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Subhrajyoti Mishra
Department of Horticulture, College of Agriculture, JAU, Junagadh, Gujarat, India

KM Karetha
Department of Horticulture, College of Agriculture, JAU, Junagadh, Gujarat, India

Meera B Solanki
Department of Horticulture, College of Agriculture, JAU, Junagadh, Gujarat, India

Bhavin Gohel
Department of Horticulture, College of Agriculture, JAU, Junagadh, Gujarat, India

Corresponding Author:
Subhrajyoti Mishra
Department of Horticulture, College of Agriculture, JAU, Junagadh, Gujarat, India

Comparative account of leaf Morphometrics in strawberry (*Fragaria x ananassa* Duch.) cv. winter down under horizontal and vertical production systems

Subhrajyoti Mishra, KM Karetha, Meera B Solanki and Bhavin Gohel

Abstract
In the last few decades the innovative farming technology such as vertical farming has attracted the scientific community and grower as an alternative food production method. Vertical farms use engineered growth environments and soil less cultivation techniques for growing plants indoors. Owing to scanty research in the leaf growth behaviour of strawberry under vertical cultivation system we have adopted this research to evaluate the leaf morphometrics under the vertical and horizontal production system comprising of four treatments each replicated four times. The single layer system (T_1) demonstrated significantly maximum leaf length (7.53 cm), while the four layer system (T_4) has the greater leaf width (12.06 cm). The triple layer system (T_3) has statistically significant effect on petiole length (15.34 cm). The petiole diameter was non-significantly affected among the different treatments. The four layer system (T_4) exhibited maximum leaf fresh weight (1.44 g), while the leaf dry weight (0.58 g) was supreme in the triple layer system (T_3). Again the leaf dry weight: fresh weight ratio (0.39) was excellent in the double layer system (T_2) that was closely followed by the triple layer system (T_3). Hence, it can be concluded that the adaptation of the triple layer system (T_3) of vertical gardening could be considered in strawberry cv. Winter Down under the protected structures.

Keywords: Vertical cultivation, Strawberry, leaf growth, vegetative behaviour of strawberry, effect of layers, soil less farming, low cost

1. Introduction
Today's cultivated strawberry (*Fragaria x ananassa* Duch.) was developed through the man-made hybridization of *Fragaria chiloensis* and *Fragaria virginiana*, two Native American strawberry species. It is one among the small and soft fruits of the world that was introduced to India during the early 1960s (Sharma and Sharma, 2004) [21] and currently, it has well acclimatization in temperate localities. Recently it started penetrating the subtropical and tropical belts due to technological advances. The major strawberry growing countries are the USA, Turkey, Spain, Egypt, Mexico, Russia, Japan, South Korea, Poland, Germany *etc*. In India, strawberry is grown in one thousand hectares with an annual production of 5.20 thousand metric tons (Anon, 2019) [4]. Haryana, Mizoram and Meghalaya are the top three producing states contributing 3.11, 1.08 and 0.85 thousand metric tons of production from 0.19, 0.17 and 0.10 thousand hectares respectively (Anon, 2018) [3]. A further expansion in production (8 thousand metric tons) has been noticed during the 2nd advance estimate of 2020 (Anon, 2020) [5].
The wide adaption of protected cultivation is the most efficient means to overcome climatic diversity. It is one of the best methods to extend the strawberry season, enabling programmed year-round cultivation (Hancock and Simpson, 1995) [13]. Protected conditions create a favourable microclimate for plant growth and protect them from adverse climate vagaries, resulting in early vigorous crop growth and a better yield (Dorg, 2003; Gao *et al*., 2005) [9, 11]. Studies showed that by the year 2050, the growing global population would require an estimate of 60% more food than what we produce today (Tilman *et al*., 2002; Green *et al.*, 2005; Alexandratos and Bruinsma, 2012) [22, 12, 1] while the agricultural land will be expand 2% by 2040 (Almario, 2011) [2]. In 2001, Professor Dickson Despommier of the University of Columbia introduced the vertical farming concept as an alternative to reduce agriculture's ecological footprint to produce food simultaneously with expanding the agricultural area in the city (Despommier, 2010) [8]. Vertical farming eliminate external natural processes since crops

will be grown under carefully selected and well-monitored conditions, designed to maximise production density, productivity and resource use efficiency, ensuring an optimal growth rate for each species of plant year-round (White, 2010; Kozai, 2013a; Kozai, 2013b) [23, 16, 17]. It was estimated that one acre of vertical farming is equivalent to ten to twenty acre of soil based farmlands (Pantuhan, 2012).

