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Evaluating Vertical and Horizontal Distance for Vertically Farming Tomatoes (*Solanumlycop ersicum* L.) in Urban Agriculture, Daye Town, Sidama Region, Ethiopia

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Abstract: One of the most important realities of today and the future is that the number of people living in urban areas across the world is greater than that of rural areas. Implementing measures at the city level that challenge current food systems and improve urban sustainability are time sensitive and necessary, and has led to a search for sustainable and alternative methods of urban food production. Urban agriculture can be done in open and closed areas including vertical garden. The field experiment was conducted under vertical garden at Daye town, in sidama region, Ethiopia in 2022 cropping season to determine the optimum vertical and horizontal distances for tomato production under vertical garden. The experiment was laid out in Randomized Complete Block Design with factorial arrangement with three replications and consisted two vertical distances (40 cm and 50 cm) to ward vertical and two horizontal distances (50cm, and 60cm) with Total of 4 treatments combination. Interaction effects influenced days for all phonological parameters, growth, yield and yield components. 40 cm toward vertical with 60 cm toward horizontal spacing exhibited the highest tomato fruit yield (68.73 kg per structure). The highest marginal rate of return (MRR%), 5592.9 was recorded from 40 cm toward vertical with 60 cm toward horizontal spacing under this vertical garden on tomato production. Given the fact that fruit yield performance between the two vertical spacing in combinations two horizontal spacing, 40 cm toward vertical with 60 cm toward horizontal spacing is recommended for tomato production under vertical garden of Daye town and similar agro-ecologies in the midlands towns of Ethiopia.

Keywords: Interaction Effect, Tomato, Urban Agriculture, Vertical Garden, Vertical Spacing

1. Introduction

Urban agriculture can be implemented in many methods. These differences can lead to interchange of urban agriculture attitudes. Although these concepts are closely related, they may have different characteristics and ways of implementation. For instance, urban agriculture can be under controlled and uncontrolled areas including vertical garden [1]. In some studies, vertical production is defined as a sustainable garden system where only crops are grown outdoors and / or indoors and methods used in vertical farming seeks to enhance food and nutrient security, environmental protection whereas reducing air, soil and water pollution and enhance city beautification while maintaining or increasing levels of production [2]. Also vertical garden is defined as a sustainable crop growing system where only crops are grown outdoors and / or indoors [3]. According to the United Nations (UN), the current world population of 7.6 billion is expected to reach 9.8 billion by 2050 and 11.2 billion in 2100 [4]. To supply food the world by 2050, the FAO estimates that food production will have to increase by 70% from 2007 levels [5]. One of the most important facts of today and the future is that the number of people living in urban areas in the world is greater than that of rural areas. Urban farming is a town, city located in and around the residential area, mainly using human and material resources, goods and services; and it is defined as an industry that supplies human and material resources and goods and services to the urban area [1]. The fact that vertical garden enterprises are located in the city reduces transportation costs considerably and thus, both carbon emission and food losses during transportation can be reduced considerably [6]. One of the most important contributions of vertical garden to supply food, it provides production opportunities throughout the year [7]. Tomato is one of the vegetables with the highest production in the world and its production is increasing all over the world [8]. Although the importance of tomatoes in the daily diet of the people and ever increasing demand for this crop, fresh tomatoes supply during the rainy period is limited and the price climbs up [9]. Home gardening of vegetables in small land plots or in containers has been promoted in the African Great Lakes Region notably for tomatoes, onions, and cabbages. In countries Ethiopia vertical gardening is known as new and it should be promoted in urban areas as part of a national strategy to improve human nutrition. Moreover, given the land scarcity and long distances from the production areas, backyards of urban residences could contribute fresh tomato to urban consumers. However, very little is known about the productivity of tomatoes in a sunlight-dependent vertical farming technology. In addition, the appropriate vertical and horizontal spacing with locally available growth structure has not yet been documented for such a system. Therefore, this study was aimed at evaluating the productivity of tomatoes in a two-level vertical distance and two- levels of horizontal distances using growth structure made of locally available materials with different vertical distances in Daye town, Sidama Region, Ethiopia.

