Impact of plant spacing and mulch on growth parameters of strawberry (Fragaria x ananassaDuch.)

ABSTRACT

Plant spacing and mulch material have got tremendous influence on crop growth and yield.Proper crop spacing aids in adequate harvesting of solar radiation and sufficient absorption of nutrients and moisture from the soil due to well developed root system which can be accommodated by making changes in inter and intra row spacing.Although plant spacing has a prominent influence on plant growth and development but has received a sort of slight attention in strawberry cultivation.Mulching controls or increases soil temperature, maintains soil moisture, improves water and nutrient absorption and reduces weed growth.These factors have tremendous influence on crop growth and as Strawberry is a surface feeder, mulching plays a very important role.The purpose of this study was to assess the influence of spacing and mulch on growth of Strawberry.The present experiment was carried out during 2019-20 and 2020-21 in Jorhat, Assam with the objective to assess the influence of spacing and mulch on growth of Strawberry.The experiment was laid out in randomized block Design with 2 factors viz. spacing and mulch with three replications involving twenty treatments comprising of five plant spacings viz., 20 cm x 30 cm (S1), 30 cm x 30 cm (S2), 30 cm x 40 cm (S3), 40 cm x 40 cm (S4), 40 cm x 60 cm (S5) and four different mulch applications viz., paddy straw (M1), red mulch (M2), silver black mulch (M3) and no mulch (M4) and the data of individual years were subjected to pooled analysis.The treatments significantly influenced the various parameters.The experiment's findings showed that mulch material and the plant spacing had a favorable effect on strawberry growth.The pooled data revealed that 40 cm x 60 cm spacing with silver black mulch recorded maximum leaf area, Leaf Relative Water Content and minimum days from first flower opening to fruit setting which may have influence on crop yield.Standardization of spacing and mulch material according to agroclimatic condition will help farmers to cultivate Strawberry on commercial level.

Keywords: (Spacing, mulch, strawberry, growth,flowering,leaf area)

1. INTRODUCTION

"Strawberry (*Fragaria* × *ananassa*Duch.) belongs to the Rosaceae family and is cultivated all over the world for its aggregate accessory fruits. The total area of cultivated Strawberry was 3.95 thousand hectares with global production of 9.2 million tonnes during the year 2019"[1]. "Crop growth of strawberry can be increased by manipulation of plant spacing and crop management techniques. Plant spacing helps in increasing crop growth through effective utilization of solar radiation, nutrients and underground resources bringing about better photosynthate formation. Optimum plant spacing aids 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, boost water and nutrient absorption, minimize weed growth and improves fruit quality by avoiding the direct contact of soil with fruit"[2]. The present investigation aimed to study the effect of spacing and mulch on growth of strawberry.

2. MATERIAL AND METHODS

2.1. Experimental details

The study was conducted at the farmer's field at Jorhat district of India during the consecutive years 2019-2020 and 2020-2021. The field experiment plot was laid out in factorial randomized block design and consisted of three replications. The tissue culture strawberry plants of variety Sweet Charlie were planted in open condition in the experimental plot. There were 20 treatment combinations comprising of five plant spacings viz., 20 cm x 30 cm (S1), 30 cm x 30 cm (S2), 30 cm x 40 cm (S3), 40 cm x 40 cm (S4), 40 cm x 60 cm (S5) and four different mulch applications viz., paddy straw (M1), red mulch (M2), silver black mulch (M3) and no mulch (M4).

T1	S1M1	20 cm x 30 cm with paddy straw mulch
T2	S1M2	20 cm x 30 cm with red mulch
T3	S1M3	20 cm x 30 cm with silver black mulch
T4	S1M4	20 cm x 30 cm with no mulch
T5	S2M1	30 cm x 30 cm with paddy straw mulch
T6	S2M2	30 cm x 30 cm with red mulch
T7	S2M3	30 cm x 30 cm with silver black mulch
T8	S2M4	30 cm x 30 cm with no mulch
T9	S3M1	30 cm x 40 cm with paddy straw mulch
T10	S3M2	30 cm x 40 cm with red mulch
T11	S3M3	30 cm x 40 cm with silver black mulch
T12	S3M4	30 cm x 40 cm with no mulch
T13	S4M1	40 cm x 40 cm with paddy straw mulch
T14	S4M2	40 cm x 40 cm with red mulch
T15	S4M3	40 cm x 40 cm with silver black mulch
T16	S4M4	40 cm x 40 cm with no mulch
T17	S5M1	40 cm x 60 cm with paddy straw mulch
T18	S5M2	40 cm x 60 cm with red mulch
T19	S5M3	40 cm x 60 cm with silver black mulch
T20	S5M4	40 cm x 60 cm with no mulch

