Research article

Influence of different growing media on the growth and development of strawberry plants

Bolappa Gamage Kaushalya Madhavi [a], Fawad Khan [a], Anil Bhujel [a], Mustafa Jaihuni [a], Na Eun Kim [a], Byeong Eun Moon [b], Hyeon Tae Kim [a,*]

[a] Department of Bio-systems Engineering, Gyeongsang National University (Institute of Smart Farm), Jinju, 52828, Republic of Korea
[b] Institute of Smart Farm, Gyeongsang National University, Jinju, 52828, Republic of Korea

ARTICLE INFO

ABSTRACT

The optimal production of strawberries requires the essential nutrients and favourable media for vegetative and reproductive growth. The present study sought to determine the effectiveness of growth parameters and fruit yield of strawberries in different media growing under a greenhouse. To analyze the significant effect for the growth and fruit yield among the growing media, four treatments such as control soil (CS), bio plus compost (T_1), the combination of bio plus compost, and synthetic nutrient applied media/integrated media (T_2) and synthetic nutrient applied soil media (T_3) were assayed. Morphology parameters like plant height, canopy area, fresh weight, dry weight of roots were measured in each stage after eight weeks and sixteen weeks and yield attributing parameter as the number of fruits set per plant and number of fruits per plant were measured at the beginning and end of the reproductive stage eight and sixteen weeks respectively. The effects of growing media for the strawberry plant growth and productivity were analyzed using completely randomized block designs through analyzing the variance with a significance level of $p < 0.05$. The canopy area of the strawberry plants was calculated using the image processing technique applied in HSV colour space. Correspondingly, the vegetative stage and reproductive stage of T_2 plants attained the maximum plant height of 16.93 ± 0.31 cm and 19.34 ± 0.21 cm, canopy area with 23.02 ± 1.94 cm^2 and 28.78 ± 0.93 cm^2, fresh weight of 18.00 ± 3.06 g, and 20.15 ± 3.49 g, dry weight of 5.15 ± 1.26 g and 6.66 ± 2.34 g and the number of fruits set per plant 18.83 ± 2.64 and number of fruits per plant 24.17 ± 2.14 followed by T_1, T_3, and CS respectively. A comparison of the relative growth and fruit yield at the vegetative and reproductive phases of plants T_2 implied better performance. This study demonstrated that bio plus compost with synthetic nutrients act as a better source for the growth and production of strawberries under the greenhouse.

1. Introduction

Strawberry (*Fragaria* × *ananassa*) is standout cultivation in Jinju, South Korea is in its infancy and has increased logarithmically during recent decades. Favourable soil media and macro, micronutrients are the utmost important factors that aid the growth and yield of strawberry plants. Since strawberry is a shallow-rooted plant, effective nutrient management is essential for profitable production. Specifically, the soil plays an integral role as a reservoir to retain water and nutrient, and also provides physical support for the growth of the root system (Raja et al., 2018).

Correspondingly, the application of compost with synthetic nutrients as a substrate is a good management strategy to enhance the strawberry

yield in greenhouse cultivation. Therefore, the use of natural soil media integrated with synthetic nutrient solution modifies the high growth performance, better nutrient uptake, and productivity of strawberry cultivars (Wei et al., 2020). Bio plus compost (cocopeat 68.86%, peat moss (11.00%), perlite (11.00%), and zeolite (9.00%) is a standardized commercial fertilizer utilized for vegetable growth in South Korea which contains coconut waste and other biodegradable materials such as grass clipping and leaves (Khan et al., 2019). Furthermore and even more importantly, it contains a lot of environmentally beneficial microbes which enhance soil physiochemical properties, decreasing nutrition loss by decomposing the organic materials and reducing the eutrophication due to the slower nutrient release compared to other organic and mineral fertilizers (Vandecasteele et al., 2018).

---

* Corresponding author.
E-mail address: bioani@gnu.ac.kr (H.T. Kim).

In addition to that, compost quality is closely related to their maturity as stability and their indicators that have been proposed carbon/nitrogen (C: N) ratio, microbial activity, humic substance, cation exchange capacity (CEC), and germination index as revealed by Azim et al. (2014). Moreover, an appropriate combination of the C: N ratio (nutrient balance) is crucial for enhancing the compost performance and growth, and activity of the beneficial microbial population (Qasim et al., 2018). In recent decades, farmers move to environmentally sustainable materials for growing media for stabilizing the ecosystem quality due to the lower impact on global warming and improving the physicochemical properties of soil (Tejada et al., 2009). Barrett et al. (2016) revealed that compost is a reach source of fiber and acts as a structuring medium for plant roots formation.