Farmers, growing strawberry under protected structure mostly prefers the horizontal methods (*viz.*, cultivate in the soil as a single bed system) in our country as it is easy to prepare and inadequate knowledge about the vertical farming techniques. This research could help the researchers to understand the strawberry plant foliage growth behaviour under vertical production system and simultaneously put light on the comparative account of the conventionally adopted horizontal faming with the vertical farming practices.

2. Materials and Methods

The present investigation was carried out at Hi-tech Horticulture Park, Department of Horticulture, College of Agriculture, J. A. U., Junagadh (Gujarat) during 2019-20 and 2020-21. The experiment laid out in Completely Randomized Design, consisting four treatments each replicated four times. The treatment comprised of four different production systems *viz.*, single layer system (T_1), double layer system (T_2), triple layer system (T_3) and four layer system (T_4). The T_1 is considered as the conventional or horizontal production system while T_2, T_3 and T_4 are the vertical production system comprising two (L_1 and L_2), three (L_1, L_2 and L_3) and four (L_1, L_2, L_3 and L_4) layers respectively. One plot comprised of six plants. Winter Down, the genotype under study, is a short-day cultivar developed in strawberry breeding plot at Dover, Florida through hand-pollinated cross between FL. 93-103; the seed parent and FL. 95-316; the pollen parent. It is distinguished by high November through February production of fruit which is medium to large (greater than 500 grams of fruit per plant) *i.e.* the plant can produce large fruit on a relatively small plant (Chandler, 2009) [7].

2.1 Design and construction of vertical framework

The low cost vertical growing systems were constructed using cement pillars. A height of 0.8 m was maintained from one layer to another within the system. A walking path of 0.5 m was left between the treatments for easy cultural operation. The Schematic presentation of vertical growing structure for the course of the investigation was presented in Fig 1. Two iron pipes of 6 m length, kept at a spacing of 15 cm are placed on one side of the side-connecting rod attached to the cement pillars for making the structure to accommodate 12 numbers of grow bags (Fig 2). Similarly, the other two iron pipe was stuck on the other end of the side connecting rod. The distance between the two iron pipes, making a single bed, was kept at 15 cm and among the bed, it was 30 cm.