2. Materials and Methods

2.1. Description of Study Site

This study was conducted at Daye District, in Sidama Region, Ethiopia during the main cropping seasons of 2021/2022. Daye District is located at 38° 27'44''E longitude and 06° 26'59'', N latitude. The altitude of the experimental site is 1452 to 3129 meter above sea level. The climate of the site is sub-humid type with bi-modal rainfall pattern. The main rainy season is extends from June to September and the area receives an annual rainfall of 1208.5mm. The average annual temperatures of the area is 19°C. The dominant soil type is loam. According to Ethiopian agro-ecological classification the area is grouped under midland with intensive rainfall. The area is potential to grow pulse, cereals and horticultural crops. Among the vegetable crops, the major crops grown in the area, tomato is one.

2.2. Experimental Materials

Roma-VF tomato variety was used as planting material. The seed was obtained from Daye Town Administration Agricultural office, Horticulture Department. It was selected based on its adaptability and high yielding potential under rain fed and irrigation. It was released from Melkasa Agricultural Research Center (MARC) in 2007. It is a determinate type with pear-shaped fruit preferred by most farmers in the study area. Blended fertilizer in the form of NPS (19% N, 38% P_2O_5 and 7% S) and N fertilizer in the form of urea (46% N) were used for the study.

2.3. Treatments, Experimental Design and Procedures

Factorial experiment consisting of two vertical distances (40 cm and 50 cm) to ward vertical and two horizontal distances (50cm, and 60cm) with Total of 4 treatments combination was laid out in RCBD with three replications. The spacing between plots and block was 1 m and 2m, respectively. The plot size was 2.5 x 2.5 m (6.25 m^2). A wood-made structure was built. The vertical spacing was randomly distributed in the plots (wood structures). Better Boy tomato variety was planted by container. Watering was done throughout the dry season to the rainy season. In addition, weeding was done manually by picking and removing undesired plant species from containers.

2.4. Data Collected

2.4.1. Phenological Data

Days to 50% flowering was recorded as the number of days from sowing date to the date when at least 50% of the plants had at least one open flower. Days to physiological maturity was recorded at the number of days from sowing date to the date when at least 90% of plants had at least one fruit ripened and color was changed from green to yellow or red.

2.4.2. Growth, Yield and Yield Components

The plant height was measured from the ground level to the highest tip for the five sampled and tagged plants. This was done using a meter at interval of 7 days up to harvest maturity and the average plant height was calculated for each treatment. The number of leaves was recorded by counting the number of leaves at interval of 7 days for the period of 5 consecutive weeks from the day of transplanting and average of each treatment computed. The number of primary and auxiliary branches was recorded at physiological maturity, when all plants had ceased growth, branches of five sampled and tagged from each plots was counted and average computed. Number of fruit per cluster was recorded by counting the number of fruits per cluster at maturity and average of each treatment computed. The fruit weight with gram was recorded as average weight of each five randomly selected ripe fruits from five tagged plants from central rows.

Fruit diameter was recorded as average fruit diameter of five fully grown fruits from central row from five tagged plants. Fruit yield have been determined by harvesting fruit from net each structure of each treatments and resulting weights in kilo- gram.

3. Results and Discussions

3.1. Crop Phenology

3.1.1. Days to 50% Flowering

Days to 50% flowering of tomato was highly significantly ($p<0.01$) affected by the interaction effect of different vertical and horizontal distances (Table 1). The longest day to reach days to 50% flowering (76.33) was recorded at 50 cm vertical and 60 cm horizontal spacing. But statistically similar to that 50 cm veridical X 60 cm horizontal and 50 cm vertical X 50 cm horizontal distances under this vertical garden. Similarly, Shushay *et al*., also found that a combination of 30 cm intra row and 120 cm inter-row spacing took the earliest (48 days) while 30 cm intra-row and 60 cm inter-row space took the longest (52 days) time to reach days to 50% flowering. Generally, as the vertical and horizontal distances spacing increases from 40 cm to 60 cm, days to 50% flowering showed an increasing trend. Tomato plants with narrow intra-row spacing flowered and gave fruits earlier than plants with wide spacing. Since competition for light and nutrient was relatively low in plants with wide intra-row spacing, vegetative growth could be favored that eventually caused delay in flowering [9].