Generally, nitrogen, phosphorous, and potassium (NPK) are the most important macronutrient in inorganic fertilizers which need for optimal production of strawberries, enhancing soil fertility, plant growth, and soil structural ability (Khan et al., 2019). Nitrogen (N) is the most significant element for runner production, plant growth, and fruit bud formation. Moreover, the limited application of N may have a detrimental effect on the vegetative growth development of strawberry plants (Trejo-Tellez and Gomez-Merino, 2014; Cardenas-Navarro et al., 2006). Furthermore, Phosphorus (P) is one of the major nutrients for strawberry growth and development. It also plays an integral role in photosynthesis, energy transferring, the transformation of sugars into starches, and the translocation of nutrients. Specifically, Potassium (K) also plays an indispensable role in cell elongation, carbohydrate, and sugar synthesis. Therefore, NPK nutrient is significant for optimal strawberry production and increasing the quality of strawberries such as sweetness, firmness, and anthocyanin accumulation in strawberry fruit as revealed by Yoshida et al. (2000). However, nutrients and growing media are correlated with plant growth and productivity. Growth analysis demonstrates the plant's primary productivity, which determines the yield and physiological phenomena of the plant. Correspondingly, the growth parameters rely on measuring raw data such as plant height, canopy area, dry weight, and fresh weight of root (Casierra-Posada et al., 2012).

The canopy area plays a significant impact in plant photosynthesis, transpiration, and crop growth. In addition to that, it is a key index in plant breeding practices and plant growth rate measurement (Sandino et al., 2016). Therefore, modern agriculture operations focusing on nondestructive accuracy methods for canopy area measurement. Even though, in recent years many destructive methods were already investigated namely gravimetric methods, square grid meter, planimeters, and area-length regression. Nevertheless, these destructive measurements are easily affected by human subjective factors. Therefore, accuracy is low compared to non-destructive measurements (Lu et al., 2010).

Digital image processing is one good non-destructive implementation for canopy area calculation in the agriculture sector to analyze images to obtain information regarding plant growth. The colour detection model is required to calculate the leaf area in the digital image processing technique with the support of a computer. HSV (Hue, Saturation, Value) is an accurate colour model even in non-uniform illumination conditions to determine the colours of an image object which is similar to colours seen by the human eye as reported by Setyawan et al. (2018). The objective of this present study was to determine the growth and fruit yield of the strawberry plant in the different growing media such as control soil, bio plus compost, integrated media, and synthetic nutrient applied soil media.

2. Materials and methods

2.1. Experimental design

The present investigation was carried out in the controlled greenhouse at Smart Farm Research Center of Gyeongsang National University, South Korea during the winter season in 2020. The overall experiment time was 120 days in winter (from the beginning of November to the end
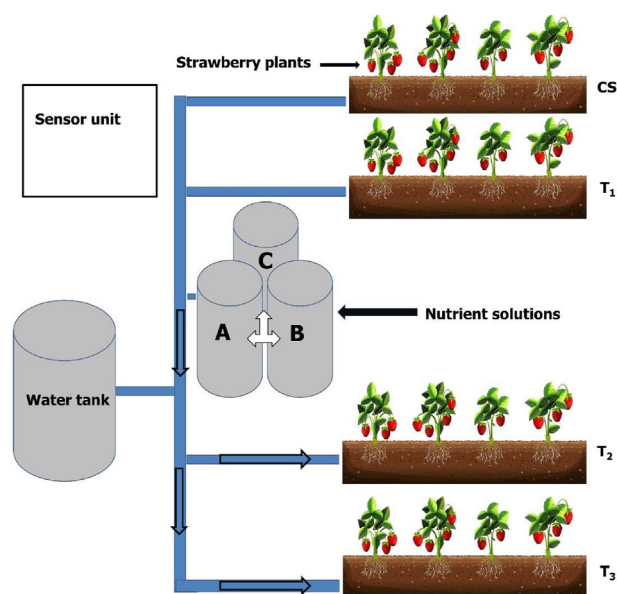
Figure 1. Schematic diagram of the nutrient solution tank (A, B, C) supplying to the treatments of strawberry plants.

of February). The significant environmental parameters namely temperature, CO_2 concentration, and humidity were daily monitored using a specific high accurate sensor unit MCH 383SD (Lutron Electronic Enterprises Co. Ltd., Taiwan) (Elanchezhian et al., 2019). In this experiment, four types of treatments including control soil, bio plus compost soil as natural media, integrated media (the combination of bio plus compost and Hoagland solution), and synthetic nutrient applied soil media (Hoagland solution and strawberry plants in the Rockwool pot) were utilized as strawberry plants growing media as shown in Figure 1. Furthermore, the C: N ratio of control soil and bio plus compost soil were 12:0.3 and 30:1 consecutively (Azim et al., 2014). The treatment used in the experiment was demonstrated in Tables 1 and 2.

