place after Mexico, Turkey and Spain for the same year with 24,227 tons [3]. Plastic pipe cultivation, which is a form and method of vertical cultivation, allows the increase in the number of plants per square meter by several times according to the diameter of the pipe used, and this in turn is positively reflected on the increase
in the productivity of the square meter. Using the vertical farming system, the density of cultivation can increase by three to four times [4]. The cultivation distances and the way plants are distributed have a major role in determining the ability of the crop to exploit the resources available to the plant such as water, nutrients and lighting, and thus reflected in the growth and yield of the resulting plants [5]. [6] note this in their study which aims at assessing the effect of distances of different cultivations on the characteristics of photosynthesis, fruit quality and production of strawberry cultivar Pircinque in southern Brazil. The study includes six agricultural distances, 5, 10, 15, 20, 25, 30 cm between one plant and another, in which the 30 cm distance between one plant and another has given the highest average number of fruits and yield for each plant and for both seasons of the study 2018-2019 and 2019-2020. These have amounted to 40 and 53.5 fruits plant⁻¹, 540.45 and 685.50 gm plant⁻¹, respectively. In a study conducted by [7] in the greenhouse of the College of Agriculture - Tikrit University to show the effect of spraying with gibberellin and nutritious solution GS on the strawberry varieties Rubygem and Festival, she noticed the superiority of the Festival variety in both the number of runners and the number of flowers, reaching to 6.54 runners Plant⁻¹ and 14.61 flower-plant⁻¹, respectively; compared to the Ruby gem variety which recorded the lowest rate of 5.27 runners plant⁻¹ and 13.14 flower plant⁻¹. On the other hand, the variety Ruby gem outperformed in the mean number of leaves, which amounted to 30.15 leaves plant⁻¹, compared to the variety Festival, which gave an average of 26.73 leaves plant⁻¹.

2. Materials and Methods

This experiment is conducted in the unheated greenhouse in the field of the Department of Horticulture and Landscape - College of Agriculture - University of Tikrit during the agricultural season (2019-2020). The soil is analyzed after taking random samples from the field soil before planting at a depth of (0-30) cm. Analysis is conducted in the postgraduate laboratories - Department of Horticulture and Landscape Planning - College of Agriculture – University of Tikrit, after mixing the sample well. The table shows some chemical and physical characteristics of the field soil before planting.

![Table 1. The physical and chemical characteristics of the soil of the greenhouse before planting](image)

The experiment was divided into three replicates. Each replicator contains three tubes, the tube length is 6 meters and the diameter is 6 inches, and each tube contains three experimental units. Thus, the number of experimental units in one replicate is 9 experimental, each experimental unit contains a number of plants that vary according to the distance between one plant and another. When the distance between one plant and another is 15 cm, the number of plants is 13 plants, when the distance between one plant and another is 20 cm, the number of plants is 10, and at the distance of 25 cm between one plant and another, the number of plants is 8 plants. The experiment was implemented by designing the RCB randomized complete plots according to the split-split-plot design system. The cultivation method was placed in the main plots and the planting distances in the sub-plots, while the cultivars took the sub-sub-plots.

The experiment includes a study of three factors:

- The First Factor: the method of cultivation, and it includes two methods of cultivation, namely, terrestrial cultivation and vertical cultivation.
- The Second Factor: the planting distances, which include three distances, 15, 20 and 25 cm between one plant and another.
- The Third Factor: Varieties which are three, namely Camarosa, Ventana, and Sweet Charlie.

Studied Characteristics:

1. Average number of leaves (leaf plant⁻¹)
2. Chlorophyll contents of the leaves (SPAD):
3. Average length of fruit (mm)
4- Average yield per plant (gm plant\(^{-1}\))
5- Average yield of a greenhouse (kg greenhouse\(^{-1}\))