3.1.2. Days to Maturity

Days to maturity of tomato was highly significantly ($p<0.01$) affected by the interaction effect with different vertical and horizontal distances (Table 1). The highest number of days to maturity (336 days) was observed at 50 cm veridical X 60 cm horizontal and which is statistically similar to that 40 cm vertical X 60 cm horizontal distances spacing. The lowest days (129.33) was recorded at 40 cm vertical X 50 cm horizontal spacing. In the same way, Shushay *et al.,* [3] also reported that 40 cm intra-row spacing took the highest number of days (92 days) to mature. Generally, as the row spacing increased in vertical garden showed an increasing trend in days. The report have shown highest number of days to maturity (86 days) was observed at 45 x 45 cm row spacing whereas the lowest maturity (84 days) took at 45 x 30 cm spacing [10].

Table 1. *Interaction effect of with regarding for days for flowering and physiological maturity.*

Treatments	DF	DM
40 cm Vertical X 60 cm Horizontal	76.33a	135a
40 cm Vertical X 50 cm Horizontal	71b	129.33c
50 cm Vertical X 60 cm Horizontal	75.33ab	136a
50 cm Vertical X 50 cm Horizontal	72.33ab	132.33b
CV	3.71	1.03
LSD	5.15	2.6

3.2. Growth Yield and Yield Components

3.2.1. Plant Height

Analysis of variance showed that plant height was significantly ($P\leq0.001$) affected by interaction effect (Table 2). In plant height, mean value of vertical and horizontal distances ranged from 75.57 cm to 47.27cm. A longer plant height of 75.57cm was recorded from combination of 40cm toward vertical and 50cm toward horizontal distanced treatment. The shorter plant height was recorded from 50cm toward vertical and 60cm toward horizontal distanced treatment. The variation in the response may be due to computation to light. Generally, the increase of vertical and horizontal distance from 40 cm to 50 cm and 50 cm to 60 cm decreased the mean plant height. Increases in plant height at closer vertical and horizontal spacing are likely to be associated with more competition among plants for solar radiation. Tomato plants' stems, as they grow and develop from seedlings to maturity, naturally seek light [11]. If the plants are growing in an area of low light intensity, and there is higher intensity light nearby, the tomato plant's stems grow toward the higher intensity light. Where there is inadequate light all around, the stems grow to be long, spindly and become etiolated. The higher growth of plants on narrow spaced treatments implies the insufficiency of sunlight and their elongation is an attempt to expose to as much energy as possible. Studies have indicated that differences resulted from the difference in daily light integral received by plants growing on the two superimposed beds on plant height [12].

3.2.2. Number of Leaves Per Plant

The analysis of data revealed significant difference ($P \leq 0.001$) due to interaction effects of vertical distance with horizontal distance on number of leaves per plant for vertical growing tomato. Greater mean number of number of leaves per plant was recorded from 4o cm to vertical treated with 60 cm horizontal distance. The lower mean number of leaves per plant was recorded from 40 cm with combination of 50 cm horizontal (Table 2). These due to tomatoes are sun-loving plants that do best when they receive full sun for the majority of the day. When plants are spaced too closely, they grow tall as they reach for the light, developing long, scrawny branches that tend to be weak. Internodes, the spaces on stems between leaves, are unusually long under these conditions. When crowding interferes with access of the plants to sun, leaves are small and low. This is in agreement with Maboko *et al*., [13] who reported significant difference among spacing of Tomato yield and yield components have been greatly affected. The leaf number increased with increasing plant spacing due to greater biomass allocation to the stem [14].

Table 2. *Interaction effect of vertical and horizontal spacing on plant height and number of leaves per plant.*

Treatments	Plant height (cm)	Number of leaves per plant
40 cm Vertical X 60 cm Horizontal	53.54c	34.66a
40 cm Vertical X 50 cm Horizontal	83.95a	18d
50 cm Vertical X 60 cm Horizontal	47.27d	26c
50 cm Vertical X 50 cm Horizontal	75.57b	29b
Interaction	**	***
CV	3.73	3.39
LSD	4.58	1.71