Initially, 32 daughter plants of strawberry were grown in each soil medium with a distance of 0.5 m (Shahzad et al., 2018) as shown in Figure 2. All the vegetative and reproductive growth parameters were measured after 8 weeks and 16 weeks after the cultivation period and yield attributing parameters like the number of fruit set and the number of fruits per plant were measured beginning and end of the reproductive stage (8 weeks and 16 weeks of planting). Plant height was measured in 25 plants of each treatment in two different stages using a metric ruler as reported by Basak et al. (2019). Generally, fresh weight and dry weight of 6 root samples from each treatment in two different stages were measured using a digital balance (Model-FX-300iWP, A&D Company Limited, Tokyo, Japan) and drying oven (Shelves for 5E-DHG6310: 2 layers, Changsha Kaiyuan Instruments Co., Ltd, Changsha 410100, PR China). The weight of roots was measured after drying at 80 °C for 48 h (Khan et al., 2019). Specifically, the number of fruits set per plant and fruit yield per plant in the reproductive stage was counted by using 6 replicates in each treatment. Eventually, the canopy area measurement

Table 1. Represent the four types of strawberry growing media used in the experiment.

Treatments	Growing media
CS	Control soil (C:N ratio-12: 0.3)
T_1	Bio plus compost (C:N ratio- 30:1)
T_2	Bio plus compost (C:N ratio- 30:1) + Synthetic nutrient (Hoagland solution)
T_3	Synthetic nutrient (Hoagland solution)

Table 2. Represent the standard chemical composition of the synthetic nutrient (Hoagland solution) applied to the strawberry plants.

Fertilizer	Chemical formula	Requirement
A		
Calcium nitrate (II)	$5\{Ca(NO_3)_2 \cdot 2H_2O\}\ NH_4NO_3$	12.21 (kg/150L)
Potassium nitrate	KNO_3	2.16 (kg/150L)
Ammonium nitrate	NH_4NO_3	0.12 (kg/150L)
Chelate	FE-EDTA	346.20 (kg/150L)
B		
Potassium nitrate	KNO_3	4.72 (kg/150L)
Potassium sulfate	K_2SO_4	0.31 (kg/150L)
Potassium phosphate	KH_2PO_4	2.98 (kg/150L)
Magnesium sulfate	$MgSO_4 \cdot 7H_2O$	7.15 (kg/150L)
Boric acid	H_3BO_3	44.00 (g/150L)
Manganese sulfate	$MnSO_4 \cdot 4H_2O$	30.00 (g/150L)
Zinc sulfate	$ZnSO_4 \cdot 7H_2O$	13.05 (g/150L)
Copper sulfate	$CuSO_4 \cdot 5H_2O$	2.40 (g/150L)
Sodium molybdate dihydrate	$Na_2MOO_4 \cdot 2H_2O$	1.50 (g/150L)
C		
Nitric acid	HNO_3	0.75 (L/150L)

RGB camera (HZ 35 W, WB 650, Korea) was used to capture the images from every 6 plant samples from each treatment from bottom to top 50 cm working distance, and end of the experiment RGB images convert to black and white image using Python programming language. Every image taken from the RGB camera was downscaled into a 0.25 ratio and extract the green, yellow and brown colour threshold using the HSV colour model and converted into a black and white image (Chumuang et al., 2016). Subsequently, the Field of view was calculated by using camera focal length, sensor size, and working distance. Eventually, the smallest feature was calculated using image resolution and field of view value. Total pixel counts were used to estimating the canopy area, according to the equation proposed by "Calculating Camera Sensor Resolution and Lens Focal Length", 2021.

2.2. Statistical analysis

The vegetative growth, reproductive growth, and yield data of strawberry plants were collected and processed in MS Excel (Microsoft Office 2019, Seattle, WA, USA). Also, standard statistical methods were used in SPSS for data evaluation including analysis of variance (one-way ANOVA) to practice with a significance level of $p < 0.05$. The significant differences between the mean values of experimental data were tested with a Post-Hoc Tukey's HSD test in Statistics 10 (SPSS Version: 22.0.0, IBM, New York, USA).

