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Effect of Plant density and Fertilizer Application Rates on Growth, Fruit Yield and Quality of Tomato (*Solanum lycopersicum* L.) in Greenhouse Condition

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Plant density and fertilization are key practices for improving the fruit quality and yield of vegetables grown in greenhouses. The experiment was performed to investigate the effects of density and fertilization on the fruit yield and quality, economic efficiency of *Solanum lycopersicum* L. at Duc Trong district of Lam Dong province. The density (50,000; 33,000; 25.000 plants ha^{-1}) and the fertilizer rates (240N – $100P_2O_5$ – $275K_2O$; 300N – $125P_2O_5$ – $344K_2O$; 360N – $150P_2O_5$ – $413K_2O$ kg and 420N – $175P_2O_5$ – $482K_2O$ kg ha^{-1}) were studied in a completely randomised split plot design with three blocks. The fertilizer rate (420N – $175P_2O_5$ – $482K_2O$ kg ha^{-1}) was produced the highest height (562.39 cm), fruit setting rate (69.87%), number of fruit per plant (95.65 fruits), average fruit weight (106.37 g), fruit yield (441.11 tons ha^{-1}) and marketable fruit yield (204.31 tons ha^{-1}). The density (25,000 plants ha^{-1}) gave the highest fruit setting rate (75.35%), number of fruit per plant (94.84 fruits), average fruit weight (113.24 g), individual fruit yield (10.02 kg per plant) and fruit yield (501.17 tons ha^{-1}). The combination of density (25,000 plants ha^{-1}) and fertilizer rate (420N – $175P_2O_5$ – $482K_2O$ kg ha^{-1}) have the highest fruit yield (613.5 tons ha^{-1}), marketable fruit yield (223.91 tons ha^{-1}) and rate of return (2.44). In addition, this combination was the best density and fertilizer level management strategy for greenhouse-grown Lahay 334 tomato cultivar in Lam Dong province, Vietnam.

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Keywords: Economic efficiency; fertilizer levels; fruit yield; plant density; tomato.

1. INTRODUCTION

The tomato (*Solanum lycopersicum* L.) is one of the most popular, nutritious, and palatable vegetables in the world [1-3]. It is very important vegetable crop which is cultivated and consumed in most parts of the world. Tomatoes are vary important for human health as they help in supplying a varying commixture of nutrients that are necessary for human health and nutrition [4]. In addition, tomatoes are rich in lycopene, which could improve the endothelial function of cardiovascular disease patients and reduce the risks of prostate cancer and possibly several other cancers [5].

In Vietnam, the tomato area is about 22 to 23 thousand hectares, of which Lam Dong is the locality with the largest tomato area, accounting for one-third of the total area of the country (7,000 - 8,000 hectares). On the other hand, Lam Dong has the advantage of climate, which is very suitable for tomato plants to grow and develop all year round. Practice shows that tomato fruit yield depends not only on biological factors but also largely on environmental conditions [6-7]. Amongst environmental conditions, plant spacing and nutrient status are two major factors affecting the vegetative growth and the reproductive phase of tomatoes. Therefore, optimum plant density and fertilizer rate can significantly enhance fruit yields.

Plant spacing has a profound effect on the growth performance and yield of tomato. Plants subjected to high plant density can result in a decreased growth rate due to reduced light interception per plant [8]. Under higher plant density, an inadequate supply of photosynthesis due to shading will become detrimental to fruit set [10]. In an optimal space, plants can efficiently utilize light, water, and nutrients, and inter- or intraspecific competition should be at a minimum. An optimum density ensures proper plant growth and development resulting in maximized yield and economic use of land. Manipulation of plant spacing is a method used to increase light interception, and efficient use, in tomato production [10-13].

The soil nutrient status is another important factor in the limitation of fruit yield in greenhouse vegetables [14-15]. Inorganic fertilization is one of the classical agronomic practices used in agricultural systems, with the aim of increasing soil fertility, crop yield, and agricultural sustainability [16-21]. Therefore, selecting suitable fertilizer rates to maximize fruit yield with an optimal plant spacing is an objective of both producers and agronomists. Although much information is available on the combination of irrigation and fertilization controlling fruit yield and quality traits [22-28] very little is known about the growth, fruit yield and fruit quality of tomato are affected by the coupling of density and fertilizer application rates.

This study was carried out to understand the influence of density and fertilizer rate on growth, yield, quality and economic efficiency of tomatoes grown in greenhouse condition at Lam Dong province, Vietnam.