"Growth parameters viz. leaf area, leaf relative water content, days to appearance of first flower and days taken from first flower opening to fruit setting were recorded at proper time during the crop cycle. The data recorded during field experimentation were subjected to the statistical analysis of variance using factorial randomised block design" as described by [3]. "The overall significance of difference among the treatments was tested, using critical differences (C.D.) at 5% level of significance. The results were statistically analyzed with the help of a windows-based computer package OPSTAT and SPSS software". [4]

2.2 Land preparation and planting:

The tissue cultured planting materials of Strawberry variety Sweet Charlie were brought from Daffodil Nursery Old, Dhupguri, Kamrup, Assam. The plants were healthy, uniform in growth with well developed root systems and were planted in 15-20 cm raised beds with spacing of different treatments. The outer leaves were pinched off and coco peats of the roots of the seedlings were washed properly. All plants were given uniform cultural practices during the course of investigation.The experimental area (open condition) was brought to a fine tilth by ploughing followed by harrowing and levelling. Weeds and stones were removed from the field. For each treatment equal sized plots each measuring 1.5 m x 2.0 m were laid out accommodating plants depending on treatment spacings in each plot. Each treatment contained three number of replication and a gap of 50 cm was left between two adjacent plots. Raised beds of 15-20 cm in height were prepared for planting the strawberry plants.Beforeplanting, the soil of each bed was enriched with 3 kg of well decomposed cow dung and then treated with Captaf @ 3g per litrewater to avoid soil borne pathogens. After that, mulching was done with different mulched materials in the plots as per respective treatments. In case of paddy straw mulching treatments, paddy straw was spread uniformly over the beds where the thickness of straw was 5 cm and plastic mulches (30 micron) of silver black and red of the treatments were spread after bed preparation. Before planting, holes were made on the mulch materials with a sharp blade at different treatments of plant to plant and row to row spacing for planting the strawberry plants by inserting in the holes. Healthy tissue cultured planting materials along with ball of earth were then planted carefully with a khurpi after treatment with Ridomil Gold @ 2 g per litre of water.Vermicompost application was made to the experimental plot as preplanting application. Vermicompost @ 2.5 t $ha^{-1}$was applied one fortnight before planting the strawberry plants and it was mixed thoroughly during bed preparation. NPK 19-19-19 was applied through foliar spraying @ 5 g l^{-1} water at ten days interval after one month of planting.he crop was lightly and continuously irrigated and optimum soil moisture level maintained in the field throughout the raising of crop.Foliar application of micronutrient Tracel at the rate of 5 g l^{-1} of water was done after one month of planting at monthly intervals.Tracel is water soluble thereby facilitating ready uptake of nutrients by plants.

3. RESULTS AND DISCUSSION

Leaf area: The leaf area of each trifoliate leaf per plant was calculated at flowering stage and was expressed in cm^2.The effect of spacing and mulch on leaf area is shown in Table 1.The interaction of spacing and mulching has recorded significant effect for all the treatments. The interactions involving spacing and mulching exhibited significant effect on leaf area for both the years of study.Treatment combination T_{19} (40 cm x 60 cm spacing with silver black mulch) registered maximum leaf area (106.07 cm^2) while minimum leaf area (59.04 cm^2) was observed in T_4.

"Leaf is the main site of photosynthetic activity and hence the estimation of leaf area is very important in the growth analysis of crop plants. Strawberry leaves at different leaf ages had a significantly different maximum photosynthetic rate and *t*he maximum photosynthetic rates of the functional leaves were generally 1-1.5 times greater than the new leaves and 80% greater than the old leaves. Functional leaves are complete in structure and rich in chlorophyll, allowing for optimal light use efficiency. The total net photosynthesis of the lower old leaves throughout the day are very low, especially on cloudy days with insufficient light. New leaves have small sizes and leaf inclination angles, low chlorophyll and protein contents and are exposed to a little light. Old leaves are located below functional leaves, some of their chlorophyll and protein decompose and they are also exposed to a little light. Functional leaves are exposed to the most light and contain the most chlorophyll and protein and the strongest photosynthetic energy, making full use of light energy. Therefore, during strawberry management, it is necessary to remove old leaves as early as possible in order to minimize the volume of low-light and light-free areas to improve the use of light energy" [5]. "Development of new leaf area is reduced substantially even under moderate water stress. In addition, several mechanisms exist in crop plants which can reduce the amount of radiation intercepted by mature foliage" [6].

"Optimum row spacing ensures better light interception and penetration into the crop canopy and enhances light utilization efficiency in crop plants"[7] . Wider spacing recorded maximum leaf area than that of closer spacing.This could be due to lessened competition for light and reduced overlapping from adjoining plants which might have enabled the plants grown at wider spacing to utilize its energy for the production of a larger leaf area. Leaf emergence reduced under very close planting owing to lower temperature inside the canopy since temperature had significant influence on leaf emergence. This might have helped in production of higher leaf area by producing wider leaves in wider spacing and narrow leaves in closer spacing.These results were supported by the findings by [8], [9], [10] and [11].