3. Results and discussion

The growing media combination T_2 in the vegetative stage resulted from maximum plant height (16.93 ± 0.31 cm), followed by T_1 (12.76 ± 0.34 cm), T_3 (9.38 ± 0.44 cm), and the lowest plant height CS (7.97 ±


Figure 2. The strawberry experiment in the greenhouse under controlled environmental conditions.

0.36 cm) were demonstrated in Figure 3. The maximum enhancement in plant height under T_2 treatment could be attributed to better nutrition retention and high water holding capacity which promotes better vegetative growth (Thakur and Shylla, 2018). Subsequently, T_1 treatment showed the highest plant height compared to T_3, which increased nutrient mineralization and production of plant growth regulators and humates by microbes compared to inorganic fertilizer solution (Arancon et al., 2003). On the other hand, bio plus compost contains more beneficial microbes which can grow and multiply, utilize carbons, nitrogens from organic matter during the decomposition process. Consequently, nitrogen promotes cell division and carbon facilitates the photosynthesis process and giving energy for plant growth as mentioned by Khan et al. (2019). Raja et al. (2018) reported that cocopeat and perlite substrates to be effective in root due to the better interchange of the cations which distributes moisture to the root growth and increasing the plant height.

Correspondingly, the maximum plant height in the reproductive stage was observed in T_2 (19.34 ± 0.21 cm) followed by T_1 (14.94 ± 0.37 cm), T_3 (12.14 ± 0.44 cm), and CS (9.82 ± 0.52 cm) as exhibited in Figure 3. Closer inspection of the plant height data, however, revealed that in both vegetative and reproductive stage plants grew exponentially, but at different rates, as described by Koelewijn (2004). Regardless, vegetative growth is continual, the onset of flowering the growth rate declined whereas reproductive structures prevail over the vegetative structures.

The response of the canopy area for growing media in the vegetative stage was high in T_2 (23.02 ± 1.94 cm^2) followed by T_1 (21.46 ± 0.31 cm^2), T_3 (18.69 ± 1.12 cm^2), and CS (15.58 ± 0.79 cm^2) as shown in Figure 4 and HSV developed images for canopy area calculation demonstrated in
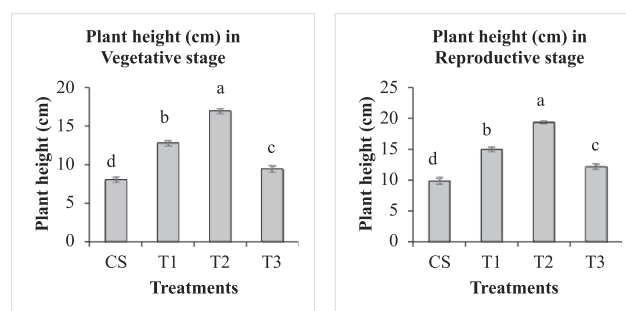
Figure 3. Effect of different growing media on plant height of strawberry in the vegetative and reproductive stages. Data indicate the means ± SD (n = 25). Different letters above bars indicate significant differences at $p < 0.05$.
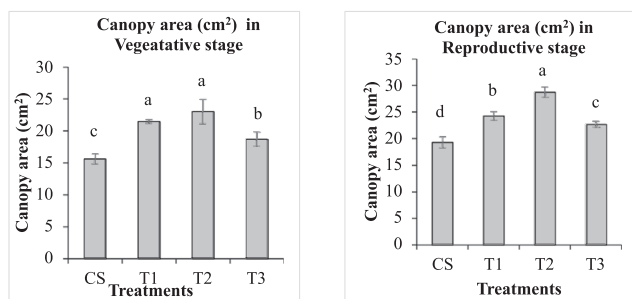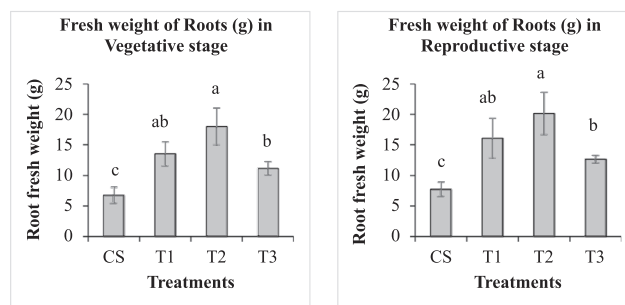
Figure 4. Effect of different growing media on canopy area of strawberry in the vegetative and reproductive stages. Data indicate the means $\pm$ SD (n = 6). Different letters above bars indicate significant differences at p < 0.05.
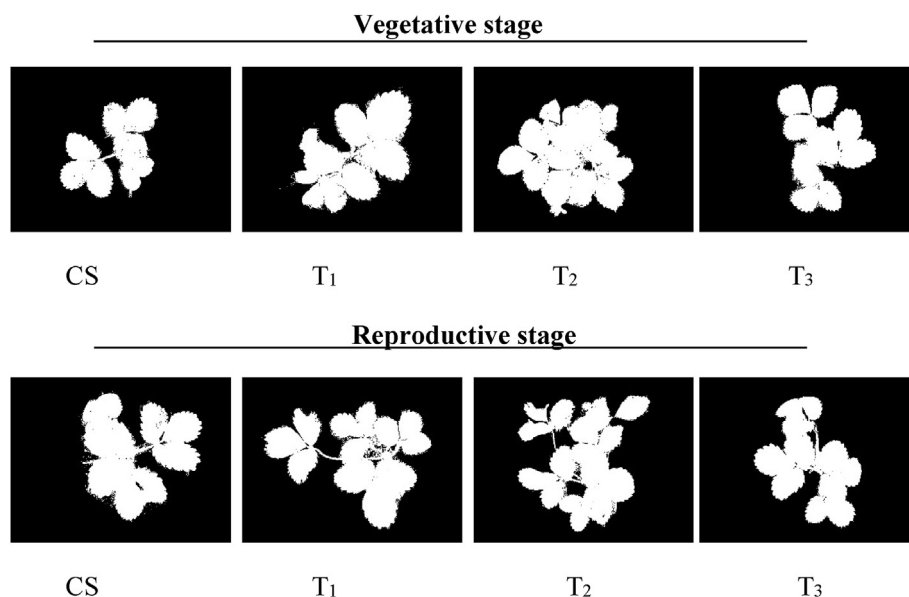