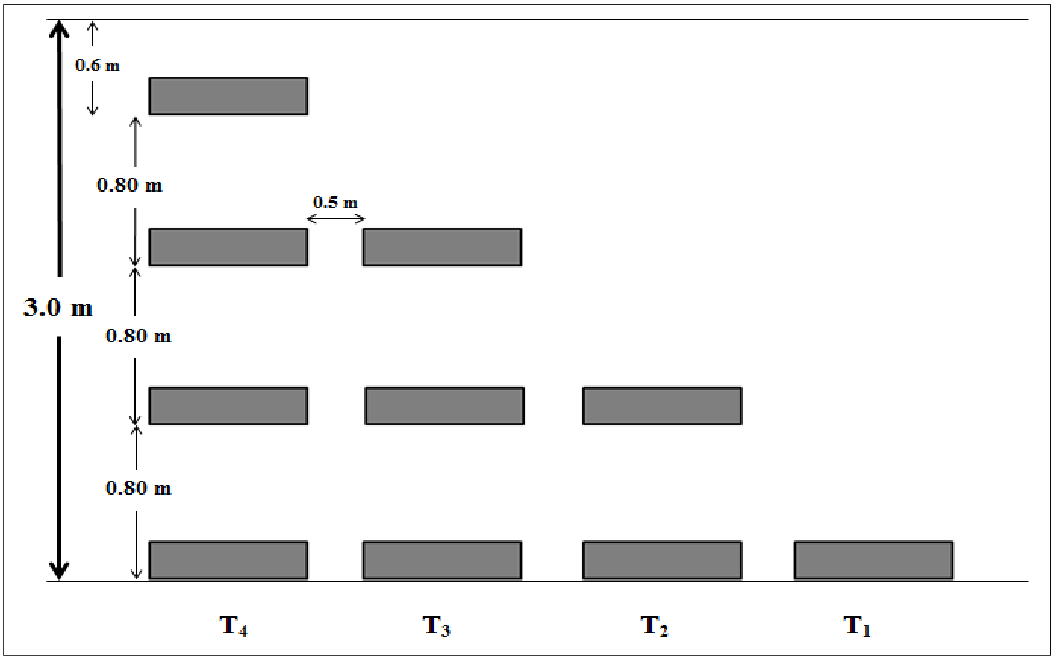

Fig 1: Schematic representation of vertical growing system

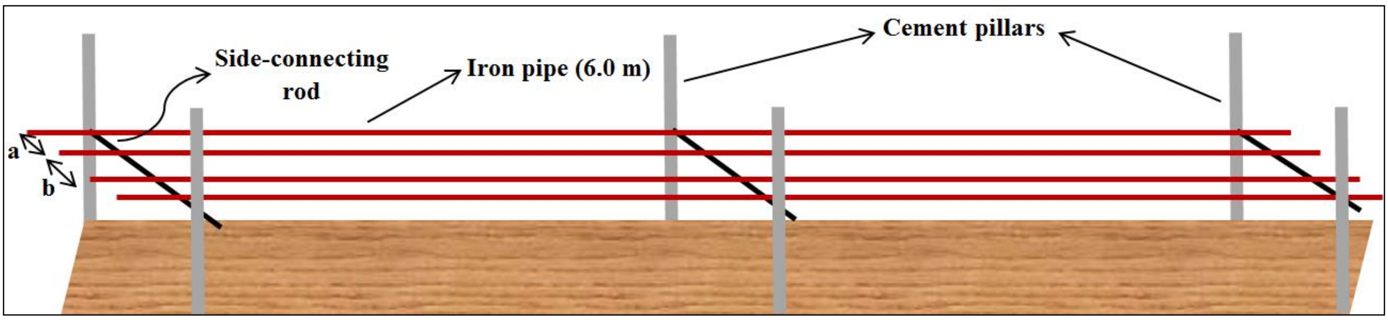

Fig 2: Schematic representation of the growing site [a (within bed) =15 cm and b (among bed)= 30 cm]

2.2 Cultural operations
The plants were supplied with plenty of water to reduce the stress after collection. After keeping overnight in the outer environment, they were transferred to the greenhouse. The dead and diseased leaves were removed from the plant using sharp secateurs. A root deep for 5 minutes with 0.05% bavistin solution was carried out to counteract the fungal pathogen. After mixing the basal fertilizer dose to the soil in grow bags, a shallow hole was made and the loosened root ball containing cocopeat was placed on the hole. Care was taken to plant the runner plant properly, *i.e*., not much above or below the crown portion. Lawn mowing was collected, dried under the sun for 10 days and were used for mulching purposes. One centimetre mulching was given after transplanting to each plant. Heavy irrigation was given just after transplanting. The various cultural operations like irrigation, manuring, weeding *etc*., were done according to the recommendation. Organic plant protection measures were taken as and when required.

2.3 Methodology adopted for data recording
Leaf morphometrical data were taken as per the scientific methods. The distance from the end of the petiole to the tip of the upper leaf lobe is regarded as leaf length and it was measured at 120 day after planting (DAP). The distance from the left lobe tip to the right lobe tip is regarded as leaf width. It was measured from fully matured leaves on the 120 DAP. Petiole length of three randomly selected leaves per plant was measured with the help of scale and the average was expressed as petiole length in centimetre (cm). Petiole width of randomly selected leaves was measured with the help of scale and the average was expressed as petiole width in millimetres (mm). Fully grown representative leaves were taken in zip bags and quickly transferred to the laboratory. Their weight was measured in electrical weighing balance and expressed in gram (g) as leaf fresh weight. After taking the fresh weight, the leaves were placed on a metal tray and dried in a hot air oven at 70°C till they attain a constant weight. With the help of electrical weighing balance they were weighed to record the dry weight (g). The ratio of leaf dry weight to fresh weight was measured by dividing the dry weight of individual leaf with its fresh weight.