Higher values of leaf area under plastic mulch was obtained which may be attributed to more water conservation,better soil hydrothermal regimes and suppression of weeds that helped the plants to produce more leaves with more leaf area. The enhancement of soil properties and soil microbial activity also led to the growth of the leaf acquiring more leaf area. These results are in line with the findings of [12], [13] and [14]. Similar results were also reported by [15] and [16] in strawberry who observed the positive role of black mulch in enhancing leaf area than other mulches of paddy straw, clear polyethylene mulch.

"Regarding the apparently higher leaf area inplants exposed to red mulch compared to paddy straw and no mulch, leaf production might be promoted by light in the red range"[17] . "However plant response to different mulch

colors is highly dependent on the species, experimental conditions and leaf area sampling as in tomato plants exposed to black or white mulches, leaf area was found to be unaffected" [18].

Table 1: Effect of spacing, mulch and spacing and mulch (S x M) interaction on Leaf area (cm^2)

Treatment	Leaf area(cm^2)		
	2019-2020	2020-21	Pooled
Spacing (S)			
S_1	77.09^e	75.42^e	76.25^e
S_2	80.72^d	78.69^d	79.71^d
S_3	83.92^c	81.60^c	82.76^c
S_4	86.50^b	84.30^b	85.40^b
S_5	87.96^a	85.58^a	86.77^a
SEd(±)	0.44	0.38	0.29
CD(P=0.05)	0.90	0.77	0.58
Mulches (M)			
M_1	75.30^c	73.65^c	74.48^c
M_2	89.45^b	87.15^b	88.30^b
M_3	101.81^a	99.68^a	100.75^a
M_4	66.39^d	63.98^d	65.19^d
SEd(±)	0.40	0.34	0.26
CD(P=0.05)	0.80	0.69	0.52

Interaction (S x M)							
Treatment combination	**2019-20**	**2020-21**	**Pooled**	**Treatment combination**	**2019-20**	**2020-21**	**Pooled**
$T_1(S_1M_1)$	71.29	69.37	70.33	$T_{11}(S_3M_3)$	102.57	101.35	101.96
T_2 (S_1M_2)	82.60	81.38	81.99	T_{12} (S_3M_4)	67.62	64.29	65.95
T_3 (S_1M_3)	94.84	92.47	93.65	T_{13} (S_4M_1)	77.30	76.25	76.78
T_4 (S_1M_4)	59.62	58.46	59.04	T_{14} (S_4M_2)	93.47	91.27	92.37
$T_5(S_2M_1)$	73.60	71.58	72.59	T_{15} (S_4M_3)	105.68	103.40	104.54
T_6 (S_2M_2)	86.43	83.38	84.91	T_{16} (S_4M_4)	69.55	66.29	67.92
$T_7(S_2M_3)$	98.58	96.47	97.52	T_{17} (S_5M_1)	78.39	76.52	77.45
T_8 (S_2M_4)	64.27	63.34	63.81	T_{18} (S_5M_2)	95.15	93.54	94.35
T_9 (S_3M_1)	75.91	74.55	75.23	T_{19} (S_5M_3)	107.40	104.74	106.07
T_{10} (S_3M_2)	89.59	86.19	87.89	T_{20} (S_5M_4)	70.91	67.51	69.21
	2019-20	**2020-2021**	**Pooled**				
SEd(±)	0.89	0.76	0.58				
CD(P=0.05)	1.80	1.54	1.16				

Leaf relative water content (%): The Relative Water content (RWC) of the recently mature leaves was determined. The effect of spacing and mulch on leaf area is shown in Table 2. In the interactions involving spacing and mulching, the variation in leaf relative water content was statistically non significant for both the years of study and pooled data with

T_{19}registering the maximum value (76.12%). Strawberry consumes a great amount of water because of its large leaf area, shallow root system and juicy texture[19];[20]. Leaf relative water content (LRWC) is an important indicator of water status in plants through their effect on cell volume; it reflects the balance between water supply to the leaf tissue and transpiration rate[21],[22].

The LRWC was found to increase at wider spacing and decrease at narrow spacing. Higher root densities of narrower planting may result in a more rapid depletion of soil water content thereby influencing LRWC. High plant population might also increase competition for water, which may reduce relative leaf water content [23],[24],[25].

Plastic mulch resulted in higher LRWC than straw mulch and no mulch treatments which might be due to favourable soil physical condition which play an important role in the root extension and absorption of moisture & nutrients. Higher values of LRWC under mulch treatments could be due to less evaporational water loss and more water conservation. The results of present study are in close conformity with those reported by [26],[27] and [28]. However, in some study it was observed that high temperature cause increase in transpiration and this change may lead to a reduction in the LRWC and loss of turgidity [29],[30] and [31].