Figure 6. Effect of different growing media on fresh weight of strawberry root in the vegetative and reproductive stages. Data indicate the means $\pm$ SD (n = 6). Different letters above bars indicate significant differences at p < 0.05.

Figure 5. Specifically, the combined use of inorganic and bio plus compost increased the strawberry vegetative growth canopy area due to an increase of NPK uptake and reducing eutrophication. Besides, N stimulates the formation of buds that subsequently develop into leaves and crowns, P promotes cell division and membrane development and K increases the sugar accumulation and growth rate consequently enhance the leaf area (Odongo et al., 2008). Arancon et al., 2003 have reported that compost increased nutrient mineralization due to increasing microbial mass and their competition. This fact directly correlated to the result of data which indicates no significant difference between T_1 and T_2 canopy area in the vegetative stage at (p < 0.05) level.

The maximum canopy area for the reproductive stage was high in T_2 (28.78 $\pm$ 0.93 cm^2) followed by T_1 (24.28 $\pm$ 0.80 cm^2), T_3 (22.69 $\pm$ 0.56 cm^2), and CS (19.29 $\pm$ 1.03 cm^2) as shown in Figure 4 and HSV developed images for canopy area calculation demonstrated in Figure 5. However, in comparison to vegetative growth, the canopy area was considerably increased in the reproductive growth stage due to the slow mineralization of nutrients from the soil as mentioned by Odongo et al. (2008).

The results obtained indicated that different growth mediums affected the fresh weight of the root differently. The highest fresh root weight in the vegetative stage was recorded in T_2 (18.00 $\pm$ 3.06 g) followed by T_1 (13.52 $\pm$ 1.97 g), T_3 (11.15 $\pm$ 1.08 g), and CS (6.74 $\pm$ 1.33) as exhibited in Figure 6. Regardless of the reproductive stage, the maximum fresh weight was observed T_2 (20.15 $\pm$ 3.49 g) followed by T_1 (16.09 $\pm$ 3.28 g), T_3 (12.63 $\pm$ 0.63 g), and CS (7.74 $\pm$ 1.19 g)

consecutively. These results have been proven that organic amendments were linked with root biomass which increases root growth. Jindo et al. (2012) have been found that during the composting process humic acid is produced. Moreover, this humic acid plays a fundamental role in plant nutrient and water uptake, cell differentiation, and lateral root formation. Thereby, root biomass was increased in T_2 when compared to other treatments in both stages. However, there was no significant difference between T_1 with T_2 and T_3 due to the synthetic nutrient solution which contains P that also directly correlated with the root growth promotion (Barita et al., 2018).