3. Results and Discussion
Data presented in Table 1-2 illustrated statistically significant variations with respect to leaf length (cm), leaf width (cm), petiole length (cm), leaf fresh weight (g), leaf dry weight (g) and leaf dry weight: fresh weight ratio among the treatments during both of the years and the pooled data. Likewise numerically visible responses were evident among the layers within the treatments (Fig 3-6), during both of the years and in pooled data. The variations due to the treatments illustrated non-significant influence on the petiole diameter (mm) during both of the seasons and in the pooled data. In contrast, quite visible variations were persistent among the layers within the treatments during the prevailing cropping cycles and in pooled for the petiole diameter.

3.1 Leaf length: The single layer system (T_1) demonstrated significantly maximum leaf length (7.48, 7.58 and 7.53 cm), which was at par with the double layer system (T_2) and triple layer system (T_3) and the minimum (6.76, 6.83 and 6.79 cm) were observed in the four layer system (T_4) (Table 1). The increased leaf length with the increased layer height was observed during the course of investigation (Fig 3). Numerically maximum leaf length (7.98, 8.13 and 8.05 cm) was exhibited by the 4th layer (L_4) of the four layer system (T_4), followed by the 3rd layer (L_3) of the triple layer system (T_3), whereas the minimum (5.46, 5.59 and 5.52 cm) was obtained in the 1st layer (L_1) of the four layer system (T_4) during the cropping periods and in pooled. The uniform availability of radiation in the single layer system might help to attain better leaf length. Increased leaf length as a consequence of increased layer height within the treatments was observed during the course of investigation. The lower layers of the vertical production system as a result of reduced irradiance have shown reduction in leaf size.

3.2 Leaf width: The four layer system (T_4) demonstrated maximum leaf width (11.97, 12.16 and 12.06 cm) during both of the years and in pooled, which was at par with the triple layer system (T_3). The minimum leaf width (10.78, 10.99 and 10.88 cm) was demonstrated in the double layer system (T_2) during both of the years and in pooled (Table 1). Numerically the maximum leaf width (16.37, 16.42 and 16.39 cm) was exhibited by the 4th layer (L_4) of the four layer system (T_4), followed by the 3rd layer (L_3) of the triple layer system (T_3), whereas the minimum (8.67, 8.87 and 8.77 cm) was obtained in the 1st layer (L_1) of the four layer system (T_4) during both of the years and in pooled (Fig 3). The increased leaf width along with the increased layer height within the treatments was observed during the course of investigation. Much larger leaf width of consecutive two upper layers in the four layer system as a result of higher photosynthetically active radiation (Fraidoon, 2011; Murthy *et al*., 2017) [10, 18] might be contributed to larger leaf width of the four layer system (T_4). The lower layers of the vertical production system as a result of reduced irradiance, has shown reduction in leaf size. The minimum leaf width of the double layer system (T_2) might be a result of uneven and poor irradiance.

3.3 Petiole length: The triple layer system (T_3) demonstrated highest petiole length (15.14, 15.53 and 15.34 cm) during both of the years and in pooled, which was at par with the four layer system (T_4) during the first year and in pooled, whereas the lowest petiole length (13.50, 14.23 and 13.87 cm) was demonstrated in the double layer system (T_2) during both of the years and in pooled (Table 1). Expansion in petiole length was evident on increased layer height within the treatments. Numerically the maximum petiole length (19.75, 19.70 and 19.72 cm) was exhibited by the 4th layer (L_4) of the four layer system (T_4), followed by the 3rd layer (L_3) of the triple layer system (T_3), whereas the minimum (10.75, 10.62 and 10.68 cm) was obtained in the 1st layer (L_1) of the four layer system (T_4) during both of the years as well in pooled (Fig 3). The larger petiole length of triple layer system (T_3) might be associated with the relatively less shading effect of the upper layers to the 1st layer compare to that found in the four layer system (T_4). The progressive reduction in solar radiation from 4th to 1st layer could have influenced petiole length in the four layer system (T_4). The 1st layer (L_1) of the four layer system (T_4), which harnesses the lowest (34.60-37.08%) radiation, has shown greater reduction in the petiole length. The minimum petiole length of the double layer system (T_2) might be a result of uneven and poor irradiance. The difference in photosynthetic rate among layers might be responsible for this unevenness. In contrast, Awang and Atherton (1995) [6] reported that low light intensity, resulted longer petiole formation in strawberry. Chandler (2009) [7] reported the similar trend in petiole length for the cv. Winter Down.