Table 2 : Effect of spacing, mulch and spacing and mulch (S x M) interaction on Leaf Relative Water Content (%)

Treatment	Leaf Relative Water Content (%)		
	2019-2020	2020-21	Pooled
Spacing (S)			
S_1	70.80^{d}	72.03^{c}	71.41^{d}
S_2	71.05^{c}	72.24^{c}	71.65^{c}
S_3	71.42^{b}	72.63^{b}	72.02^{b}
S_4	72.05^{a}	73.05^{a}	72.55^{a}
S_5	72.15^{a}	73.25^{a}	72.70^{a}
SEd(±)	0.12	0.12	0.08
CD(P=0.05)	0.24	0.24	0.17
Mulches (M)			
M_1	70.99^{c}	72.25^{c}	71.62^{c}
M_2	74.03^{b}	75.12^{b}	74.57^{b}
M_3	74.80^{a}	76.15^{a}	75.47^{a}
M_4	66.15^{d}	67.04^{d}	66.60^{d}
SEd(±)	0.11	0.11	0.08
CD(P=0.05)	0.22	0.22	0.15

Interaction (S x M)							
Treatment combination	**2019-20**	**2020-21**	**Pooled**	**Treatment combination**	**2019-20**	**2020-21**	**Pooled**
$T_1(S_1M_1)$	70.33	71.76	71.04	$T_{11}(S_3M_3)$	74.77	76.15	75.46
T_2 (S_1M_2)	73.23	74.45	73.84	T_{12} (S_3M_4)	66.28	67.22	66.75
T_3 (S_1M_3)	74.16	75.42	74.79	T_{13} (S_4M_1)	71.31	72.65	71.98
T_4 (S_1M_4)	65.45	66.46	65.96	T_{14} (S_4M_2)	74.92	75.43	75.18
$T_5(S_2M_1)$	70.65	71.85	71.25	T_{15} (S_4M_3)	75.46	76.67	76.06
T_6 (S_2M_2)	73.55	74.70	74.13	T_{16} (S_4M_4)	66.50	67.45	66.98

$T_7(S_2M_3)$	74.24	75.63	74.94	T_{17} (S_5M_1)	71.81	72.75	72.28
T_8 (S_2M_4)	65.76	66.70	66.27	T_{18} (S_5M_2)	74.65	76.09	75.37
T_9 (S_3M_1)	70.84	72.23	71.53	T_{19} (S_5M_3)	75.37	76.86	76.12
T_{10} (S_3M_2)	73.78	74.91	74.35	T_{20} (S_5M_4)	66.79	67.29	67.04
		2019-20		**2020-2021**		**Pooled**	
SEd(±)		0.24		0.24		0.17	
CD(P=0.05)		NS		NS		NS	

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Days to appearance of first flower (days): Data of days taken to appearance of first flower from planting under different treatments was recorded and has been presented in Table 3. The interactions involving spacing and mulching showed non significant effect on number of days to appearance of first flower during the second year of study and pooled data while first year of study showed significant effect. Treatment combination T_3 registered the minimum number of days to appearance of first flower (33.50 days).

Closer spacing took minimum number of days to first flowering and flower bud appearance delayed successively as the planting distances were increased. This might be due to more competition among plants in closer spacing for space, light and air and nutrition, hence closer spaced plants tended to grow vertically and led to early physiological maturity as a result of their growth. The plants grown at closer spacing completed their vegetative growth earlier and entered into reproductive phase than wider spacing, resulting in earlier flower bud initiation in closer spaced plants. The longest days to flowering with a wider spacing might be due to the fact that more nutritional area available in the wider spacing might have caused the crop to flower later than the narrower spacing. Furthermore, this result might be because wider spacing had a better light interception as compared to the narrow row spacing, resulting in more number of days to flowering. The results of the present study are in conformity with the findings by[32];[33];[34];[35];[36];[37]. This findings are in contrast to the views of [38] and [39] who reported early flowering and fruiting in wider spaced plants which might be due to less interplant competition and more leaf surfaces exposed to light, which increased the metabolism of the plant causing early physiological maturity, flowering and subsequent fruiting.

Silver black and red mulch showed early flowering which might be due to accumulation of more heat units that induced early flowering under sub tropical conditions. Earliness in silver black mulch could be due to its reflective properties which increased light interception into inner canopy that might have resulted in early flowering and fruiting in strawberry. Maximum number of days to appearance of first flower was observed in no mulch and paddy straw due to presence of low temperature which might have affected the flowering. These results are in conformity with the earlier findings of [40];[41];[42];[43];[44]. [45] noted that a film that filtered red light, decreasing R/FR ratio, would promote flowering in plants.