The maximum dry weight of root in the vegetative stage was measured T_2 (5.15 $\pm$ 1.26 g) followed by T_1 (3.40 $\pm$ 0.23 g), T_3 (3.09 $\pm$ 0.29 g), and CS (1.95 $\pm$ 0.26 g) as demonstrated in Figure 7. Especially, the highest root dry weight was obtained T_2 due to the greater P was found in organic amendment soil as reported by Preusch et al. (2004). According to the dry weight results in the vegetative stage, there was no significant difference between T_1 with T_2 and T_3 due to bio plus compost decomposed inactive nutrients and gradually release to maintain the available nutrient level of the soil. Thereby, the root biomass increased in bio plus compost and synthetic nutrient contain soil at the same rate (Hasnain et al., 2020).

The highest dry weight of root in the reproductive stage was showed T_2 (6.66 $\pm$ 2.34 g) followed by T_1 (4.33 $\pm$ 1.35 g), T_3 (3.03 $\pm$ 0.12 g), and CS (2.21 $\pm$ 0.29 g) respectively. Furthermore, humic substance caused for increasing root molecular weight as revealed by Jindo et al. (2012). Thereby, a combination of bio plus compost and synthetic nutrient

Figure 5. HSV developed images for canopy area calculation of strawberry plants in the vegetative and reproductive stages.
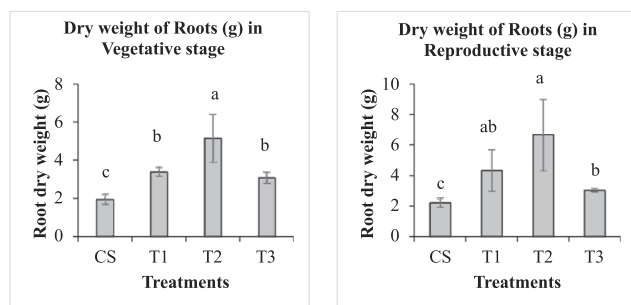
Figure 7. Effect of different growing media on the dry weight of strawberry root in the vegetative and reproductive stages. Data indicate the means ± SD (n = 6). Different letters above bars indicate significant differences at p < 0.05.
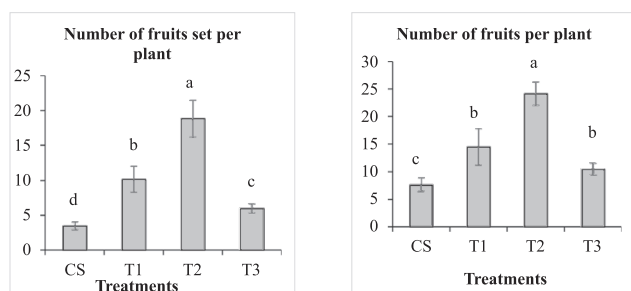
Figure 8. Effect of different growing media on the number of fruits set and the number of fruits per plant in the reproductive stage. Data indicate the means ± SD (n = 6). Different letters above bars indicate significant differences at p < 0.05.

supplied high minerals with humic substances for strawberry root growth when compared to synthetic nutrient and control soil. Nevertheless, there was no significant difference between T_1 with T_2 and T_3 in the reproductive stage due to the bio plus compost contain soil supplied the same amount of minerals during the composting process like as synthetic nutrients applied soil sample.

The maximum number of fruits set per plant in the reproductive stage significantly difference was recorded T_2 (18.83 ± 2.64) followed by T_1 (10.17 ± 1.83), T_3 (6.00 ± 0.63), and CS (3.50 ± 0.55) as shown in Figure 8. With regards to the fruit yield data, appreciable differences among various treatments in the number of fruits per plant were recorded in T_2 (24.17 ± 2.14) followed by T_1 (14.50 ± 3.27), T_3 (10.50 ± 1.05), and CS (7.67 ± 1.21) consecutively. It is obvious from the data related to strawberry fruit set could be large increases in soil microbes leading to the production of hormones acting as a plant growth regulator which promotes the development of reproductive structures as mentioned by Arancon et al., 2003. On the other hand, low availability and the slow release of nutrients from the CS is supposed to be responsible for the low yield compared to other treatment. Ayesha et al. (2011) reported that the utilize of the organic substrate and inorganic substrate in appropriate portions optimizes water and oxygen holding capacity. Moreover, it improves the aeration resulting in the formation of better root systems allowing better nutrient uptake required for sufficient growth and production of strawberries. Furthermore, T_2 and T_1 contain cocopeat and peat moss which are rich in coconut waste and other biodegradable material enhance the soil fertility and nutrients available for the overall production of strawberries as reported by Raja et al. (2018).