3.4 Petiole diameter: The treatments have non-significant influence on the petiole diameter (mm) during both of the seasons and in the pooled data (Table 1). Though the layers influence the petiole length but negligible effect were noticed among the layers with regards to the petiole diameter (Fig 3).

Table 1: Influence of production systems on leaf morphological parameters of strawberry cv. Winter Down under protected condition.

Treatments	Leaf length (cm)			Leaf width (cm)			Petiole length (cm)			Petiole diameter (mm)		
	2019-20	2020-21	Pooled	2019-20	2020-21	Pooled	2019-20	2020-21	Pooled	2019-20	2020-21	Pooled
T_1	7.48	7.58	7.53	11.10	11.07	11.08	14.04	14.50	14.21	3.2	3.18	3.19
T_2	7.23	7.35	7.29	10.78	10.99	10.88	13.50	14.23	13.87	3.11	3.19	3.15
T_3	7.21	7.31	7.26	11.65	11.99	11.82	15.14	15.53	15.34	2.92	2.94	2.93
T_4	6.76	6.83	6.79	11.97	12.16	12.06	14.66	14.80	14.73	2.82	3.00	2.91
S.Em. ±	0.13	0.16	0.10	0.25	0.28	0.19	0.30	0.30	0.21	1.16	0.12	0.12
C.D. at 5%	0.41	0.48	0.30	0.77	0.87	0.55	0.94	0.93	0.62	NS	NS	NS
C.V. %	3.71	4.32	4.03	4.42	4.88	4.65	4.24	4.07	4.16	7.73	7.73	8.00

Table 2: Influence of production systems on leaf growth parameters of strawberry cv. Winter Down under protected condition

Treatments	Leaf fresh weight (g)			Leaf dry weight (g)			Leaf dry weight: fresh weight ratio		
	2019-20	2020-21	Pooled	2019-20	2020-21	Pooled	2019-20	2020-21	Pooled
T_1	0.93	1.06	0.99	0.30	0.35	0.33	0.32	0.34	0.33
T_2	1.17	1.19	1.18	0.45	0.47	0.46	0.39	0.40	0.39
T_3	1.40	1.43	1.42	0.57	0.59	0.58	0.39	0.39	0.39
T_4	1.43	1.45	1.44	0.56	0.58	0.57	0.38	0.39	0.38
S.Em. ±	0.04	0.05	0.03	0.02	0.02	0.01	0.01	0.01	0.01
C.D. at 5%	0.12	0.17	0.10	0.06	0.07	0.04	0.03	0.03	0.02
C.V. %	6.48	8.41	7.55	8.21	8.98	8.63	4.56	4.31	4.44