2. MATERIALS AND METHODS

2.1 Site Description

The field experiment was conducted in greenhouse condition at the Duc Trong district, Lam Dong province, Vietnam ($11^0 41' 50''$ N , $108^0 18' 58''$ E , altitude of 1400m above the sea level) from October 2019 to April 2020. The temperature, light and photo synthetically active radiation, relative humidity and solar radiation inside the greenhouse were recorded using an automatic weather station which was located in the centre of the greenhouse. The greenhouse was oriented east-west, with an area of 720 m^2 (12 treatments, 3 replications, 20 m^2 per spot). Two rows of tomato plants were transplanted on the bed top on 8 Oct 2019. Furrow-film mulch was cultivated using the local traditional planting patterns and calendars using tomato ridging in a tube with a two-line layout.

2.2 Experimental Design

The experiment was set up as two - way factorial combination, the main factor was the density whilst another one was fertilizer rate, and was designed by Split Plot Design with 12 treatments and 3 replications. The density was divided into 3 levels: D1- 50,000 plants/ha, D2- 33,000 plants/ha and D3- 25,000 plants/ha. The additional fator was fertilizer rate which was set up in 4 rates as 240N – $100P_2O_5$ – $275K_2O$ kg ha^{-1} (F1), 300N – $125P_2O_5$ – $344K_2O$ kg ha^{-1} (F2), 360N – $150P_2O_5$ – $413K_2O$ kg ha^{-1} (F3), and 420N – $175P_2O_5$ – $482K_2O$ kg ha^{-1} (F4).

Each treatment plot received the same rates of cow dung (40 tons ha^{-1}) and lime powder (1 ton ha^{1}) being applied before planting. Urea (N 46.4%), superphosphate (P2O5 44%), and potassium chloride (K2O 50%) were used for the fertilization. The whole fertilizer was divided into 5 applications, with the first application being at 15 days after transplanting (DAT) (10%), the second 25 DAT (10%), the 3th 35 DAT (10%), the 4th 45 DAT (15%), and the last (55%) throughout the harvest period (7 days per time). The drip line consisted of an inserted cylinder head, a drip irrigation pipe with an inner diameter of 8 mm, a drop head span of 45 cm, a head flow of 1.38 L h-1, and a drip irrigation operating pressure of 0.3 Mpa.

Tomato seed (cv. Lahay 344) of indeterminate growth habit were sown in 200 cavity polystyrene trays filled with Hygromix to produce transplants according to methods described by Maboko and Du Plooy [29].

2.3 Growth, Yield and Yield Components

Plant height (cm) was the only physiological characteristics of tomato measured while the following yield components analysis were determined: (i) fruit set (%); (ii) average fruit weight (g); (iii) number of fruit per plant; (iv) individual fruit yield (kg per plant); (v) fruit yield (tons per ha); and (vi) marketable fruit yield (ton per ha).

2.4 Measurement of Fruit Quality

The fruit quality was measured during the third fruit enlargement period. For each measurement, five fruits of similar size and maturity and with no external defects were chosen from each plot. The brix content was measured using a digital refractometer (Link Co. Ltd., Taiwan), the nitrate concentration (NC) was measured using ultraviolet-spectrophotometry.

2.5 Statistical Analysis

An analysis of variance was conducted on the parameters of growth and yield components such as plant height, average fruit weight, number of fruit per plant, individual fruit yield, fruit yield, marketable fruit yield and Brix content using a two-way analysis of variance (GLM procedure in SAS version 9.2, SAS Institute Limited, North Carolina, USA). Tukey's HSD multiple range test results were considered significant at $P \leq 0.05$.

3. RESULTS

3.1 Effect of Plant Density and Fertilizer Levels on Plant Height Lahay 334 Tomato Cultivar

The results showed that the mean plant height of tomato planted at different density increased with time, showing significant differences from 60 – 180 days after transplanting (DAT), especially highly significant differences ($P \leq 0.01$) at the age of 120 and 150 DAT. The D1 (50,000 plants ha^{-1}) gave the highest average height (554.66 cm) followed by the D2 (33,000 plants ha^{-1}) then the D3 (25,000 plants ha^{-1}) (Table 1). An increase in plant height was observed with the presence of fertilizer levels, however, the difference was not statistically significant ($P > 0.05$). There was not interaction between the plant density and fertilizer levels for height of tomato during period of growth time.