3.2.3. Number of Branches Per Plant

Analysis of variance revealed that number of branches per plant was significantly different among the tested distances ($P \leq 0.001$), due to interaction effect. 40 cm vertical distanced with 60 cm was produced the highest number of branches per plant (6.66) (Table 4). On the contrary, the lowest value of number of branches per plant (2.33 and 2.66) were recorded from 50 cm vertical distance with 60 cm and 40 cm vertical distance with 60 cm without significant difference between each other. Therefore, this result elaborates the effect of row and plant spacing as a result of different plant population density per unit area that caused higher and lower number of leaves per plant. This can be attributed to the less competition for available nutrients, water and light by the plants in the early growth and development stages [14]. Cushman *et al*. (2005) grew ‘Clemson Spineless’ okra in a greenhouse and observed that number of leaves and generative nods increased with wider spacing combinations initially, but reduced at further reduction of plant population density. This was also in line with the finding of Odeleye *et al*., [15] who reported significant differences in the number of okra leaves among different spacing treatments; the highest number of leaves per plant obtained at the intermediate and wider spacing. Report from Hadgu *et al.,* [16] magnifies wider inter-and intra-row spacing significantly increased the number of leaves during the course of observation in sesame crop; probably this could be most likely due to the availability of growth factors and better penetration of light at the wider spaced plants.

3.2.4. Number of Fruit Per Cluster

There was a significant ($p<0.05$) difference in the number of fruit per cluster as affected by vertical and horizontal spacing and their interactions under this vertical tomato production. The number of fruit per cluster decreased as the spacing combinations reduced (Table 5). Maximum number of fruit per cluster (6.33) was obtained from the 40 cm vertical and 60 cm horizontal spacing combination but not significantly different with 50 cm vertical and 60 cm horizontal spacing. On the other hand, the lowest numbers of fruit per cluster (2.66) was recorded from the narrow spacing combinations of 40 cm x 50 cm vertical and horizontal respectively with values that were statistically at par to 50 cm vertical and 60 cm horizontal. Since tomato bears a many flower/cluster, the number of fruit per cluster largely determines the number of fruit it can bear. Narrow spacing increases competition among adjoining plants for available aerial space for canopy formation. This prevents profuse branching and production of flowering and fruits. Therefore, it would be logical to expect fewer number of fruiting points produced per cluster under higher densities, because of fewer blooms per plant under high population. This may lead to the percentage of barren/unfruitful plants increased with increasing the plant density indicating reduction in fruiting points per cluster. This conformed to finding of Tomato yield and yield components have been reported to be greatly affected by plant spacing [13]. Ayarna *et al.,* [17] recorded an increased accumulation of photosynthesis for fruit development with wider spacing.

Table 3. *Interaction effect of vertical and horizontal spacing on number of fruit per cluster and number of branches per plant.*

Treatments	Number of branches per plant	Number of fruit per cluster
40 cm Vertical X 60 cm Horizontal	6.66a	6.33a
40 cm Vertical X 50 cm Horizontal	2.66c	2.66c
50 cm Vertical X 60 cm Horizontal	2.33c	4.33bc
50 cm Vertical X 50 cm Horizontal	4.33b	4.66ab
Interaction	***	***
CV	14.4	20.28
LSD	1.08	1.7

3.2.5. Fruit Weight

In the current study fruit weight was significantly influenced by both vertical and horizontal distances differences, though the interaction effect of the two main factors showed significant. The highest fruit weight (131.52 g) was recorded from 40 cm vertical and cm 60 horizontal distances followed by 40 cm vertical and cm 50 horizontal distances (figure 1). The significant variations were recorded in fruit weight among different distances on vertical garden [18]. In this study mean fruit weight also increased along with increasing in intra-row spacing. Shushay *et al.*, [3] also observed that fruit weight is significantly affected by intra-row spacing and the highest fruit weight was found at intra-row space of 30 cm which is statistically not significantly different from 40 cm (66.3 g) while the least fruit weight was scored at intra-row spacing of 20 cm. In contrast, Balemi [19] reported that the highest mean value of fruit weight of the tomato was obtained at a spacing of 100 x 30 cm whereas the lowest value was recorded at a spacing of 60 x 45 cm. This result could be attributed to the minimal plant to plant competition exhibited by wider spacing.

