Influence of spacing and mulching on strawberry (*Fragaria* x *ananassa*) Duch.) root development

ABSTRACT

~~Therefore, a~~The field experiment was conducted at the farmer's field in Jorhat district of Assam, during two consecutive years of 2019-20 and 2020-21 to study the effect of plant spacing and mulching on root volume of strawberry. The experiment was laid out in a randomized block design with three replications based on 2 factors *viz*. plant spacing and mulch material. The trial consisted of a total of twenty treatments keeping five different plant spacing levels *viz*., 20 cm × 30 cm (S_1), 30 cm × 30 cm (S_2), 30 cm × 40 cm (S_3), 40 cm × 40 cm (S_4), 40 cm × 60 cm (S_5) and four different mulching materials viz., paddy straw (M_1), red mulch (M_2), silver black mulch (M_3) and no mulch (M_4). Plant spacing and type of mulch material ~~have~~ had significant influence on crop growth and yield. Results revealed that 40 cm × 60 cm spacing under silver black mulch recorded maximum root volume which may have a positive impact on crop yield. Studies indicate that mulching plays a vital role in conserving soil moisture, enhancing nutrient and moisture uptake, regulating soil temperature and reducing weed growth. Moreover, plant spacing sets area availability for each plant that further determines the amount of nutrients and moisture available for growth and development. ~~However, very little research has been performed to study the effect of spacing and mulches on growth and development of strawberry.~~ Strawberry is a surface feeder crop, and hence, mulching plays a very important role in providing optimum conditions for root development. ~~Therefore, a field experiment was conducted at the farmer's field in Jorhat district of Assam, during 2019-20 and 2020-21 to study the effect of plant spacing and mulching on root volume of strawberry. The experiment was laid out in a randomized block design with three replications based on 2 factors *viz*. plant spacing and mulch material. The trial consisted of a total of twenty treatments keeping five different plant spacing levels *viz*., 20 cm × 30 cm (S_1), 30 cm × 30 cm (S_2), 30 cm × 40 cm (S_3), 40 cm × 40 cm (S_4), 40 cm × 60 cm (S_5) and four different mulching materials viz., paddy straw (M_1), red mulch (M_2), silver black mulch (M_3) and no mulch (M_4). Results revealed that 40 cm × 60 cm spacing under silver black mulch recorded maximum root volume which may have a positive impact on crop yield.~~

Keywords: *Crop geometry, Mulch, Root volume, Spacing, Strawberry*

INTRODUCTION

Strawberry (*Fragaria* x *ananassa* Duch.) a prominent fruit crop, belonging to the Rosaceae family is cultivated worldwide (Jadhao and Dey, 2021). The total area of cultivated strawberry in India during the year of 2019 was reported to be 3.95 thousand hectares with global production of 9.2 million tonnes (Mahmood *et al*., 2021). Enhancing strawberry yield in terms of both quantity and quality under limited land resource is the need of the hour (Meena *et al*., 2023). Crop growth as well as yield of strawberry can be enhanced by manipulation of crop geometry and crop management techniques. Plant spacing aids in increasing crop growth through efficient application of solar radiation, nutrients and underground resources giving rise to better photosynthate formation. Optimum plant spacing helps in sufficient harvesting of solar radiation and adequate absorption of nutrients and moisture from the soil due to well-developed root system by making changes in inter and intra row spacing. Mulching has impact on soil temperature, soil moisture regulation, boosts water and nutrient absorption, minimize weed growth and improves fruit quality by avoiding the direct contact of soil with fruit (Kijchavengkul *et al.*, 2008). Roots contribute significantly in crop growth since roots are the plant part that absorbs water and nutrients from the soil (Tajima, 2021). The space available to plants directly influences growth and development of particular plant. Plant spacing helps in root growth as roots will grow and expand in all directions. Moreover, with extensive root growth, competition between plant roots diminishes thus expanding water and nutrient uptake which will enhance the volume of plant roots (Hanum, 2018). The competition between neighboring roots may decrease soil nutrient resources thereby inhibiting root growth. Generally in areas free of other roots, plants grow roots more preferentially (Gersani *et al*., 2001). Toxic exudates by plant roots may cause non-specific inhibitory effects on root of neighboring plants and also non-toxic chemical signals in genetically similar plants may specifically affect the roots of nearby plants (Jiang *et al*., 2013). Kashkool *et al*. (2020) in his study reported those wide distances between plants leads to maximum root growth. Mulching have got advantageous condition for water and temperature which have an impact on the root system of the plant, encouraging root development and enhancing root secretion (Wang *et al.*, 2019). Mulch inhibit water runoff and helps soil with more time for absorption of rainwater and this supplementary moisture facilitates plant root expansion, that to a greater extent stabilizes the soil by promoting root growth (El-Beltagi *et al*.,