3.2 Effect of Plant Density and Fertilizer Levels on Fruit Set, Fruit Number, Fruit Weight and Fruit Yield Lahay 334 Tomato Cultivar

The results (Table 2) showed that there was a significant difference ($P \leq 0.01$) in the fruit set rate of tomatoes at different densities and fertilizer levels. The higher the density, the lower the fruit setting rate. When planted at the density of 25,000 plants ha^{-1} on different fertilizer levels, tomatoes had the highest fruiting rate (75.35%) and the lowest was when planting at a density of 50,000 plants ha^{-1} (57,37%). Between the density of 25,000 plants ha^{-1} compared with 50,000 plants ha^{-1}, the fruiting rate is 18% different. This shows that when planting plants at high density, the rate of fruit set is severely reduced, due to the crowded population, many ineffective flower clusters, and the rate of flower drop is very high. The different fertilizer levels gave different fruit set at a significant difference ($P \leq 0.01$). The fertilizer treatments of F3 (360 N – 150 P2O5 - 413 K2O kg ha^{-1}) and F4 (420 N - 175 P2O5 - 482 K2O kg ha^{-1}) had a higher fruit set than the other ones (69,16 and 69,87%), respectively. However, there was not interaction between plant density and fertilizer levels on fruit set of Lahay 334 tomato cultivar in greenhouse condition.

Number of fruits per plant is an important indicator to get high individual yield. The results showed that the interaction between plant density and fertilizer levels for number of fruits per plant was statistically significant (P<0.01). The treatment of low density produced number of fruits per plant higher than that of high density. In term, the treatment with 25,000 plants ha^{-1} gave the highest fruit number per plant (94.84 fruits per plant), followed by treated with 33,000 plant ha^{-1}, 50,000 plant ha^{-1} with values of 73.55; 69.09 fruits per plant, respectively. In contrast, the number of fruits per plant in different fertilizer treatments increased with the increase of fertilizer level, the F4 fertilizer treatment gave the highest number of fruits per plant (95.65 fruits per plant) compared with the other treatments of F3 (85.73 fruits per plant); F2 (73.34 fruits per plant) and F1 (61.92 fruits per plant). The combination with the F4 fertilizer level and the density of D3 had the highest number of fruits per plant (119.74 fruits per plant).

Table 1. Effect of plant density and fertilizer levels on height of Lahay 344 tomato cultivar

DAT	Density	Fertilizer levels				
		F1	**F2**	**F3**	**F4**	**Average**
90	D1	232.89	239.45	248.13	264.29	246,19 a
	D2	213.28	265.72	235.77	257.42	243,05 a
	D3	205.68	226.16	216.88	205.27	213,50 b
	Average	217.29	243.78	233.59	242.32	
	CV(%): 11.61		F_D: 1.28*	F_F: 1.28^{ns}	F_{DF}: 0.8^{ns}	
120	D1	323.81	329.75	345.06	342.44	335,27 a
	D2	356.6	362.91	331.49	372.14	355,79 a
	D3	291.27	307.95	294.87	305.33	299,86 b
	Average	323.89	333.54	323.81	339.97	
	CV(%): 6.31		F_D: 22.06**	F_F: 1.29^{ns}	F_{DF}: 0.98^{ns}	
150	D1	433.68	454.3	466.72	443.76	449,61 a
	D2	404.77	460.95	438.73	470.96	443,85 ab
	D3	393.45	413.61	401.36	413.05	405,37 b
	Average	410.63	442.95	435.6	442.59	
	CV(%): 7.81		F_D: 6.07**	F_F: 1.83^{ns}	F_{DF}: 0.6^{ns}	
180	D1	520.98	546.67	577.49	573.49	554,66 a
	D2	509.01	547.47	550.33	589.42	549,06 a
	D3	524.78	502.6	510.46	524.25	515,52 b
	Average	518.26	532.25	546.09	562.39	
	CV(%): 7.12		F_D: 3.64*	F_F: 2.17^{ns}	F_{DF}: 0.83^{ns}	

In the same average group, the values with the same accompanying characters do not have statistical significance P <0.05; ns: none significant; * significant difference (p<0.05); ** significant difference (p<0.01)

Table 2. Effect of plant density and fertilizer levels on yield components of Lahay 344 tomato cultivar