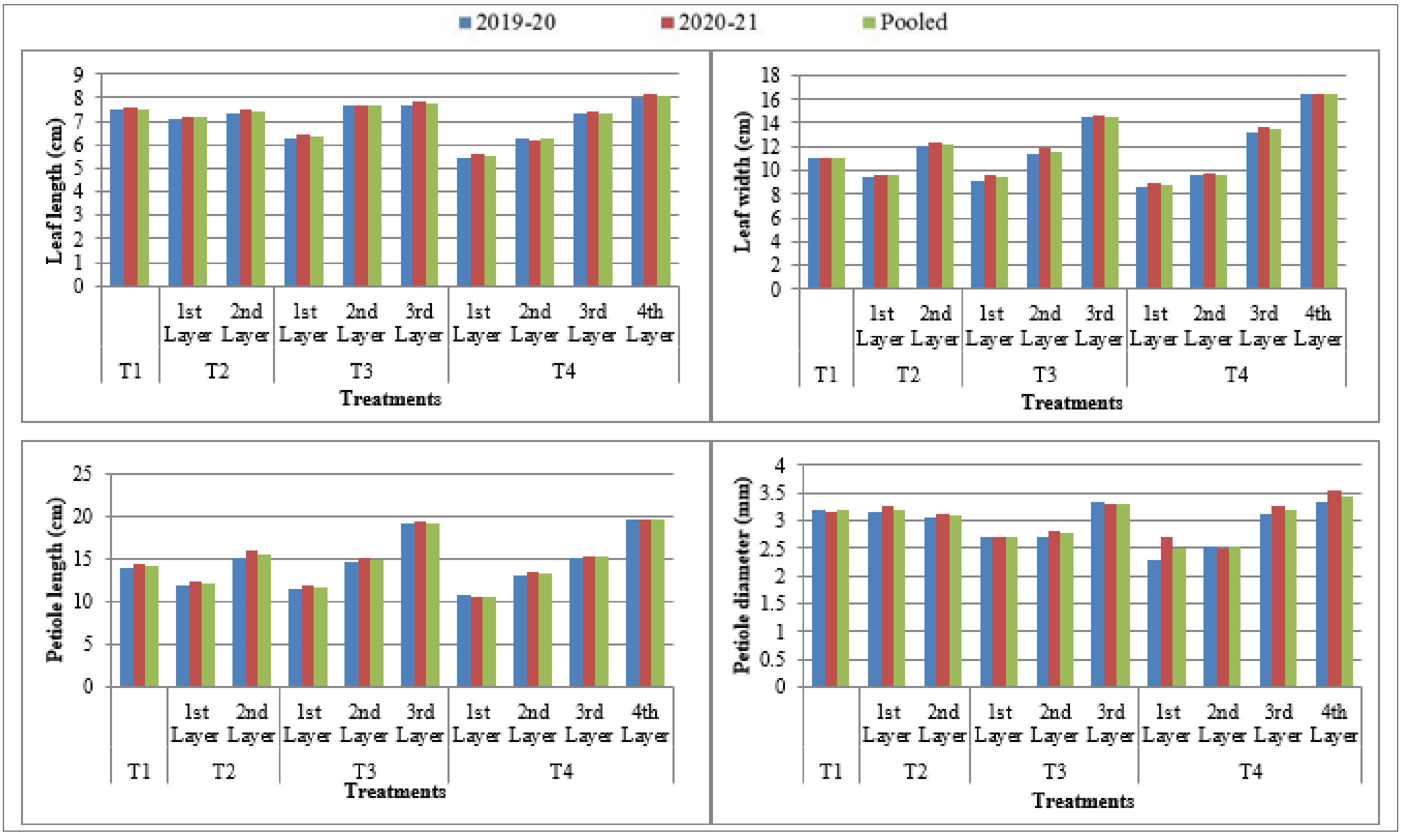

Fig 3: Influence of layers among the treatment on leaf morphological parameters of strawberry cv. Winter Down under protected condition.