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2022). Mulches also build up congenial environment for root growth that encourages plant growth and productivity (Kader *et al*., 2019).

Root volume appears to be a very significant index of plant growth as there is always competition between individual plants for nutrition, water and root space. Insufficient reports are available regarding root volume under different plant spacing and mulching in strawberry. In this study, root volume under different conditions of plant spacing and mulch were investigated to provide guidelines for optimizing crop geometry and suitable mulch material in strawberry production.

MATERIALS AND METHODS

The trial was done at the farmer's field ~~at~~ in Jorhat district of India during two consecutive years of 2019-2020 and 2020-2021. The field experiment plot was laid out in factorial randomized complete block design and consisted of three replications. The tissue culture strawberry ~~plants~~ seedlings of variety Sweet Charlie were transplanted in open condition in the experimental plot. There were 20 treatment combinations comprising of five plant spacings *viz*., 20 cm × 30 cm (S_1), 30 cm × 30 cm (S_2), 30 cm × 40 cm (S_3), 40 cm × 40 cm (S_4), 40 cm × 60 cm (S_5) and four different mulch applications *viz*., paddy straw (M_1), red mulch (M_2), silver black mulch (M_3) and no mulch (M_4). Root volume after harvesting of the crop was recorded. The root volume was measured by water displacement method as suggested by Mishra and Ahmed (1987) and expressed in cubic ~~centimetre~~centimeter (cc). The plant roots were scooped and adhered soil removed carefully without damaging the roots. The volumes of the water in the cylinder were recorded before and after submerging the roots into the cylinder. Statistical analysis of pooled data was performed using windows-based computer software OPSTAT (Sheoran *et al*., 1998).

Commented [Ma1]: What is red mulch? Is it red polythene mulch? Pls define it in brief.

Commented [Ma2]: Pls define the type of silver black mulch.

RESULTS AND DISCUSSION

The various treatments exerted influence on root volume of strawberry and the observations recorded as influenced by the treatments are presented in table 1. The combined analysis of both years data revealed that the ~~maximum~~ highest root volume (23.62 cc) was observed under plant spacing of 40 cm × 60 cm (S_5) and followed by spacing of 40 cm × 40 cm (S_4) with 22.80 cc while the ~~minimum~~ lowest root volume (19.65 cc) was reported under S_1 (20 cm × 30 cm).

Table 1: Effect of spacing, mulch and spacing and mulch (S×M) interaction on root volume (cc)

Treatment	Root volume (cc)		
	Year: 2019-2020	Year: 2020-21	Pooled
Spacing (S):			
S_1	20.42^{e}	18.88^{d}	19.65^{e}
S_2	21.66^{d}	19.84^{c}	20.75^{d}
S_3	22.46^{c}	21.04^{b}	21.75^{c}
S_4	23.22^{b}	22.37^{a}	22.80^{b}
S_5	24.20^{a}	23.04^{a}	23.62^{a}
SEd (±)	0.35	0.39	0.26
CD (P=0.05)	0.71	0.78	0.52
Mulches (M)			
M_1	18.07^{c}	16.54^{c}	17.30^{c}
M_2	26.44^{b}	24.67^{b}	25.55^{b}
M_3	31.24^{a}	29.98^{a}	30.61^{a}
M_4	13.82^{d}	12.95^{d}	13.38^{d}
SEd (±)	0.31	0.35	0.23
CD (P=0.05)	0.64	0.70	0.46
Interaction (S×M)			
T1 (S1M1)	16.49	14.44	15.46