Table 3 : Effect of spacing, mulch and spacing and mulch (S x M) interaction on days to appearance of first flower

Treatment	**Days to appearance of first flower**		
	2019-2020	**2020-21**	**Pooled**
Spacing(S)			
S_1	36.69^a	39.00^a	37.85^a

S_2	37.25[b]	39.49[b]	38.37[b]
S_3	38.21[c]	40.02[c]	39.11[c]
S_4	39.00[d]	40.41[d]	39.70[d]
S_5	39.41[d]	41.17[e]	40.29[e]
SEd(±)	0.20	0.16	0.13
CD(P=0.05)	0.42	0.33	0.26
Mulches(M)			
M_1	40.52[c]	42.67[c]	41.60[c]
M_2	34.20[b]	36.39[b]	35.29[b]
M_3	33.72[a]	35.66[a]	34.69[a]
M_4	44.00[d]	45.37[d]	44.69[d]
SEd(±)	0.18	0.15	0.11
CD(P=0.05)	0.37	0.29	0.23

Interaction (S x M)

Treatment combination	2019-20	2020-21	Pooled	Treatment combination	2019-20	2020-21	Pooled
$T_1(S_1M_1)$	38.19	41.83	40.00	$T_{11}(S_3M_3)$	33.82	35.85	34.84
T_2 (S_1M_2)	33.10	35.40	34.25	T_{12} (S_3M_4)	43.96	45.38	44.67
T_3 (S_1M_3)	32.45	34.56	33.50	T_{13} (S_4M_1)	41.77	43.40	42.59
T_4 (S_1M_4)	43.02	44.25	43.63	T_{14} (S_4M_2)	35.11	36.70	35.91
$T_5(S_2M_1)$	39.43	41.98	40.70	T_{15} (S_4M_3)	34.40	35.92	35.16
T_6 (S_2M_2)	33.30	35.83	34.56	T_{16} (S_4M_4)	44.72	45.60	45.16
$T_7(S_2M_3)$	32.98	35.40	34.19	T_{17} (S_5M_1)	42.48	43.59	43.04
T_8 (S_2M_4)	43.27	44.76	44.02	T_{18} (S_5M_2)	35.17	37.71	36.44
T_9 (S_3M_1)	40.73	42.54	41.63	T_{19} (S_5M_3)	34.92	36.55	35.74
T_{10} (S_3M_2)	34.32	36.33	35.32	T_{20} (S_5M_4)	45.04	46.84	45.94
	2019-20		**2020-2021**		**Pooled**		
SEd(±)	0.41		0.33		0.26		
CD(P=0.05)	0.83		NS		NS		

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Days from first flower opening to fruit setting: Data of number of days taken from first flower opening to fruit setting under different treatments was recorded and has been presented in Table 4. The interactions involving spacing and mulching showed significant differences on days from first flower opening to fruit setting during both the years of study. Treatment combination T_{19} (40 cm x 60 cm spacing with silver black mulch) took minimum days from first flower opening to fruit setting (4.75 days) while maximum days from first flower opening to fruit setting (9.69 days) was observed in T_4.

Optimum conditions for fruit set include high light intensity, warm temperature, and adequate soil moisture and nutrients. Wider spacing may result in minimum days required for fruit set compared to other interactions due to less competition for mineral nutrients and water between the plants. Higher fruit setting in plant under wider spacing might be due to greater photosynthetic activity because of exposure of more number of leaves to sunlight, while availability of poor sunlight to the

lower leaves of the plant at closer spacing becomes a limiting factor and adversely affects the flowering and fruiting. Research results are in accordance with the findings of [10];[46];[47];[48].

Silver black polyethylene mulch gave minimum days to fruit setting than other mulch materials. This might have been influenced by favourablecanopy temperature, soil temperature and moisture conditions provided by the silver black mulch. Moreover, it might also have improved the fruit set due to reduction of flower drop by minimizing the moisture stress. The results are in agreement with the observation of [13];[15];[49];[16];[53].

Table 4: Effect of spacing, mulch and spacing and mulch (S x M) interaction on days from first flower opening to fruit setting

Treatment	Days from first flower opening to fruit setting		
	2019-2020	2020-21	Pooled
Spacing(S)			
S_1	6.67^{d}	8.01^{d}	7.34^{d}
S_2	6.39^{c}	7.63^{c}	7.01^{c}
S_3	6.19^{b}	7.34^{b}	6.76^{b}
S_4	5.73^{a}	7.01^{a}	6.37^{a}
S_5	5.64^{a}	6.96^{a}	6.30^{a}
SEd(±)	0.09	0.07	0.05
CD(P=0.05)	0.18	0.14	0.12
Mulches (M)			
M_1	5.98^{b}	7.70^{c}	6.84^{c}
M_2	5.13^{a}	6.04^{b}	5.59^{b}
M_3	5.03^{a}	5.59^{a}	5.31^{a}
M_4	8.36^{c}	10.20^{d}	9.28^{d}
SEd(±)	0.08	0.06	0.05
CD(P=0.05)	0.16	0.13	0.10
Interaction (S x M)			