3. Results and Discussion

3.1. Average Number of Leaves (Leaf Plant\(^{-1}\))

The data in Table (2) indicate that the treatment of terrestrial cultivation is significantly superior to the treatment of vertical cultivation by recording an average number of leaves that amount to 13.74 leaf plant\(^{-1}\), while the treatment of vertical cultivation has recorded an average number of leaves that amount to 13.12 leaf plant\(^{-1}\). As for the general effect of the varieties, the Sweet Charlie variety outperformed all other varieties scoring an average of 15.97 leaf plant\(^{-1}\), while Camarosa variety has scored 13.52 leaf plant\(^{-1}\), followed by Ventana variety with 10.79 leaf plant\(^{-1}\). As for planting distances, the distances D\(^1\) and D\(^2\) outperformed by giving the highest number of leaves reaching 13.87 and 13.97 leaf plant\(^{-1}\), respectively, compared to the lowest number of leaves, 12.44 leaf plant\(^{-1}\), at the distance D\(^3\). As for the dual interaction treatments between the cultivation method and varieties, the M1V3 treatment outperformed the rest of the treatments in giving the largest number of leaves reaching 16.68 leaf-1, while the lowest number of leaves for treatments of M\(_1\)V\(_1\) and M\(_1\)D\(_2\) in giving the highest average number of leaves with 12.02 leaf plant\(^{-1}\). As for the dual interaction treatments between varieties and distances, the dual interaction treatment between Sweet Charlie variety and distances D\(_1\), D\(_2\) and D\(_3\) outperformed the rest of the treatments by giving the highest average number of leaves with 15.57, 15.60 leaf plant\(^{-1}\) and 15.73 leaf plant\(^{-1}\), while the lowest number of leaves are 8.92 leaf plant\(^{-1}\) with the treatment V\(_2\)D\(_1\). The M\(_1\)V\(_2\)D\(_3\) triple interaction treatment outperformed the rest of the varieties in the average number of leaves, giving 17.87 leaf plant\(^{-1}\), while the lowest number of leaves is recorded with the triple interaction M\(_2\)V\(_2\)D\(_1\) treatment amounting to 8.43 leaf plant\(^{-1}\).

Table 2. Effect of cultivation of method, planting distances, Varieties and the interaction in Average number of leaves (leaf plant\(^{-1}\))

| Method of cultivation × Varieties | Planting distances | Varieties | Method of cultivation |
|----------------------------------|-------------------|----------|----------------------|
|                                  | D\(_1\) | D\(_2\) | D\(_3\) |
| 12.60                            | 14.33  | 13.53  | 13.52 |
| Efg                              | cd     | def    | c      |
| 9.40                             | 12.13  | 11.50  | 11.01 |
| Ij                               | fg     | gh     | D      |
| 16.57                            | 17.87  | 15.60  | 16.68 |
| Ab                               | a      | bc     | A      |
| 13.07                            | 13.23  | 14.27  | 13.52 |
| Defg                             | defg   | cde    | C      |
| 8.43                             | 10.23  | 13.07  | 10.58 |
| ij                               | hi     | defg   | D      |
| 14.57                            | 15.33  | 15.87  | 15.26 |
| Cd                               | bc     | bc     | B      |

Effect of planting distances

| Method of cultivation × cultivation distance | Varieties × cultivation distance |
|---------------------------------------------|----------------------------------|
| 13.74                                       | Terrestrial cultivation          |
| a                                           | 12.86                            |
|    | 14.81                            |
|    | 13.54                            |
| 13.12                                       | Vertical cultivation             |
| B                                           | 12.02                            |
|    | 12.93                            |
|    | 14.40                            |

The general effect of the varieties

| Varieties × cultivation distance |
|----------------------------------|
| 12.83                            |
| 13.90                            |
| 13.52                            |
| V\(_1\)                           |
| Bc                               |
| b                                |
| 12.90                            |
| V\(_2\)                           |
| 11.18                            |
| 12.28                            |
| 10.79                            |
3.2. Chlorophyll contents of the leaves (SPAD)

It is clear from Table (3) that there are significant differences in the total chlorophyll content of the leaves, as the terrestrial cultivation method is significantly superior to the vertical cultivation in this characteristic, recording 49.25 SPAD compared to 47.88 SPAD. Also, the Sweet Charlie variety is significantly superior to the rest of the varieties in this characteristic by giving 50.47 SPAD, while the Sweet Charlie has given the lowest value for this characteristic in the Camarosa variety amounting to 47.27 SPAD. Regarding the distance between plants, it is noted from the same table that the distance D3 is significantly superior to the rest of the distances in the content of chlorophyll in leaves amounting to 49.98 SPAD compared to the lowest content of chlorophyll which is 46.45 SPAD. The dual interaction treatment M1V3 significantly outperformed the rest of the treatments by giving 51.07 SPAD, while the M1D1 treatment has given the lowest chlorophyll content amounting to 46.37 SPAD. Treatments M1D2 and M1D3 are significantly superior by giving 50.18 and 50.54 SPAD, while the lowest chlorophyll content is recorded with the M2D1 treatment by 45.88 SPAD. Treatment V3D3 is significantly superior to the rest of the interaction treatments in this characteristic giving 51.80 SPAD compared to treatment V1D1 which has given the lowest SPAD value of 44.56. Through the same table, with regard to the triple interaction treatments among the study factors, it is noted that the M1V3D3 treatment is significantly superior to the rest of the treatments in this characteristic by giving 52.53 SPAD compared to the lowest content of chlorophyll at the M2V1D1 treatment with 44.20 SPAD.