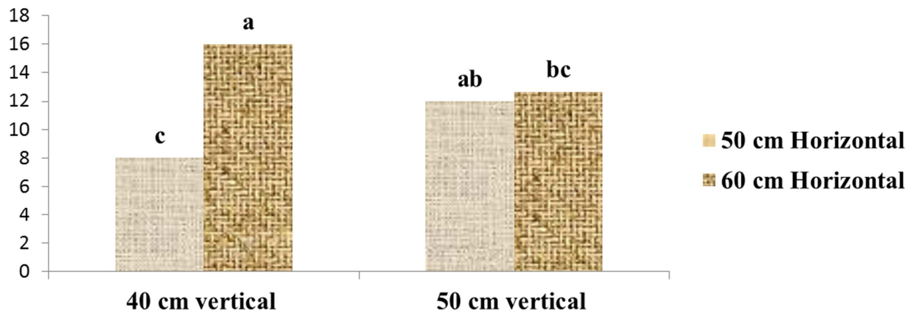

Figure 1. *Interaction effect of vertical and horizontal spacing on fruit weight.*

3.2.6. Fruit Diameter

Vertical and horizontal spacing showed a highly significant ($p<0.05$) due to interaction effect and on fruit diameter (figure 2). The highest average fruit diameter (4.18 cm) was recorded at combination of the Vertical and horizontal spacing. But it was statistically similar with that of 50 cm vertical and 60 cm horizontal and 50 cm vertical and

50 cm horizontal spacing. On the other hand, the lowest fruit diameters (2.7cm) were recorded at the 40 cm vertical and 50 cm horizontal. The highest fruit diameters (4.047 and 4.20 cm) were recorded at the wider spacing (100 x 40 cm) at Fala and Tumuga sites, respectively [8]. However, it was not significantly different from the treatment combination of 50 cm inter-row spacing with 30 cm intra-row spacing which produced the fruits having diameter of 3.86 and 3.76 cm, respectively. The lowest fruit diameters 3.347 and 3.270 cm were recorded from the treatment combination of 50 x 20 cm. Similarly, Muhammad and Singh [20] observed the highest fruit diameter at 60 cm (4.27 cm) than at 40 cm and 20 cm intra-row spacing. Ahmad and Singh (2005) confirmed that the wider spacing minimized competition of nutrient, water and radiation, grater circulation of air and interception of light.

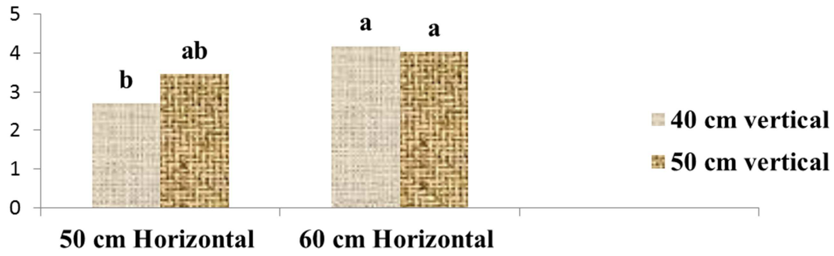

Figure 2. *Interaction effect of vertical and horizontal spacing on fruit diameter.*

3.2.7. Number of Fruit Per Plant

The number of fruit per plant varied among the different vertical and horizontal distances spacing and their interaction. Results pertaining to the number of fruit per plant depicted that maximum number of fruit per plant (16) was recorded in spaced 40 cm vertical and 60 cm horizontal. The minimum number of fruit per plant (8) was recorded from 40 cm vertical and 50 cm horizontal. The number of fruit per plant is an important factor to increase the yield of okra [21]. Number of fruit per plant depends upon the number of branches per plant, as more branches were observed in wider spacing which ultimately gives higher number of fruit per plant. This was probably because plants had competition for light in closer spacing, thus resulting in less number of fruit per plant. But, sparsely spaced plants have ample access to light and thus profuse lateral growth takes place; as a result, number of branches and fruit per plant increases. Higher branching observed in wide row and plant spacing was a major cause of the increased number of fruit per plant. Singh [21] showed that fruit retention was 23% greater in okra when plant density was 4 rather than 16 plants m-2. The total number of fruits per plant decreased as planting density increases, which could be due to the increased plant competition for growth resources in higher planting densities. The reduced competition for light and reduced over-lapping from adjacent tomato plants could have enabled the plants grown at wider spacing to utilize its energy for maximum branching and subsequently, the production of a larger leaf area, greater number of fruit per plant. [22].