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Treatment	Root volume (cc)		
	Year: 2019-2020	Year: 2020-21	Pooled
T2 (S1M2)	24.15	22.31	23.23
T3 (S1M3)	28.61	27.39	28.00
T4 (S1M4)	12.43	11.37	11.90
T5 (S2M1)	17.39	15.44	16.41
T6 (S2M2)	25.47	23.28	24.38
T7 (S2M3)	30.43	28.57	29.50
T8 (S2M4)	13.35	12.07	12.71
T9 (S3M1)	18.25	16.70	17.47
T10 (S3M2)	26.75	24.67	25.71
T11 (S3M3)	31.38	29.83	30.61
T12 (S3M4)	13.45	12.96	13.20
T13 (S4M1)	18.89	17.54	18.21
T14 (S4M2)	27.33	26.44	26.89
T15 (S4M3)	32.40	31.78	32.09
T16 (S4M4)	14.27	13.73	14.00
T17 (S5M1)	19.36	18.58	18.97
T18 (S5M2)	28.49	26.63	27.56
T19 (S5M3)	33.38	32.34	32.86
T20 (S5M4)	15.58	14.60	15.09
SEd (±)	0.70	0.78	0.52
CD (P=0.05)	NS	NS	NS

~~Interaction (S×M)~~

~~Treatment combination~~	~~2019-20~~	~~2020-21~~	~~Pooled~~	~~Treatment combination~~	~~2019-20~~	~~2020-21~~	~~Pooled~~
~~T1 (S1M1)~~	~~16.49~~	~~14.44~~	~~15.46~~	~~T11 (S3M3)~~	~~31.38~~	~~29.83~~	~~30.61~~
~~T2 (S1M2)~~	~~24.15~~	~~22.31~~	~~23.23~~	~~T12 (S3M4)~~	~~13.45~~	~~12.96~~	~~13.20~~
~~T3 (S1M3)~~	~~28.61~~	~~27.39~~	~~28.00~~	~~T13 (S4M1)~~	~~18.89~~	~~17.54~~	~~18.21~~
~~T4 (S1M4)~~	~~12.43~~	~~11.37~~	~~11.90~~	~~T14 (S4M2)~~	~~27.33~~	~~26.44~~	~~26.89~~

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Treatment	Root volume (cc)						
	Year: 2019-2020			Year: 2020-21	Pooled		
T5 (S2M1)	17.39	15.44	16.41	T15 (S4M3)	32.40	31.78	32.09
T6 (S2M2)	25.47	23.28	24.38	T16 (S4M4)	14.27	13.73	14.00
T7 (S2M3)	30.43	28.57	29.50	T17 (S5M1)	19.36	18.58	18.97
T8 (S2M4)	13.35	12.07	12.71	T18 (S5M2)	28.49	26.63	27.56
T9 (S3M1)	18.25	16.70	17.47	T19 (S5M3)	33.38	32.34	32.86
T10 (S3M2)	26.75	24.67	25.71	T20 (S5M4)	15.58	14.60	15.09

	2019-20	2020-2021	Pooled
SEd(±)	0.70	0.78	0.52
CD(P=0.05)	NS	NS	NS

[Superscript by same letter indicates they are at par; S_1: 20 cm × 30 cm; S_2: 30 cm × 30 cm; S_3: 30 cm × 40 cm; S_4: 40 cm × 40 cm; S_5: 40 cm × 60 cm; M_1: Paddy straw; M_2: Red mulch; M_3: Silver black mulch; M_4: No mulch, Plot size: 3 m^2]