	Density	Fertilizer levels				
		F1	**F2**	**F3**	**F4**	**Average**
Fruit set (%)	D1	58.15	52.97	58.92	59.45	57.37 c
	D2	67.76	66.11	69.14	73.7	69.18 b
	D3	69.98	75.53	79.43	76.45	75.35 a
	Average	65.30 b	64.87 b	69.16 a	69.87 a	
	CV(%): 4.92		F_D: 103.66**	F_F: 6.2**	F_{DF}: 2.25^{ns}	
No fruits per plant	D1	56.91 g	67.25 efg	73.00 def	79.21 cde	69.09 b
	D2	61.23 fg	67.15 efg	77.83 cde	88.00 c	73.55 b
	D3	67.62 efg	85.63 cd	106.36 b	119.74 a	94.84 a
	Average	61.92 d	73.34 c	85.73 b	95.65 a	
	CV(%): 8.82		F_D: 46.53**	F_F: 39.7**	F_{DF}: 3.37**	
Average fruit weight (g)	D1	90.2	90.17	94.06	95.97	92.60 c
	D2	93.61	94.84	100.95	106	98.85 b
	D3	105.86	113.53	116.41	117.15	113.24 a
	Average	96.56 c	99.51 b	103.81 a	106.37 a	
	CV (%): 2.9		F_D: 152.9**	F_F: 19.6**	F_{DF}: 1.81^{ns}	

In the same average group, the values with the same accompanying characters do not have statistical significance P <0.05; ns: none significant; * significant difference (p<0.05); ** significant difference (p<0.01)

The results summarized in Table 2 indicated that treatment with 25,000 plants per hectare had the maximum average fruit weight (113.24 g), whereas the lowest average fruit weight 92.6 g was recorded in control treatment (50,000 plants per hectare) at statistically significant difference ($P \leq 0.01$). It seems that low plant density gave the highest fruit weight compared to high plant density. Furthermore, using F3 and F4 fertilizer level for three density treatments produced the average fruit weight (103.81 and 106,37g) respectively ($P \leq 0.01$).

The plant density and fertilizer levels effects on yield characteristics (individual fruit yield, fruit yield and marketable fruit yield) during the year of the experiments are summarized in Table 3. The individual treatments of plant density or fertilizer levels significantly ($P \leq 0.01$) affected the yield characteristics, significantly affected individual fruit yield and marketable fruit yield (Table 3). The interactions between the plant density and fertilizer levels were recorded as being highly significant ($P \leq 0.01$) for the yield characteristics, but there was no significant interaction between the plant density and fertilizer levels for the fruit yield (Table 3). The data showed that yield characteristics were more sensitive to fertilizer rates than plant density.

Averaging across fertilizer rates, the plant density of D1 and D2 decreased individual fruit yield by 42.2% and 39.12%, compared to D3; averaging across plant densities, F1, F2 and F3 were 35.94%, 24.82% and 7.82% lower than F4 (Table 3). In the F4 treatment, individual fruit yield in D1 and D2 was 43.19% (6.97 kg/plant) and 41.07% (7.23 kg/plant) lower than in D3 (12.27 kg/plant), respectively. On average over the four fertilizer rates, fruit yield in D3 (501.17 tons/ha) was higher than D2 (305.08 tons/ha) and D1 (290.17 tons/ha) (Table 3). Overall, fruit yield was greater in the D3F4 treatment than in the other treatments; fruit yield increased with a decreasing planting density (averaging across the fertilizer application rate) or an increasing fertilizer application rate (averaging across the density treatments).

For marketable fruit yield, in the F4 treatment, marketable fruit yield in D1 and D2 was 204.69 (tons/ha) and 184.33 (tons/ha) lower than in D3 (223.91 tons/ha), respectively. On average over the four fertilizer rates, marketable fruit yield in D3 (188.52 tons/ha) was higher than D2 (167.78 tons/ha). Overall, fruit yield was greater in the D3F4 treatment than in the other treatments; fruit yield increased with a decreasing planting density (averaging across the fertilizer application rate) or an increasing fertilizer application rate (averaging across the density treatments).

3.3 Effect of Plant Density and Fertilizer Levels on Fruit Quality of Lahay 334 Tomato Cultivar

The effects of density and fertilization on the brix and nitrate contents in the growing season of the experiment are summarized in Table 4. The interactions between density and fertilization were an important factor for the brix contents; however, there was no significant interaction between density and fertilization in relation to brix content (5.2 – 5.5%) (Table 4). The nitrate concentration values ranged from 52.0 to 115.0 mg kg^{-1} in the growing seasons under different density and fertilizer treatments (Table 4). In the same density, nitrate concentration increased with an increasing fertilizer application rate or in the same fertilizer rate, nitrate concentration increased with a decreasing planting density. The highest mean nitrate concentration was 115.0 mg kg^{-1} in the D3F4 treatment, which was significantly higher than in the other treatments. However, there was not interaction between plant density and fertilizer levels on nitrate concentration of Lahay 334 tomato cultivar in greenhouse condition.