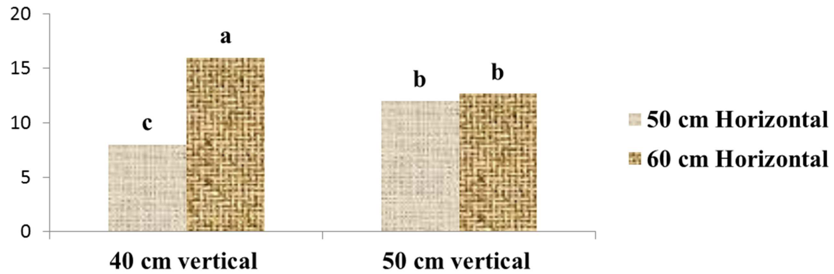

Figure 3. *Interaction effect of vertical and horizontal spacing on number of fruit per plant.*

3.2.8. Total Fruit Yield Per Structure

A highly significant ($p<0.05$) different due interaction effect of vertical and horizontal spacing Maximum total fruit yield (68.73 kg per structure) was obtained at 40 cm vertical and 60 cm horizontal spacing. The lowest total fruit yield (38.66 kg per structure) was recorded at 40 cm vertical and 50 cm horizontal spacing. Results also showed that the highest and significantly different fruit yield (45.52 and 50.65 t ha-$^{1)}$ was obtained from the treatment combination of 50 cm inter-row with 20 cm intra-row spacing, respectively [8]. Whereas, the lowest total fruit yield (13.9 and 27.92 t ha^{-1}) was recorded from wider spacing of 100 cm inter-row with 40 cm intra-row spacing, respectively and clearly indicated that short set (determinant) 22\ tomato types increased their yield potential at optimum spacing as compared to wider spacing. The plant spacing of 80 x 30 cm resulted in the highest mean total fruit yield whereas spacing of 100 x 30 cm gave the lowest mean total fruit yield [19]. Awas *et al.*, [23] results also show the highest total yield was recorded at 40 x 30 cm (68.51 t ha^{-1}). The lowest total fruit yield was recorded at 100 x 30 cm (53.56 t ha^{-1}). The highest total fruit yield of the tomato cultivars at optimum spacing could be due to the higher plant population per plot at optimum spacing than at wider spacing. Moreover, the closer spacing might have enabled maximized use of the applied nutrients better than the wider spacing which give smaller yield [19].

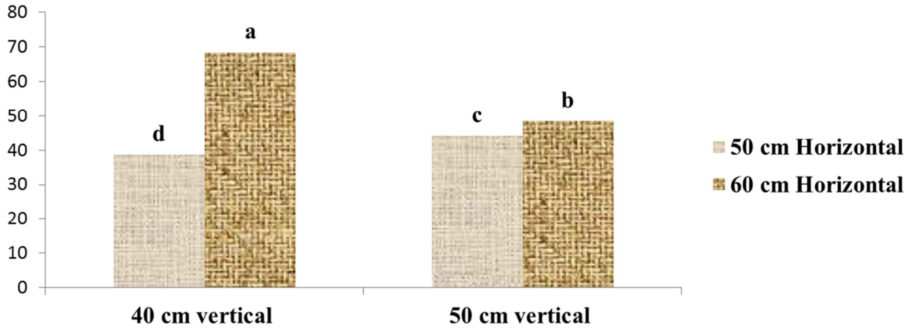

Figure 4. *Interaction effect of vertical and horizontal spacing on Total fruit yield per structure with kilogram.*

3.3. Economic Analysis

In the result of present study, the costs of fertilizers, tomato seedling, steel, wood to make structure, labor costs for agronomic practice were used for the analysis. To identify treatments with the optimum return to the farmers' investment, marginal rate of return analysis was performed on non-dominated treatments. According to CIMMYT [24], the minimum acceptable marginal rate of return (MRR%) should be 100% for acceptance.

Partial budget analysis of the combination of vertical distances with different horizontal distances on tomato production under vertical garden was presented in Tables 4 and 5. The highest net benefit of ETB 1745.655 per structure and marginal rate return of 5592.909091% with value to cost ratio of ETB 4.28 per unit of investment were obtained from combination of 40 cm vertical and 60 cm horizontal spaced treatments under vertical production. This was followed by net benefit of ETB 1130.435 per structure and marginal rate of return of 517.1136364% from combination of 50 cm vertical and 60 cm horizontal spaced treatments. Therefore, the combination of 40 cm vertical and 60 cm horizontal spacing is economically feasible for tomato production under vertical garden in Daye town.