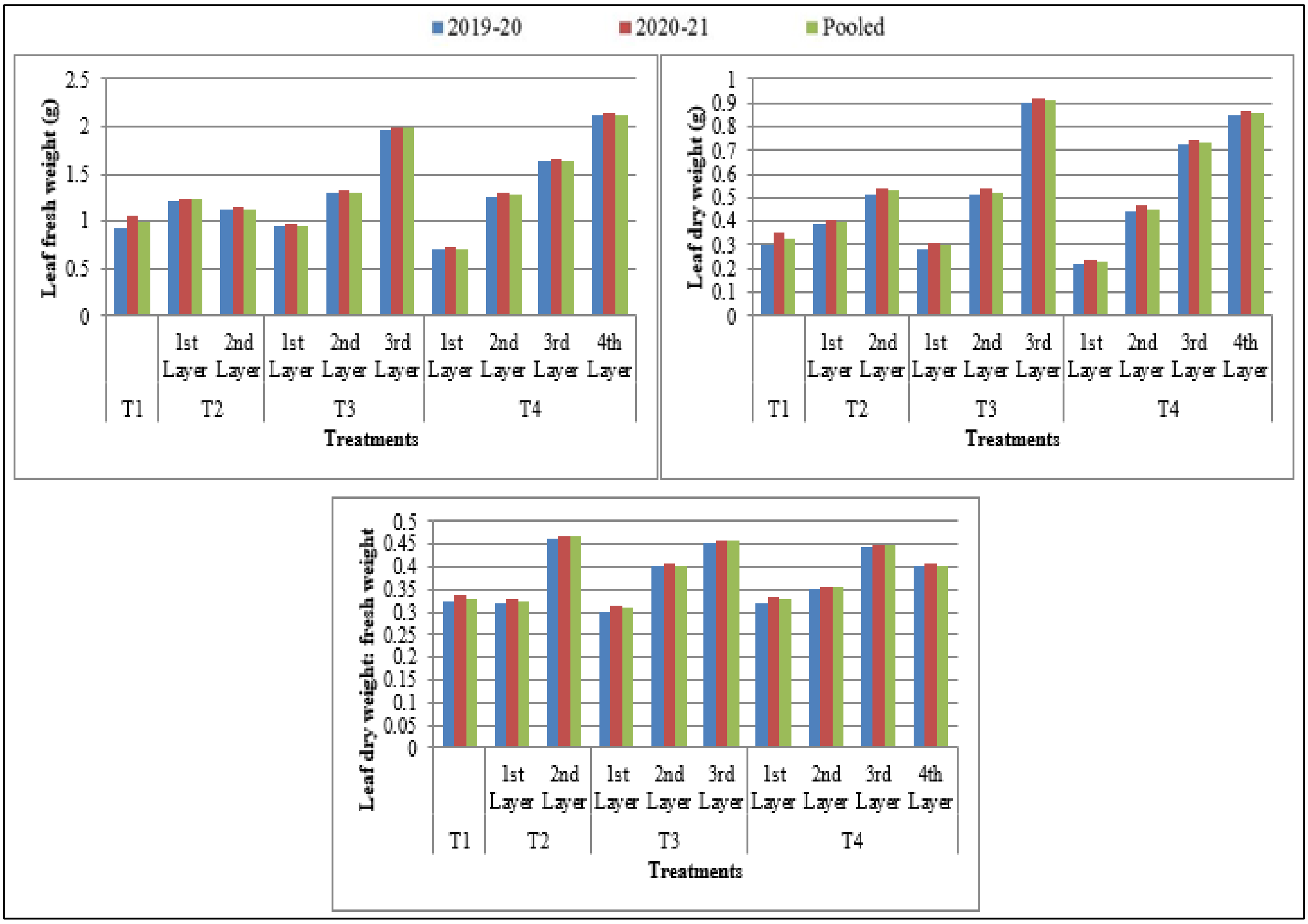

Fig 4: Influence of layers among the treatment on leaf growth parameters of strawberry cv. Winter Down under protected condition

3.5 Leaf fresh weight: The four layer system (T_4) exhibited maximum leaf fresh weight (1.43, 1.45 and 1.44 g), which was at par with the triple layer system (T_3) and the minimum (0.93, 1.06 and 0.99 g) was demonstrated in the single layer system (T_1) during both of the years and pooled (Table 2). Numerically the maximum leaf fresh weight (2.11, 2.14 and 2.13 g) was exhibited by the 4th layer (L_4) of the four layer system (T_4), followed by the 3rd layer (L_3) of the triple layer system (T_3), whereas the minimum (0.70, 0.72 and 0.71 g) was in the 1st layer (L_1) of the four layer system (T_4) during both of the years and pooled (Fig 4). Light intensity increases the net photosynthetic assimilation rate (Nobel, 1999) [19] that stimulate maximum root activity hence greater absorption of the moisture from the root zone. The upper layers receive maximum of the solar radiation, thereby inducing maximum moisture absorption (Hancock, 1999) [14]. The grater quantity of moisture in the leaves might result in more leaf fresh weight in the four layer system (T_4). Both the low light and temperature in the single layer system may leads to less fresh weight of leaves.