4. Conclusion

The findings of the present study concluded that the growing media directly correlated with the growth and productivity of strawberries cultivated under the greenhouse. Combination of bio plus compost and synthetic nutrient (Hoagland solution) applied media significantly improved the strawberry growth and yield compared to bio plus compost, Synthetic nutrient, and control soil supplied media. The results revealed that an increasing trend of vegetative and reproductive growth of strawberries under the following growing media correlated positively with the number of fruits set and the number of fruits per plant. Moreover, T_2 has the highest fertilization potential (labile organic matter accompanied with mineralizable nutrients) and rich in cocopeat and peat moss that have higher available minerals as well as beneficial microbial biomass that leads to producing humic substances. These substances affect the production of plant growth regulators which increase the growth and yield of the strawberries in passively ventilated greenhouse conditions.

Declarations

Author contribution statement

Bolappa Gamage Kaushalya Madhavi: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools, or data; Wrote the paper.

Fawad Khan: Conceived and designed the experiments.

Anil Bhujel; Mustafa Jaihuni; Na Eun Kim; Byeong Eun Moon: Contributed reagents, materials, analysis tools, or data.

Hyeon Tae Kim: Conceived and designed the experiments; Contributed reagents, materials, analysis tools, or data.

Data availability statement

Data included in article/supplementary material/referenced in article.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

References

Arancon, N.Q., Edwards, C.A., Bierman, P., Metzger, J.D., Lee, S., Welch, C., 2003. Effects of vermicomposts on growth and marketable fruits of field-grown tomatoes, peppers and strawberries: the 7th international symposium on earthworm ecology· Cardiff· Wales· 2002. Pedobiologia 47 (5-6), 731–735.

Ayesha, R., Fatima, N., Ruqayya, M., Qureshi, K.M., Hafiz, I.A., Khan, K.S., Kamal, A., 2011. Influence of different growth media on the fruit quality and reproductive growth parameters of strawberry (Fragaria ananassa). J. Med. Plants Res. 5 (26), 6224–6232.

Azim, K., Ouyihya, K., Amellouk, A., Perissol, C., Thami Alami, I., Soudi, B., 2014. Dynamic composting optimization through C/N ratio variation as a startup parameter. Build. Org. Brid. 3, 787–790.

Barita, Y., Prihastanti, E., Haryanti, S., Subagio, A., 2018. The influence of granting npk fertilizer and nanosilic fertilizers on the growth of Ganyong plant (Canna edulis Ker.). J. Phys. Conf. 1025 (No. 1), 012054. IOP Publishing.

Barrett, G.E., Alexander, P.D., Robinson, J.S., Bragg, N.C., 2016. Achieving environmentally sustainable growing media for soilless plant cultivation systems–A review. Sci. Horticult. 212, 220–234.

Basak, J.K., Qasim, W., Okyere, F.G., Khan, F., Lee, Y.J., Park, J., Kim, H.T., 2019. Regression analysis to estimate morphology parameters of pepper plant in a controlled greenhouse system. J. Biosyst. Eng. 44 (2), 57–68.

Calculating Camera Sensor Resolution and Lens Focal Length. Ni.Com, 2021. Retrieved 23 February2021. https://www.ni.com/enus/support/documentation/supplemental/18/calculating-camera-sensor-resolution-and-lens-focal-length.html.

Cardenas-Navarro, R., López-Pérez, L., Lobit, P., Ruiz-Corro, R., Castellanos-Morales, V.C., 2006. Effects of nitrogen source on growth and development of strawberry plants. J. Plant Nutr. 29 (9), 1699–1707.

Casierra-Posada, F., Pena-Olmos, J.E., Ulrichs, C., 2012. Basic growth analysis in strawberry plants (Fragaria sp.) exposed to different radiation environments. Agron. Colomb. 30 (1), 25–33.

Chumuang, N., Thaiparnit, S., Ketcham, M., 2016. Algorithm design in leaf surface separation by degree in hsv color model and estimation of leaf area by linear regression. In: 2016 12th International Conference on Signal-Image Technology & Internet-Based Systems (SITIS). IEEE, pp. 628–631.

Elanchezhian, A., Khan, F., Basak, J.K., Park, J., Okyere, F.G., Lee, Y.J., Kim, H.T., 2019. June). Analysis of water retention capacities of various compost and its relationship to strawberry moisture level. In: International Symposium on Advanced Technologies and Management for Innovative Greenhouses: GreenSys2019, 1296, pp. 899–906.