Based on the pooled analysis of data, the ~~maximum~~ highest root volume (30.61 cc) was observed in silver black mulch (M_3) and followed by Red mulch (M_2) with 25.55 cc; while the ~~minimum~~ lowest root volume (13.38 cc) was reported under no mulch condition (M_4). The interactions involving spacing and mulching exhibited non-significant effect on root volume during the two years of study period. The pooled data with treatment combination of spacing of 40 cm × 60 cm and silver black mulch (T_{19}) registered the ~~maximum~~ highest root volume (32.86 cc). Root volume is an important parameter that reflects the crop growth. Wider spacing reported considerably higher root volume which might have made air circulation in the soil and supplied oxygen for better root growth and development. This might help roots to come in contact with large volume of soil to absorb more nutrients and moisture for plant growth, resulting into higher dry matter production with higher nutrient uptake. The availability of sufficient space for individual plants improved the foraging capacity by the horizontal spread of roots that in turn, increased the root volume. Widely spaced plants produced higher root volume which could also be due to minimum competition for soil nutrients and solar energy that stimulated photosynthates

accumulation in the roots. The results are in confirmation with the findings of Li *et al*. (2021), Misganaw and Yeshambel (2021) and Paramesh *et al.* (2013). Gao *et al*. (2023) in their study also found that at a closer plant spacing in cotton plants, the lateral roots exhibited densely overlapping growth and mainly competed for resources and when the competition for soil water between plants intensified, it resulted in reduction in total root volume.

The higher root volume under mulching might be primarily due to moderation of hydrothermal regimes leading to favorable soil-air-water relations, which encouraged proliferation and elongation of roots and the adequate moisture under mulches reduced the soil strength for root penetration and proliferation. Silver black plastic mulches are higher in reflecting Photosynthetically Active Radiation (PAR) than other mulches and also reduce water loss. The lower root volume under no mulch treatment might be due to poor moisture levels in the soil and suboptimal thermal regimes. The results were supported by the findings of Wien (1993), Verma *et al.* (2005), Pandey *et al.* (2016), Kumar *et al.* (2018), Amare and Desta (2021), Kumar *et al.* (2021) and Rahmani *et al.* (2021). Chen *et al*. (2023) in their study also reported that with the increase of soil moisture, root morphological indexes such as total root volume increased. Liu *et al*. (2019) noted that when soil moisture was reduced, then root volume and other root growth indicators also decreased significantly. Ashrafuzzaman *et al.* (2011) observed in their work on capsicum that mulch produced impressively higher root volume in comparison to the control (bare soil).

CONCLUSION

Strawberry is a surface feeder and shallow rooted crop that demands continuous maintenance of optimum soil moisture for better crop establishment, growth and yield. Soil moisture and nutrient stress influence the development of plant root system as the competition among plants for these resources will eventually affect the assimilation process by the competing root systems. Under wider plant spacing, there will always be minimum competition for space, light and air and nutrition among the plants and a favourable hydrothermal regime conditions will be provided by suitable mulching. Hence, it can be concluded that under ideal plant spacing and appropriate mulch material will have a positive impact on root volume of strawberry. The results indicated that 40 cm × 60 cm spacing with silver black mulch recorded maximum root volume in

Strawberry. Root development and distribution are very significant for root-water and nutrient uptake studies in soil-plant systems. There is further scope of study on the response of different growing system on root architecture of strawberry. Moreover, a study on root characteristics of strawberry under various soilless growing systems can deepen the knowledge on strawberry cultivation under protected condition.

REFERENCES

Amare, G., Desta, B., 2021. Coloured plastic mulches: impact on soil properties and crop productivity. *Chemical and Biological Technologies in Agriculture* 8(4) DOI: https://doi.org/10.1186/s40538-020-00201-8.