3.6 Leaf dry weight: The triple layer system (T_3) demonstrated the maximum leaf dry weight (0.57, 0.59 and 0.58 g), which was at par with the four layer system (T_4) and the lowest (0.30, 0.35 and 0.33 g) was demonstrated in the single layer system (T_1) during both of the years and in pooled (Table 2). Higher leaf dry weight was evident with increasing layer height up to 3rd layer within the treatments (Fig 4). Numerically the maximum leaf dry weight (0.90, 0.92 and 0.91 g) was exhibited by the 3rd layer (L_3) of the triple layer system (T_3) that was closely followed by the 4th layer (L_4) of the four layer system (T_4), whereas the minimum (0.22, 0.24 and 0.23 g) was obtained in the 1st layer (L_1) of the four layer system (T_4) during both of the years and in pooled. Light intensity increases net photosynthetic assimilation rate (Nobel, 1999) [19], whereas high temperature causes low stomatal conductance that reduces transpiration rate and the plant body's cooling capacity (Nobel, 1999) [19]. The more light intensity along with greater temperature closes the somata and obstructs the normal photosynthetic process. Hence, heating of leaves reduces plant photosynthetic capacity. Higher leaf dry weight was evident with increasing layer height within the treatments up to 3rd layer (L_3). The triple layer system (T_3) received relatively lower temperature than the upper layer (L_4) of four layer system (T_4). That influences storage of more photosynthates, thereby increasing the leaf dry weight. Low irradiance decreased leaf growth and dry weight (Wright and Sandrang, 1995; Awang and Atherton, 1995) [24, 6] hence lower dry weight was observed in the lower layers of the vertical production system. Similar results were also demonstrated by Fraidoon (2011) [10]; Murthy *et al*. (2017) [18] and Hidaka *et al*. (2016) [15] in strawberry under different vertical production systems. The low light and temperature as well as lesser fresh weight of leaf in the single layer system may leads to lower dry weight of leaves in it.

3.7 Leaf dry weight: fresh weight ratio: The double layer system (T_2) demonstrated the maximum leaf dry weight: fresh weight ratio (0.39), which was at par with the triple layer system (T_3) and the four layer system (T_4), whereas the minimum (0.33) was demonstrated in the single layer system (T_1) in the pooled data (Table 2). There was a visible enhancement of the leaf dry weight: fresh weight ratio over increased layer height up to the 3rd layer within the treatment, there after it was reduced (Fig 4). Among the layers, numerically the maximum leaf dry weight: fresh weight ratio (0.46) was exhibited by the 2nd layer (L_2) of the double layer system (T_2), followed by the 3rd layer (L_3) of the triple layer system (T_3), whereas the minimum (0.31) was obtained in the 1st layer (L_1) of the triple layer system (T_3) in pooled. In the presence of required solar radiation and lesser temperature, there might be reduction in the plant catabolic processes that might favour more photosynthesis (Nobel, 1999) [19]. Water availability in the root zone is more, if the plants are present in optimum temperature condition. Storage of more of assimilates in the corresponding leaf of double layer system (T_2) might leads to higher leaf dry weight: fresh weight ratio. Again comparatively more dry weight in leaves with less fresh weight might be attributed to the more leaf dry weight: fresh weight ratio in the double layer system (T_2). The low light and temperature as well as lesser fresh weight and dry weight of leaf in the single layer system might cause reduction in the leaf dry weight: fresh weight ratio.

4. Conclusion
The result revealed critical disparity among the treatments for the different characters. The vertical cultivation system was much superior in terms of leaf growth than the horizontal cultivation system. Based on the results obtained from the present investigation, it can be comprehended that the triple layer system (T_3) demonstrated comparative superior leaf morphometric performances. Hence, it can be concluded that the adaptation of the triple layer system (T_3) of vertical gardening with a spacing of 0.80 m among the layers could be considered in strawberry cv. Winter Down under the protected structures.

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