3.4 Effect of Plant Density and Fertilizer Levels on Economic Efficiency of Lahay 334 Tomato Cultivar

The results of Table 5 showed that different plant densities gave benefit/cost (B/C) that were inversely proportional to production costs. The density D1 gave a lower B/C than the density D3 from 0.7 to 1.1 times. In contrast, for the fertilizer levels, when increasing the fertilizer level on different densities, the B/C increased from 0.1 to 0.7 times. Planting tomatoes at density D3 combined with F3 or F4 fertilizer level gave B/C of from 2.3 to 2.4 times.

4. DISCUSSION

The results showed that there was interaction between the plant density and fertilizer levels for height of tomato ($P \leq 0.05$). In this study the plant height of tomato increased with increase in plant density combined with increased fertilizer level. The optimum plant density for optimal plant

Table 3. Effect of plant density and fertilizer levels on fruit yield of Lahay 344 tomato cultivar

	Density	Fertilizer levels				
		F1	**F2**	**F3**	**F4**	**Average**
Individual fruit yield (kg/plant)	D1	4.54 f	5.39 ef	6.32 dce	6.97 c	5.80 b
	D2	5.00 f	5.52 def	6.65 cd	7.23 c	6.10 b
	D3	7.42 c	8.98 b	11.43 a	12.27 a	10.02 a
	Average	5.65 d	6.63 c	8.13 b	8.82 a	
	CV (%): 6.79		F_D: 69.44**	F_F: 75.13**	F_{DF}: 5.82**	
Fruit yield (tons/ha)	D1	226.83	269.33	316.17	348.33	290.17
	D2	249.83	276.17	332.67	361.67	305.08
	D3	371	448.83	571.33	613.5	501.17
	Average	282.56	331.44	406.72	441.17	
	CV (%): 9.81		F_D: 96.13ns	F_F: 78.15ns	F_{DF}: 13.62ns	
Marketable fruit yield (tons/ha)	D1	176.62 de	185.96 cd	195.51 bc	204.69 b	190.70 a
	D2	150.20 fg	162.64 ef	173.95 de	184.33 cd	167.78 b
	D3	138.51 g	178.67 cde	213.00 ab	223.91 a	188.52 a
	Average	155.11 c	175.75 b	194.15 a	204.31 a	
	CV(%): 4.17		F_D: 33.14**	F_F: 72.86**	F_{DF}: 11.35**	

*In the same average group, the values with the same accompanying characters do not have statistical significance P <0.05; ns: none significant; * significant difference (p<0.05); ** significant difference (p<0.01)*

Table 4. Effect of plant density and fertilizer levels on fruit quality of Lahay 344 tomato cultivar

	Density	Fertilizer levels				
		F1	**F2**	**F3**	**F4**	**Average**
Brix (%)	D1	5.31	5.32	5.65	5.26	5.39
	D2	5.47	5.40	5.51	5.42	5.45
	D3	5.33	5.32	5.30	5.52	5.37
	Average	5.37	5.35	5.49	5.40	
	CV(%): 5,09		F_D: 0.29ns	F_F: 0.43ns	F_{DF}: 0.67ns	
Nitrate (mg/kg)	D1	52	57	58	82	62.2
	D2	72	75	84	93	81.0
	D3	92	97	104	115	102.0
	Average	72.0	76.3	82.0	96.6	
	CV(%): 12.3		F_D: 48.53ns	F_F: 33.7ns	F_{DF}: 2.37ns	

In the same average group, the values with the same accompanying characters do not have statistical significance P <0.05; ns: none significant

Table 5. Effect of plant density and fertilizer levels on economic efficiency of Lahay 344 tomato cultivar