Treatment combination	2019-20	2020-21	Pooled	Treatment combination	2019-20	2020-21	Pooled
$T_1(S_1M_1)$	6.54	8.33	7.43	$T_{11}(S_3M_3)$	5.36	5.42	5.39
T_2 (S_1M_2)	5.68	6.83	6.25	T_{12} (S_3M_4)	8.24	10.24	9.24
T_3 (S_1M_3)	5.72	6.24	5.98	T_{13} (S_4M_1)	5.65	7.43	6.54
T_4 (S_1M_4)	8.75	10.63	9.69	T_{14} (S_4M_2)	4.74	5.45	5.10
$T_5(S_2M_1)$	6.25	7.78	7.01	T_{15} (S_4M_3)	4.33	5.27	4.80
T_6 (S_2M_2)	5.43	6.55	5.99	T_{16} (S_4M_4)	8.19	9.90	9.05
$T_7(S_2M_3)$	5.46	5.82	5.64	T_{17} (S_5M_1)	5.59	7.36	6.47
T_8 (S_2M_4)	8.44	10.36	9.40	T_{18} (S_5M_2)	4.53	5.34	4.94
T_9 (S_3M_1)	5.87	7.64	6.76	T_{19} (S_5M_3)	4.27	5.23	4.75
T_{10} (S_3M_2)	5.30	6.04	5.67	T_{20} (S_5M_4)	8.17	9.89	9.03

	2019-20	2020-2021	Pooled
SEd(±)	0.18	0.15	0.12
CD(P=0.05)	0.37	0.30	0.23

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4. CONCLUSION

The study exhibited that the optimum plant spacing and suitable mulch material had a considerable influence on crop growth, yield and quality of strawberry. The results indicated that 40 cm x 60 cm spacing with silver black mulch recorded maximum leaf area, Leaf Relative Water Content and minimum days from first flower opening to fruit setting. However, minimum number of days to appearance of first flower was obtained in 20 cm x 30 cm spacing with silver black mulch.

REFERENCES

1. Mahmood, M.M. and Al-Dulaimy, A.F. Response of strawberry cv. Festival to culture media and foliar application of nano and normal micronutrients. IOP Conf. Series: Earth Envt. Sci., 2021;904: 1-11.

2. Kijchavengkul, T.; Auras, R.; Rubino, M.; Gouajia, M. and Fernanadez, R.T. Assessment of aliphatic–aromatic copolyester biodegradable mulch films. Part I: Field study. Chemosphere, 2008; 71: 942-953.

3. Panse, V.G. and Sukhatme, P.V. Statistical Methods for Agricultural Workers, Indian Council of Agricultural Research, New Delhi.1985.

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

5. Li, Z. and Gao, Z.. Simulation of photosynthetic capacity of strawberry plants at different leaf ages. Adv. J. Food Sci. Technol., 2015;9(9): 735-740.

6. Begg, J.E. (). Morphological adaptations of leaves to water stress. In: Adaptations of plants to water and high temperature stress. Turner, N.C. and Kramer, P.J. (eds.). John Wiley and Sons, New York,1980; pp. 33-42.

7. Eberbach, P. and Pala, M. Crop row spacing and its influence on the partitioning of evapotranspiration by winter-grown wheat in northern Syria. Plant Soil, 2005;268: 195-208.

8. Narkar, N.D. Effect of spacing and plant growth regulators on growth and yield of Okra (Abelmoschusesculentus L. Moench) var. VarshaUphar. Ph.D Thesis submitted to DrBalasahebSawant Konkan KrishiVidyapeeth, Dapoli.2016.

9. Al Ramamneh, E.; Al Rawashdeh, Z.; Karajeh, M. and Abu-Romman, S. Plant response of strawberry to intra-row spacing and growing conditions in South of Jordan. Asian. J. Pl. Sci., 2013; 12(5): 201-207.

10. Hazarika, T.K.; Lalrinfeli, L.; Lalchhanmawia, J. and Nautiyal, B.P. Effect of planting density on growth, yield and quality of strawberry (Fragaria × ananassa) cv. Camarosa. Ind. J. Agril. Sci., 2019;89(3): 489-493.

11. Sonkar, P.; Ram, R.B. and Meena, M.L. Effect of various mulch materials and spacing on growth , yield and quality of Strawberry. Hort. Flora Res. Spectrum, 2012;1(4): 323-327.