Table 3. Effect of cultivation of method, planting distances, Varieties and the interaction in Chlorophyll contents of the leaves (SPAD)

| Method of cultivation × Varieties | Planting distances | Varieties | Method of cultivation |
|----------------------------------|--------------------|-----------|----------------------|
|                                  | D<sub>3</sub>      | D<sub>2</sub>| D<sub>1</sub>        |
| 44.92                            | 50.80              | 48.77     | 48.16                |
| 46.23                            | Bc                 | fg        | Cd                   |
| 49.90                            | 50.77              | 52.53     | 51.07                |
| cde                              | Bc                 | a         | A                    |
| 44.20                            | 47.10              | 47.80     | 46.37                |
| j                                | Hi                 | gh        | E                    |
| 44.90                            | 47.87              | 49.39     | 47.39                |
| j                                | Gb                 | def       | D                    |
| 48.53                            | 50.03              | 51.07     | 49.88                |
| fg                               | Bcde               | b         | B                    |
| 47.02                            | 50.18              | 50.54     | 49.25                |
| d                                | A                  | a         | A                    |
| 45.88                            | 48.33              | 49.42     | 47.88                |
| e                                | C                  | b         | B                    |

Effect of planting distances

| Method of cultivation × cultivation distance |
|---------------------------------------------|
| 47.02                                       |
| 45.88                                       |

The general effect of the varieties

| Varieties × cultivation distance |
|----------------------------------|
| 44.56                            |
| 45.57                            |
3.3. Average Length of the Fruit (mm)

The results of Table (4) show that the terrestrial cultivation method is significantly superior in the average fruit length, amounting to 35.54 mm compared to the vertical method which amounts to 34.09 mm. Moreover, the Sweet Charlie variety records the highest fruit length and significantly reaches 39.94 mm compared to the lowest fruit length of 27.28 mm for the Ventana variety. The distance D3 is significantly superior to the rest of the distances by giving a fruit length of 36.36 mm, while the lowest fruit length is recorded at 33.87 mm at the distance D2. The two treatments $M_1V_3$ and $M_2V_3$ significantly outperformed the average fruit length of 39.69 and 40.19 mm respectively, compared to the lowest length with 25.58 mm at the $M_1V_1$ treatment. Also, the $M_1D_3$ interaction treatment is significantly superior to the rest of the treatments in giving the highest fruit length of 37.35 mm compared to the lowest fruit length recorded at the interaction treatment between vertical cultivation and the distance 15 cm reaching 33.10 mm. The $V_3D_3$ interaction treatment is significantly superior in this characteristic recording 41.25 compared to the lowest value for this characteristic with 25.85 mm at $V_2D_1$. The effect of the triple treatment of the study factors shows the effect of the treatments $M_1V_1D_3$, $M_1V_3D_1$, $M_1V_3D_3$, $M_2V_3D_2$ and $M_2V_3D_3$ significantly on the length of the fruit, amounting to 40.67, 40.80, 41.10, 40.57 and 41.40 mm, respectively. The lowest rate for this characteristic is 23.67 mm at the treatment $M_2V_2D_1$.

Table 4. Effect of cultivation of method, planting distances, Varieties and the interaction in Average length of the fruit (mm)

| Method of cultivation × Varieties | Planting distances | Varieties | Method of cultivation |
|----------------------------------|--------------------|-----------|----------------------|
|                                  | $D_1$              | $D_2$     | $D_3$            |
| $c$                              | 37.13              | 36.00     | 40.67             | 37.93 |
| $e$                              | 28.03              | 28.67     | 30.27             | 28.99 |
| $a$                              | 40.80              | 37.17     | 41.10             | 39.69 |
| $c$                              | 37.03              | 35.90     | 36.57             | 36.50 |
| $g$                              | 23.67              | 24.93     | 28.13             | 25.58 |
| $b$                              | 38.60              | 40.57     | 41.40             | 40.19 |
|                                  | $V_1$              | $V_2$     | $V_3$            |
|                                  | Terrestrial cultivation | Vertical cultivation |         |

Effect of planting distances

| Method of cultivation × cultivation distance |
|----------------------------------------------|
| $b$                                           |
| $d$                                           |

The general effect of the varieties

| Varieties × cultivation distance |
|---------------------------------|
| $V_1$                           |
| $V_2$                           |
| $V_3$                           |
3.4. Average Yield per Plant (gm plant\(^{-1}\))