Ashrafuzzaman, M., Abdul Halim, M., Ismail, M.R., Shahidullah, S.M., Hossain, M. A.,2011. Effect of Plastic Mulch on Growth and Yield of Chilli (*Capsicum annuum* L.). *Brazilian Archives of Biology and Technology* 54(2), 321-330.

Chen, X., Chen, Y., Zhang, W., Zhang, W., Wang, H., Zhou, Q., 2023. Response characteristics of root to moisture change at seedling stage of *Kengyilia hirsuta*. *Frontiers in Plant Science*. 13:1052791.DOI: 10.3389/fpls.2022.1052791

El-Beltagi, H.S., Basit, A., Mohamed, H.I., Ali, I., Ullah, S., Kamel, E.A.R., Shalaby, T.A., Ramadan, K.M.A., Alkhateeb, A.A., Ghazzawy, H.S., 2022.Mulching as a Sustainable Water and Soil Saving Practice in Agriculture: A Review. *Agronomy* 12(8),1881. DOI:https://doi.org/10.3390/agronomy12081881

Gao, C., Li, M., Li, D., 2023. Root architecture and visualization model of cotton group with different planting spacing under local irrigation. *Frontiers in Plant Science* 14,1080234. DOI: 10.3389/fpls.2023.1080234.

Gersani M., Brown, J.S. O'Brien E.E., 2001. Tragedy of the commons as a result of root competition. *Journal of Ecology* 89,660-669.

Hanum, C.,2018. Growth, yield and movement of phosphate nutrients in soybean on P fertilizer, straw mulch and difference of plant spacing. In: *International Conference on Agriculture,*

Environment, and Food Security IOP Conf. Series: Earth and Environmental Science 122,012051.

Jadhao, K.R., Dey, P., 2021. Phylogenetic Analysis of Strawberry, *Fragaria* × *ananassa* (Rosaceae: Fragaria) using Cytochrome C Heme Attachment Protein (ccsA) Gene. *Research Biotica* 3(3), 145- 153.

Jiang, W., Wang, K., Wu, Q., Dong, S., Liu, P., Zhang, J., 2013. Effects of narrow plant spacing on root distribution and physiological nitrogen use efficiency in summer maize.*The Crop Journal* 1, 77-83.

Kader, M.A., Singha, A., Begum, M.A., Jewel, A., Khan, F.H., Khan, N.I., 2019**.**Mulching as water-saving technique in dryland agriculture: Review article. *Bulletin of the National. Research Centre 43*, 147.DOI: https://doi.org/10.1186/s42269-019-0186-7.

Kashkool, H.R., Radhi, N.J.,Hassan W.F.,2020. Effect of plant spacing system and soil amendment in growth and yield of Rice plants (*Oryza sativa* L.) *Plant Archives* 20(1), 2710-2714.

Kijchavengkul, T., Auras R., Rubino M., Gouajia M., Fernanadez, R.T., 2008. Assessment of aliphatic–aromatic copolyester biodegradable mulch films. Part I: Field study. *Chemosphere* 71(5), 942- 953.DOI: doi: 10.1016/j.chemosphere.2007.10.074.

Kumar, U.,2018. Performance of strawberry (*Fragaria × ananassa* Duch.) varieties under Western Malwa Plateau conditions. *M.Sc. (Hort) Thesis*,Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya, Gwalior.

Kumar, V., Chandolam, J.C., Prasad, S., Kumar, A., Patel, S.S., Regar, K.L., Singh, A.K., Kumar, M.,2021. Effect of mulching on weed biomass, root growth, yield and economics of tomato (*Lycopersicon esculentum* L.) in semi-arid region of Bihar. *Pharma Innovation Journal* 10(10), 1989-1991.

Li,Y., Yang,J.,Shi,Z.,Pan,W.,Liao,Y.,Li,T.,Qin,X.,2021. Response of root traits to plastic film mulch and its effects on yield. *Soil & Tillage Research* 209,104930.