12. Sharma, S.R. Effect of spacing and pinching on growth, flowering and yield of Chrysanthemum (Chrysanthemum coronarium L.) cv. Marry Mix. M.Sc (Hort) Thesis submitted to MaharanaPratap University of Agriculture & Technology, Udaipur.2007.

13. Ali, A. and Gaur, G.S. Effect of mulching on growth, fruit yield and quality of strawberry (FragariaananassaDuch.). The Asian J. Hort., 2007;2(1): 149-151.

14. Dwivedi, S.K.; Singh, B. and Elipaljor. Effect of mulch on establishment and growth of apple sapling in cold arid conditions of Ladakh. Progr. Horti., 2000;32(1): 42-45.

15. Kaur, P. and Kaur, A. Effect of various mulches on the growth and yield of strawberry cv. chandler under sub-tropical conditions of Punjab. Int. J. Recent Trends Sci. Techno.,2017; 25(1): 21-25.

16. Singh, R.; Sharma, R.R. and Jain, R.K. Planting time and mulching influenced vegetative and reproductive traits in strawberry (Fragaria x ananassaDuch.) in India. Fruits, 2005;60(6): 395-403.

17. Nishiyama, M. and Kanahama, K. Effect of light quality on growth of everbearing strawberry plants. Acta Hort., 2009;842: 151-154.

18. Decoteau, D. Leaf area distribution of tomato plants as influenced by polyethylene mulch surface color. Hort Technol., 2007; 17(3): 341-345.

19. Zahedi, S.M.; Moharrami, F.; Sarikhani, S. and Padervand, M. Selenium and silica nanostructure-based recovery of strawberry plants subjected to drought stress. Sci. Rep., 2020;10(1): 1-18.

20. Madhavi, B.G.K.; Khan, F.; Bhujel, A.; Jaihuni, M.; Kim, N.E.K.; Moon, B.E. and Kim, H.T. Influence of different growing media on the growth and development of strawberry plants. Heliyon.,2021; 7(6): e07170.

21. Lugojan, C. and Ciulca, S. Evaluation of relative water content in winter wheat. J. Hort. Fores. Biotechnol., 2011;15: 173-177.

22. Ober, E.S.; Bloa, M.L.; Clark, C.J.A.; Royal, A.; Jaggard, K.W. and Pidgeon, J.D. Evaluation of physiological traits as indirect selection criteria for drought tolerance in sugar beet. Field Crops Res., 2005;91: 231-249.

23. Archer, E. and Strauss, H.C. The effect of plant spacing on the water status of soil and grapevines. S. Afr. J. Enol. Vitic., 1989;10(2): 49-58.

24. Ahmed, B.E.A.M.; Abass, D.A.; Mohmmed, S.J. and Naiem, A.R.I. Response of physiological parameters and water use efficiency to water stress and plant population in Soybean (Glycine max L). Haya: Saudi J. Life Sci.,2017; 2(9): 362-365.

25. Sahoo, M.R.; Roy, S.S.; Singh, N.R.; Indrani Devi, Y.; Prakash, N. and Ngachan, S.V. (). Physiological and biochemical properties of sweet potato as affected by agronomic practices under sub-tropical North Eastern Hills of India. J. Root Crops, 2013;39(2): 117-122.

26. Shokri, B.; Ghaderi, N. and Javad, T. Effect of plastic mulch on some physiological and morphological characteristics of strawberry under drought stress. Iran. J. Hort. Sci., 2016; 46(4): 535-547.

27. Kaur, K.P. Effect of FYM levels and mulch sources on growth, productivity and water use of Brinjal (Solanummelongena) at varying irrigation depth. M.Sc (Agri) Thesis submitted to CSK Himachal KrishiViswavidyalaya, Palampur, India;2015.

28. Ahmad, S.; Raza, M.A.S.; Saleem, M.F.; Zahra, S.S.; Khan, I.H.; Ali, M.; Shahid, A.M.; Iqbal, R. andZaheer, M.S. Mulching strategies for weeds control and water conservation in cotton. ARPN J. Agril. Biol. Sci., 2015;10(8): 299-306.

29. Kesici, M.; Gulen, H.; Ergin, S.; Turhan, E.; Ipek, A. and NeziheKoksal, N. Heat-stress tolerance of some strawberry (Fragaria × ananassa) cultivars. Not. Bot. Hort. Agrobo.,2013; 41(1): 244-249.

30. Cansev, A. Physiological effects of high temperature treatments on leaves of olive cv. 'Gemlik'. Plant Arch.2012; 12: 521-525.

31. Díaz-Pérez, J.C.;Shackel, K.A. and Sutter, E.G. Effects of in vitro-formed roots and acclimatization on water status and gas exchange of tissue cultured apple shoots. J. Amer. Soc. Hort. Sci., 1995;120(3): 435-440.