The data in Table (5) indicate that the terrestrial cultivation treatment is significantly superior in the rate of yield per plant by recording a rate of 238.6 gm plant\(^{-1}\) compared to the vertical cultivation treatment, which recorded the lowest rate for this characteristic amounting to 171.9 gm Plant\(^{-1}\). As for the general effect of the varieties, Sweet Charlie variety significantly outperformed the rest of the varieties in this characteristic by giving the highest yield of 231.6 gm plant\(^{-1}\) compared to the lowest value for this characteristic of 174.2 gm plant-1 for Ventana variety. Regarding the general effect of planting distances, the distance D3 significantly outperformed by giving an average of 212.3 gm plant\(^{-1}\), compared to the distance D1, which gave the lowest value of 196.9 gm plant-1. The dual interaction treatment between vertical cultivation and Sweet Charlie variety is significantly superior to the rest of the interaction treatments in giving the highest average yield of one plant reaching 272.8 gm plant\(^{-1}\). The dual interaction treatment between vertical cultivation and Ventana variety has recorded the lowest rate of 147.6 gm plant\(^{-1}\).

Concerning the two interaction treatments between the cultivation method and the distances, the interaction treatment between the terrestrial cultivation and the distance D3 significantly outperformed the rest of the interaction treatments by recording the largest yield per plant amounting to 246.3 gm plant\(^{-1}\), which has not differed significantly from the interaction M3D2 which has given 242.7 gm plant\(^{-1}\). As for the dual interaction treatment between varieties and distances, treatments V3D2 and V3D3 significantly outperformed the rest of the interaction treatments by giving an average of 243.5 and 240.4 gm plant\(^{-1}\), respectively. The lowest rate of yield per plant is observed when interaction V2D3 gives 171.4 gm plant\(^{-1}\). The triple interaction treatment between the terrestrial cultivation, Sweet Charlie variety and the distances D2 and D3 significantly outperformed the rest of the triple interaction treatments by giving an average yield of 282.4 and 287.5 gm plant\(^{-1}\). The lowest rate of this characteristic is recorded with the M2V2D3 treatment at 139.3 gm plant\(^{-1}\).

Table 5. Effect of cultivation of method, planting distances, Varieties and the interaction in Average yield per plant (gm plant\(^{-1}\))

| Method of cultivation × Varieties | Planting distances | Varieties | Method of cultivation |
|----------------------------------|--------------------|-----------|----------------------|
|                                  | D3                 | D2        | D1                  |
| 230.07                           | 248.10             | 248.36    | 242.18              |
| bc                               | b                  | B         | b                   |
| 201.46                           | 197.71             | 203.15    | 200.77              |
| cd                               | d                  | Cd        | c                   |
| 248.43                           | 282.39             | 287.46    | 272.76              |
| b                                | a                  | A         | a                   |
| 178.16                           | 153.22             | 202.17    | 177.84              |
| de                               | ef                 | Cd        | c                   |
| 150.05                           | 153.37             | 139.33    | 147.58              |
| ef                               | ef                 | F         | d                   |
| 172.90                           | 204.69             | 193.41    | 190.33              |
| de                               | cd                 | D         | c                   |

Effect of planting distances

| Method of cultivation × cultivation distance |                      |          |
|--------------------------------------------|----------------------|----------|
| 226.65                                     | 242.73               | 246.32   | 238.57              |
| b                                          | ab                   | A        | a                   |
| 167.04                                     | 170.42               | 178.31   | 171.92              |
| c                                          | c                    | C        | b                   |

*Numbers with same letter means no significant on Duncan test at probability of 5%.
The general effect of the varieties × cultivation distance

| Method of cultivation × Varieties | Planting distances | Varieties | Method of cultivation |
|----------------------------------|--------------------|-----------|----------------------|
|                                  | D3                 | D2        | D1                  | V1                  |
| Terrestrial cultivation          | 620.91             | 775.30    | 958.64              | 784.95              |
|                                  | fg                 | de        | Ab                  | b                   |
| Vertical cultivation             | 507.86             | 617.84    | 839.41              | 655.04              |
|                                  | h                  | g         | Cd                  | c                   |
|                                  | 718.64             | 882.47    | 1035.10             | 878.74              |
|                                  | ef                 | bc        | A                   | a                   |
|                                  | 505.43             | 478.80    | 742.37              | 575.53              |
|                                  | h                  | h         | E                   | d                   |
|                                  | 348.33             | 479.27    | 625.25              | 484.28              |
|                                  | i                  | h         | Fg                  | e                   |
|                                  | 483.52             | 639.65    | 720.48              | 614.55              |
|                                  | h                  | fg        | Ef                  | cd                  |

Effect of planting distances

| Method of cultivation × cultivation distance | Method of cultivation |
|---------------------------------------------|-----------------------|
| Terrestrial cultivation                     | 615.80                |
| d                                            | 758.54                |
| d                                             | 944.38                |
| Terrestrial cultivation                      | 772.91                |
| d                                            | 445.76                |
| d                                             | 532.57                |
| d                                             | 696.04                |
| Vertical cultivation                         | 558.12                |

*Numbers with same letter means no significant on Duncan test at probability of 5%.