Table 4. *Partial Budgets and Dominance Analysis of vertical growing tomato yield Influenced with different vertical and horizontal spacing.*

Treatments	Average fruit yield per structure	Adjusted fruit yield per structure	Gross field benefit per structure	Total variable cost (Birr per structure)	Net benefits (Birr per structure)	Dominance
40 cm VX 50cm H	38.66	34.794	1217.79	456	761.79	
50 cm V X 50cm H	44.18	39.762	1391.67	375	1016.67	D
50 cm V X 60cm H	48.49	43.641	1527.435	397	1130.435	
40 cm V X 60cm H	68.37	61.533	2153.655	408	1745.655	

Table 5. *Marginal Analysis of vertical growing tomato yield Influenced with different vertical and horizontal spacing.*

Treatments	Total variable cost (Birr per structure)	Net benefits (Birr per structure)	Marginal variable cost per structure	Marginal net benefits (Birr per structure)	Marginal Rate of Return%
40 cm V X 50cm H	456	761.79	-------	-------	---------
50 cm V X 50cm H	375	1016.67	D	D	
50 cm V X 60cm H	397	1130.435	22	113.765	517.1136364
40 cm V X 60cm H	408	1745.655	11	615.22	5592.909091

4. Summary and Conclusion

The results revealed highly significant (P ≤ 0.001) to interaction effects of vertical distances with variation of different horizontal distances on phonological parameters, Growth, yield and yield components. The highest mean number of plant height 83.95 cm was recorded from 40 cm distanced toward vertical treated with 60 cm to distance toward horizontal. Greater mean number of number of leaves per plant was recorded from 40 cm to vertical treated with 60 cm horizontal distance. 40 cm vertical distanced with 60 cm was produced the highest number of branches (6.66) per plant. Maximum number of fruit per cluster (6.33) was obtained from the 40 cm vertical and 60 cm horizontal spacing combination but not significantly different with 50 cm vertical and 60 cm horizontal spacing. The highest average fruit diameter (4.18 cm) was recorded at combination of the Vertical and horizontal spacing. But it was statistically similar with that of 50 cm vertical and 60 cm horizontal and 50 cm vertical and 50 cm horizontal spacing under vertical garden on tomato production. Maximum total fruit yield (68.73 kg per structure) was obtained at 40 cm vertical and 60 cm horizontal spacing. The highest net benefit of ETB 1745.655 per structure and marginal rate return of 5592.909091% with value to cost ratio of ETB 4.28 per unit of investment were obtained from combination of 40 cm vertical and 60 cm horizontal spaced treatments under vertical production. This was followed by net benefit of ETB 1130.435 per structure and marginal rate of return of 517.1136364% from combination of 50 cm vertical and 60 cm horizontal spaced treatments. Given the fact that fruit yield performance between the two vertical distances in combination with two horizontal distances 40 cm toward vertical and 60 cm toward horizontal is recommended to vertical production of tomato under vertical garden at Daye town and similar agro-ecologies in the cities and towns of Ethiopia.

Data Availability

Data are available on request from Hailu Hameso.

Competing Interests

The authors declare that they have no competing interests.

References

[1] Eigenbrod, C. N. Gruda (2015). Urban vegetable for food security in cities. A review. Agron Sustain Dev 35: 483–498. doi: 10.1007/s13593-014-0273-y.

[2] Coyle B. D., and B. Ellison. 2017. Will consumers find vertically farmed produce ‘‘out of reach? Choices 32: 1–8.

[3] Shushay, C. B. Fasigaw, G. Tekle, Y. Kahsay, N. Weldu, and G. Zerabruk. 2017. Response of yield and yield components of tomato (Solanum lycopersicon L.) to different inter and intr arow spacing at Merebleke, Northern Ethiopia. African Journal of Agricultural Research, 2614-2619.

[4] UN (2019) Goal 2: Zero Hunger. Sustainable Development Goals. United Nations. https://www.un.org/sustainabledevelopment/hunger/. Accessed 24 Sep 2019.

[5] Bernard, B. A. Lux (2017) How to feed the world sustainably: an overview of the discourse on, agroecology and sustainable intensification. Reg Environ Chang 17: 1279–1290. doi: 10.1007/s10113-016-1027-y.

[6] Knorr, D. C. S. H. Khoo,, M. A. & Augustin (2018). Food for an urban planet: Challenges and research opportunities. Frontiers in Nutrition, 4, 73. https://doi.org/10.3389/fnut.2017.00073.

[7] Al. Kodmany, K. 2018. The vertical farm: A review of developments and implications for the vertical city. Buildings 8 (24): 1–36.