32. Birhanu, A.; Tadesse, T. and Tadesse, D. Effect of inter- and intra-row spacing on yield and yield components of mung bean (*Vignaradiata* L.) under rain-fed condition at Metema District, northwestern Ethiopia. Agric. Food Secur.,2018; 7: 84.

33. Rajput, V.; Abhishek Kumar, J. and Tomar, S. (2020). Effect of pinching and spacing on flowering attributes of african marigold (Tageteserecta L.). Pl. Archv., 20: 516-519.

34. Bindu, R.H. Effect of plant growth regulators and spacing on growth, flower yield and carotenoid content of African Marigold (Tageteserecta L.) cv. PusaNarangiGainda. M.Sc. (Hort) Thesis submitted to Andhra Pradesh Horticultural Univ., Hyderabad;2010.

35. Khanna, K.; Arora, J. and Singh, J. Effect of spacing and pinching on growth and flower production of carnation (Dianthus caryophyllus) cv. Marguerite Scarlet. Ind. J. Hort.,1986; 43: 148-152.

36. Sharma, S.R. Effect of spacing and pinching on growth, flowering and yield of Chrysanthemum (Chrysanthemum coronarium L.) cv. Marry Mix. M.Sc (Hort) Thesis submitted to MaharanaPratap University of Agriculture & Technology, Udaipur; 2007.

37. Dhemre, J.K.; Shirsath, N.S. and Naphade, A.S. (). Effect of different plant densities and season on flowering of China aster. J. Soils Crops, 1997; 7(2): 136-138.

38. Niels, V. On-farm assessment of banana plant density in Rwanda. M.Sc Thesis submitted to Katholieke University, Leuven.2009.

39. Sarrwy, S.M.A.; Mostafa, E.A.M. and Hassan, H.S.A. Growth, yield and fruit quality of Williams Banana affected by different planting distances. Intern. J. Agril. Sci., 2012; 7: 266-275.

40. Sujatha, S. Studies on the influence of mulching on growth and yield of Strawberry (FragariaananassaDuch.) cv. Camarosa under shade net conditions. M.Sc. (Hort) Thesis submitted to Dr Y.S.R. Horticultural Univ., West Godavari;2016.

41. Singh, R. and Asrey, R. Growth, earliness and fruit yield of micro-irrigated strawberry as affected by planting time and mulching in semiarid regions. Ind. J. Horti., 2005; 62(2): 148-151.

42. Sharma, N.C.; Sharma, S.D. and Spehia, R.S. Effect of plastic mulch colour on growth, fruiting and fruit quality of strawberry under polyhouse cultivation. Int. J. Bio-res. Stress Mngt., 2013; 4(2): 314-316.

43. Singh, R.; Sharma, R.R. and Goyal, R.K. Interactive effect of planting time and mulching on Chandler strawberry (FragariaananassaDuch.). Scient. Hort.,2007; 111: 344-351.

44. Sujatha, S.; Suchitra, V.D.; Swami, V.; Subbaramamma, P.; Uma Krishna, K. and Saravanan, L. Influence of mulching materials on growth and yield of strawberry (FragariaananassaDuch.) cv. Camarosa under shadenet conditions of coastal Andhra Pradesh. Int. J. Agril. Sci., 2018;14(1): 219-224.

45. Black, B.L.; Swartz, H.J.; Deitzer, G.F.; Butler, B. and Chandler, C.K. (). The effects of conditioning strawberry plug plants under altered red/far red light environments. Hort. Sci.,2005; 40: 1263-1267.

46. Tariq, R.; Qureshi, K.M.; Hassan, I.; Rasheed, M. and Qureshi, U.S. Effect of planting density and growing media on growth and yield of Strawberry. Pak. J. Agric. Res.,2013; 26(2): 113-123.

47. Thakur, G.; Singh, A.K.; Maurya, P.K.; Patel, P. and Kumar, U. Effect of plant spacing on growth, flowering, fruiting and yield of Capsicum (Capsicum annuum L.) hybrid buffalo under natural ventilated polyhouse. J. Pharmacog. Phytochem., 2018;SP1: 78-81.

48. Zec, G.; Vulić, T.; Milatović, D.; Đorđević, B. and Čolić, S. The influence of planting density on characteristics of one-year old peach and nectarine shoots. Proc. IInd Balkan Symposium on Fruit Growing Eds.: M. Coman and E. ChituActa Hort. 981, ISHS. 2013; pp. 249-254.

49. Sharma, V.K. and Goel, A.K. Effect of mulching and nitrogen on growth and yield of strawberry. Int. J. Sci. Environ. Technol., 2017; 6(3): 2074-2079.

50. Prasad, M.; Minz, M.; Kumar, R. and Das, B. Effect of mulching and PGRs on growth, yield and economics of Strawberry (FragariaananassaDuch.) cv. Douglas. J. Interacad., 2012;16(1): 44-55.
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