3.5. Average Greenhouse Yield (kg Greenhouse⁻¹)

The results of Table (6) indicate that the cultivation of the terrestrial method is significantly superior to the vertical method in the average yield of the greenhouse with an increase of 38.48%. Also, for the varieties, the Sweet Charlie variety is significantly superior in this characteristic with an increase of 31.07% from the Ventana variety. Concerning the general effect of planting distances, the distance of 25 cm between one plant and another exceeded in the characteristic of greenhouse yield, with an increase of 54.53% in the distance of 15 cm between one plant and another. The dual interaction treatment between vertical cultivation and Sweet Charlie and Camarosa varieties is superior in giving the highest percentage increase in the greenhouse yield amounting to 81.45%. As for the dual interaction treatments between the two methods of cultivation and the distances, the interaction treatment between the terrestrial cultivation and the distance D1 is superior to the rest of the interaction treatments, reaching 111.86%. Regarding the dual interaction treatment between varieties and distances, treatments V1D3 and V3D3 outperformed the rest of the interaction treatments by giving an increase rate of 98.67 and 105.04, respectively. The M1V3D3 triple interaction treatment is superior by giving the highest percentage increase of 197.29%.

The results obtained can be explained as the terrestrial cultivation outperformed in the characteristics of the number of leaves, the content of chlorophyll in leaves, the number of fruits, the average length and yield of one plant, and the total yield of the greenhouse (Tables 2, 3, 4, 5, 6). There is the fact that the roots extended in the soil more than that in the pipe cultivation, which consequently leads to the formation of a strong root system, and this helps to absorb large amounts of nutrients from the soil.
and thus the formation of a good vegetative group, represented by the number of leaves (Table 2) and the increase in the leaf area. This increase in the number of leaves and leaf area is followed by an increase in the outputs of the carbon metabolism process which includes proteins and carbohydrates and its gathering in the storing plant parts; with an increase in the percentage of nutrients in the leaves and thus an increase in the dry weight of the plant. This is reflected positively on the increase in yield by increasing the number of fruits, the length, diameter and weight of the fruit, the rate of yield per plant and the total yield of the greenhouse [8]. These results are in line with the results by [9, 10]. With regard to varieties, it is noted from the tables that the Sweet Charlie variety outperformed in both the number of leaves and the content of chlorophyll in leaves. This may be attributed to the genetic variation between varieties [11, 12, 13] and its impact on the difference in the vegetative growth strength of the three varieties. These results are in line with what is indicated by [2, 14] in that the nature of the growth of the strawberry plant varies according to the cultivated variety as well as the varietal response to the environmental conditions prevailing in the planting site. As for the cultivation distance, it is concluded that there is a significant superiority when increasing the cultivation distance in the characteristics of the number of leaves and total chlorophyll, which leads to an increase in the food area for each seedling, in addition to the availability of better environmental conditions, as well as the lack of competition between plants for water, nutrients, lighting and temperature. Also, these conditions are ideal for the formation of a strong root system that helps absorb water and nutrients better. The absorption of these elements activates the vital processes in the plant, especially the process of photosynthesis, and this in turn works to form a strong vegetative group represented by the number of leaves and their content of chlorophyll. The results of this study are in line with the findings by [15] in that increasing the number of plants per unit area leads to an increase in competition between plants for water, light and nutrients, which is negatively reflected on the vegetative growth of the plant. A significant increase is observed in the average leaf area of Elsanta strawberry variety as the distance between plants increased, which reached three times when the distance of 25 cm is adopted between one plant and another compared to the distance of 10 cm. When adopting the distance of 20 cm between one plant and another, the average number of leaves reached about two times compared to the distance of 10 cm between plants.

4. Conclusions
On the basis of present investigation, it is concluded that conventional cultivation is better than vertical cultivation in giving the highest growth and yield of strawberry plants. Sweet Charlie and Camarosa are better than Ventana in characteristics of growth and yield. The space is 25 is best spacing as compared to other spacing taken under study for influencing the growth and yield of strawberry.

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