Hasnain, M., Chen, J., Ahmed, N., Memon, S., Wang, L., Wang, Y., Wang, P., 2020. The effects of fertilizer type and application time on soil properties, plant traits, yield and quality of tomato. Sustainability 12 (21), 9065.

Jindo, K., Martim, S.A., Navarro, E.C., Perez-Alfocea, F., Hernandez, T., Garcia, C., Canellas, L.P., 2012. Root growth promotion by humic acids from composted and non-composted urban organic wastes. Plant Soil 353 (1), 209–220.

Khan, F., Okyere, F.G., Basak, J.K., Qasim, W., Park, J., Arulmozhi, E., Kim, H.T., 2019. Comparison of different compost materials for growing strawberry plants. In: International Symposium on Advanced Technologies and Management for Innovative Greenhouses: GreenSys2019, 1296, pp. 869–876.

Koelewijn, H.P., 2004. Rapid change in relative growth rate between the vegetative and reproductive stage of the life cycle in Plantago coronopus. New Phytol. 163 (1), 67–76.

Lu, C., Ren, H., Zhang, Y., Shen, Y., 2010. Leaf area measurement based on image processing. In: 2010 International Conference on Measuring Technology and Mechatronics Automation, 2. IEEE, pp. 580–582.

Odongo, T., Isutsa, D.K., Aguyo, J.N., 2008. Effects of integrated nutrient sources on growth and yield of strawberry grown under tropical high altitude conditions. Afr. J. Horticult. Sci. 1.

Preusch, P.L., Takeda, F., Tworkoski, T.J., 2004. N and P uptake by strawberry plants grown with composted poultry litter. Sci. Hortic. 102 (1), 91–103.

Qasim, W., Lee, M.H., Moon, B.E., Okyere, F.G., Khan, F., Nafees, M., Kim, H.T., 2018. Composting of chicken manure with a mixture of sawdust and wood shavings under forced aeration in a closed reactor system. Int. J. Recycl. Org. Waste Agric. 7 (3), 261–267.

Raja, W.H., Kumawat, K., Sharma, O., Sharma, A., Mir, J., Nabi, S.U., Qureshi, I., 2018. Effect of different substrates on growth and quality of Strawberry cv. chandler in soilless culture. Pharma Innov. J 7, 449–453.

Sandino, J.D., Ramos-Sandoval, O.L., Amaya-Hurtado, D., 2016. Method for estimating leaf coverage in strawberry plants using digital image processing. Rev. Bras. Eng. Agrícola Ambient. 20 (8), 716–721.

Setyawan, T.A., Riwinanto, S.A., Nursyahid, A., Nugroho, A.S., 2018. Comparison of HSV and LAB color spaces for hydroponic monitoring system. In: 2018 5th International Conference on Information Technology, Computer, and Electrical Engineering (ICITACEE). IEEE, pp. 347–352.

Shahzad, U., Ijaz, M., Nauman Noor, M.S., Hassan, Z., Kahn, A.A., Calica, P., 2018. Variations in growing media and plant spacing for the improved production of strawberry (Fragaria ananassa cv. Chandler). Philipp. J. Sci. 147 (4), 705–713.

Tejada, M., Hernandez, M.T., Garcia, C., 2009. Soil restoration using composted plant residues: effects on soil properties. Soil Tillage Res. 102 (1), 109–117.

Thakur, M., Shylla, B., 2018. Influence of different growing media on plant growth and fruit yield of strawberry (Fragaria× ananassa Duch.) cv. Chandler grown under protected conditions. Int. J. Curr. Microbiol. Appl. Sci. 7 (4), 2724–2730.

Trejo-Tellez, L.I., Gomez-Merino, F.C., 2014. Nutrient Management in Strawberry: Effects on Yield, Quality and Plant Health. Strawberries: Cultivation, Antioxidant Properties and Health Benefits. In: Malone, Nathan (Ed.). Nova Science Publishers, pp. 239–267.

Vandecasteele, B., Debode, J., Willekens, K., Van Delm, T., 2018. Recycling of P and K in circular horticulture through compost application in sustainable growing media for fertigated strawberry cultivation. Eur. J. Agron. 96, 131–145.

Wei, H., Liu, C., Ryong Jeong, B., 2020. An optimal combination of the propagation medium and fogging duration enhances the survival, rooting and early growth of strawberry daughter plants. Agronomy 10 (4), 557.

Yoshida, Y., Goto, T., Hirai, M., Masuda, M., 2000. Anthocyanin accumulation in strawberry fruits as affected by nitrogen nutrition. In: IV International Strawberry Symposium, 567, pp. 357–360.