Treatment	Marketable fruit yield (tons ha^{-1})	Total income (VND ha^{-1})	Cost (VND ha^{-1})	Benefit (VND ha^{-1})	B/C
D1F1	176.62	1.059.720.000	514.639.000	545.081.000	1.06
D1F2	185.96	1.115.760.000	518.270.500	597.489.500	1.15
D1F3	195.51	1.173.060.000	521.894.500	651.165.500	1.25
D1F4	204.69	1.228.140.000	525.490.000	702.650.000	1.34
D2F1	150.20	901.200.000	467.039.000	434.161.000	0.93
D2F2	162.64	975.840.000	470.670.500	505.169.500	1.07
D2F3	173.95	1.217.650.000	474.294.500	743.355.500	1.57
D2F4	184.33	1.290.310.000	477.890.000	812.420.000	1.70
D3F1	138.51	969.570.000	444.639.000	524.931.000	1.18
D3F2	178.67	1.250.690.000	448.270.500	802.419.500	1.79
D3F3	213.00	1.491.000.000	451.894.500	1.039.105.500	2.30
D3F4	223.91	1.567.370.000	455.490.000	1.111.880.000	2.44

VND: Vietnam dong

competition, optimum use of light, water and nutrients, will produce more yields [30]. Moreover, plant density affects most of growth parameters of crops even under optimal growth conditions and therefore it is considered a major factor in determining the degree of competition between plants [31]. It is possible that increase in plant height following the decrease of plant spacing was brought about by the increase in the inter plant competition over light and the disruption of balance of growth regulators. It has been shown that the decrease in light penetration into middle and lower layer decrease auxin decomposition and thus plant height increases [32]. Similar findings have been reported by authors [33-35] who working with planting spacing of tomato. Gasim [36] reported that increase in plant height as result of increase in compound fertilizer is due to the fact that nitrogen promotes plant growth, increases number of internodes and length of internodes which result in progressive increase in plant height. However, plants that were grown in a wider spacing and reduced fertilizer applied resulted in shorter plants. This could be attributed to insufficient amounts of nutrients required to facilitate increase in plant height or might be due to minimal or no competition of light which is very important for photosynthesis; this is because when plant are crowded they tend to strive to access available light. Similar findings have been reported by Adekiya and Agbede, [37] who observed that NPK fertilizer significantly increased plant height in tomato compared to the control.

In this study plant density and fertilizer level applied influenced the fruit set, the number of fruit per plant, average fruit weight, individual fruit yield, fruit yield, marketable fruit yield and fruit quality of tomatoes. Number of fruits per plant, average fruit weight, individual fruit yield, fruit yield and marketable fruit yield increased with increase in fertilizer level combined with reduced plant density. This might be due to the fact that less space available with more competition for soil nutrient, moisture and less light, might result to low photosynthetic activity and reduced growth and development. This resulted to smaller fruit as compared to wider spacing which has more nutrients and solar radiation which accelerate anabolic processes and ultimately the fruit size will be increased. The application of 420N – $175P_2O_5$ – $482K_2O$ kg ha^{-1} seems to have resulted to synthesis of more carbohydrate by virtue of having more source foliage which accelerates the fruit formation as compared to lower dosage of fertilizer. According to Streck *et al*., [38] the potential size of tomato fruit depends on their position in the inflorescence and the cultivar, but the size they reach also depends on the total of assimilates produced by photosynthetic tissues and the number of fruit that compete for these assimilates. Plant density management influences the balance between vegetative and reproductive growth of the tomato plant, as it affects the penetration of solar radiation inside the canopy and thus photosynthesis. Changes in the power of the sources, through a change in planting density or increasing the availability of radiation, indirectly affect the distribution of dry matter between plant organs [39]. According to Larcher [40], the total of assimilates of a plant is directly proportional to photosynthesis, which is a function of the flux density of solar radiation, the atmospheric CO2 concentration and leaf area. In this sense, increasing density causes a reduction in leaf area per plant and increased shading, and it is expected that the fresh fruit mass decreases with increasing plant density, which is observed in table 2,3. Our results are consistent with Paththinige *et al.,* [41], Wamser *et al*.,[44] Tiago Luan Hachmann *et al*., [43] who reported that, in most vegetables crop, appropriate plant spacing and fertilizer level lead to optimized plant growth and fruit yield whereas too high or low fertilizer and plant spacing could result in relatively lower yield and poor fruit quality.

5. CONCLUSIONS

Our results demonstrated a positive correlation between plant density and fertilizer levels. The individual factors of the plant density or fertilizer level, along with their interaction significantly affected the number of fruit per plant, individual fruit yield and marketable fruit yield. Interestingly, average fruit weight, individual fruit yield, fruit yield and marketable fruit yield were more sensitive to fertilizer than to density. Considering the trade-off amongst fruit yield, fruit quality and economic efficiency, D3F4 was the best density and fertilizer level management strategy for greenhouse-grown Lahay 334 tomato cultivar in Lam Dong province, Vietnam.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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