[8] Abrha, H. A. Kebede, B. Amare and M. Desta. 2015. Effect of Inter and Intra-Row Spacing on Yield and Yield Components of Tomato (*Solanum lycopersicum* Linn.) in South Tigray, Ethiopia. *Journal of Natural Sciences Research,* 2224-3186.

[9] Getahun D. and D. Bikis. 2015. Responses of Tomato Varieties to Intra-row Spacing Under Rain-fed Production. *Agricultural Science Research Journal Vol. 5 (12),* 171 - 179.

[10] Yadav, S. K. D. Ameta, S. K. Sharma, R. B. Dubey, H. Rathore, R. S. Kumar and V. K. Kapuriya, 2017. Effect of Spacing and Training on Vegetative Growth Characteristics and Yield of Tomato (Solanum lycopersicum L.) Grown in Polyhouse. *International Journal of Current Microbiology and Applied Sciences ISSN: 2319-7706 Volume 6 Number 5,* pp. 1969-1976.

[11] Seid, H. K. Merema and W. Mestawat. 2013. Effect of intra row spacing on the growth and development of tomato. International Journal of Sciences, 10: 19-24.

[12] Morgan L. (2013). Daily light integral (DLI) and greenhouse tomato production. The Tomato Magazine. 10-15. Available at: https://www.specmeters.com/assets/

[13] Maboko, M. M., C. P. Du Plooy, and S. Chiloane, (2017). Yield of determinate tomato cultivars grown in a closed hydroponic system as affected by plant spacing. *Horticult. Brasileira* 35, 258–264. doi: 10.1590/s0102-053620170217.

[14] Mehla, C. P. V. K. Srivastava, S. Jage, R. Mangat, J. Singh and M. Ram. 2000. Response of tomato varieties to N and P fertilization and spacing. *Indian J. Agri. Res*., 5 (2): 67–71.

[15] Odeleye, F. A. Dada, M. Odeleye and A. Olaleye. 2005. Response of okra to varying levels of poultry manure and plant population density under sole cropping. *J. Food, Agri. Environ.,* 3 (4): 68-74.

[16] Hadgu G.. 2006. Effect of Planting Methods and Spacing on Yield and Yield Attributes of Sesame (*Sesamum indicum* L.) in the Lowland Plain of Humera, Western Tigray, Ethiopia. An MSc. Thesis presented tothe School of Graduate Studies of Alemaya University.

[17] Ayarna, A. W. S. Tsukagoshi, G. O. Nkansah, G. O., and K. Maeda, (2019). Effect of spacing and topping on the performance of hydroponically grown tomato under tropical conditions. *J. Agric. Crops* 5, 23–30. doi: 10.32861/jac.52.23.30.

[18] Desalegn, R. T. Wakene and S. Addis. 2016. Tomato (Lycopersicon esculentum Mill.) varieties evaluation in Borana zone, Yabello district, southern Ethiopia. Journal of Plant Brreding and Crop, 8: 206-10.

[19] Balemi T. 2008. Response of tomato cultivars differing in growth habit to nitrogen and phosphorus fertilizers and spacing on vertisol in Ethiopia. Acta agriculturae Slovenica, 103 - 119.

[20] Muhammad A. and A. Singh 2007. Intra-row spacing and pruning effects on fresh tomato yield in Sudan Savannah of Nigeria. *Journal of Plant sciences*, 2: 153-161.

[21] Singh, B. P. 1996. Effect of row and plant spacing on yield ad yield components of okra. *Indian J. Agron*., 35: 439-441.

[22] Ebrahim M. and D. Ali. 2013. Plant spacing and cultivar affects yield components, qualitative traits and early ripening of tomato (Lycopersicon esculentum Mill). Notulae Scientia Biologicae, 5: 494-98.

[23] Awas, G. T. Abdisa, K. Tolosa and A. Chali. 2010. Effect of interrow spacing with double row arrangement on yield and yield component of tomato (*Lycopersicon esculuntum* Mill.) at Adami Tulu Agricultural Research Center (Central Rift Valley of Oromia, Ethiopia). *African Journal of Agricultural Research Vol. 6 (13)*, 2978-2981.

[24] CIMMYT (1988). From Agronomic data to Farmer Recommendations: An Economic work Book. Mexico, D. F.: CIMMYT.