Liu, T.Y., Chen, M. X., Zhang,Y., Zhu, F.Y., Liu,Y.G., Tian, Y., Fernie A.R., Ye, N., Zhang, J., 2019.Comparative metabolite profiling of two switchgrass ecotypes reveals differences in drought stress responses and rhizosheath weight. *Planta* 250(4), 1355–1369. DOI: 10.1007/s00425-019-03228-w.

Mahmood, M.M., Al-Dulaimy, A.F.,2021. Response of strawberry cv. Festival to culture media and foliar application of nano and normal micronutrients. IOP Conf. Series: *Earth and Environmental Science* 904,1-11. DOI : 10.1088/1755-1315/904/1/012067.

Meena, R.L., Bunker, R.R., Ram, R.B., Meena, D.C., Meena, A.K., Meena, S.K. and Salvi A.,2023. The Efficacy of Different Mulching with Spacing on Growth and Yield of Strawberry (*Fragaria ananassa* Duch.) cv Chandler. *International Journal of Plant & Soil Science* 35(5), 59-68. DOI: 10.9734/IJPSS/2023/v35i52821

Misganaw, A., Yeshambel, Y., 2021. Effect of row spacing on growth and yield components of Carrot (*Dacusa carrot* L). *Journal of Horticulture* 8(2), 1-6.

Misra,R.D., Ahmed,M.,1987.Root parameters and their measurement. In: *Manual on irrigation agronomy*. Oxford and IBH Publishing Company Pvt. Ltd. New Delhi.pp:319-326.

Pandey, S., Tewari, G.S., Singh, J., Rajpurohit, D., Kumar, G.,2016. Efficacy of mulches on soil modifications, growth, production and quality of strawberry (*Fragaria* × *ananassa* Duch.). *International Journal of Science and Nature* 7(4), 813-820.

Paramesh, V., Sridhara, C.J., Shashidhar, K.S., 2013. Effect of integrated nutrient management and planting geometry on root parameter and nutrient uptake of aerobic rice. *Agriulture Update* 8(1&2), 217-220.

Rahmani, W., Salleh, M.N., Hamzah, M.Z., Abdu, A., Ishak, M.F., Khadir, W.R.W.A., Awang, M.R., Ibrahim, Z., Majid, A.F.A., Salleh, M.S.A., Anuar, A., Alias, M.A.B.,2021. Effect of different types of mulching on soil properties and tree growth of Magnolia champaca planted at the Montane Rainforest in Cameron Highlands, Pahang, Malaysia. *International Journal of Forestry Research* 2021, 1-11.DOI: https: // doi.org /10.1155 /2021/ 5517238

Sheoran, O.P., Tonk, D.S., Kaushik, L.S., Hasija, R.C., Pannu, R.S,1998. Statistical software package for agricultural research workers. In: *Recent Advances in information theory, Statistics & Computer Applications*. (Eds.) Hooda, D.S. and Hasija, R.C. Department of Mathematics Statistics, CCS HAU, Hisar, pp. 139-143.

Tajima R., 2021.Importance of individual root traits to understand crop root system in agronomic and environmental contexts. *Breeding Science* 71(1), 13-19. DOI: 10.1270/jsbbs.20095.

Verma, M.L., Bhardwaj, S.P., Thakur, B.C., Bhandari, A.R.,2005. Nutritional and mulching studies in apple. *Indian Journal of Horticulture* 62(4), 332-335.

Wang, B., Wan, Y., Wang, J., Sun, J., Huai, G., Lv, C., Cui, L., 2019.Effect of biodegradable mulch film on peanut yield and soil physical and chemical properties in Southern Xinjiang, China. *J. Peanut Sci.* , *48*, 38–43.

Wien, H.C., 1993. Polythene mulch stimulates really root growth and nutrient uptake of transplanted tomatoes. *Journal for the American Society for Horticultural Science* 118, 562-568.