Original Research Article

Effects of Earthing up and Pruning Systems on Yield and Net Economic Benefit of Tomato (*Solanum* l*ycopersicon*)

ABSTRACT

Tomato is a popular and extensively cultivated vegetable among the promising commodities in horticultural production in Kenya. It provides a wide variety of nutrients with many health-related benefits. Despite the importance, its yield and net economic benefits is limited by the choice of cultural practices mainly earthing up and pruning system. There is limited knowledge on the effect of integrating pruning and earthing up on tomato yield and net economic benefit. This study investigated the effect of integration of pruning and earthing up on the growth and yield of tomatoes. A split-plot experimental design, arranged in a Randomized Complete Block Design, with three replications was used. The study investigated two factors i.e. pruning system in the main plot (single stem, double stem, and triple stem) and earthing up in sub-plots. (0 cm, 10 cm, 20 cm, and 30 cm). Fruit yield data was taken after each harvest. Data were analysed using SAS version 9.4 and significant means were separated using the least significant difference at $\alpha = .05$. The findings of the study revealed that earthing up and pruning system had a significant ($p < .05$) effect on tomato yield and net economic benefit. Triple stem pruning system, earthing up to 30 cm had the highest fruits yield with 21.82 tonnes/hectare in cultivation 1 and 21.84 tonnes/hectare in cultivation 2. The findings also revealed that triple stem pruning system, earthing up to 30 cm had the highest net economic benefit per hectare in both cultivation 1 and cultivation 2. To improve tomato yield and consequently improve net economic benefit, farmers are encouraged to consider triple stem pruning system earthing up to level 30 cm.

Keywords: Earthing up, Pruning system, Growth, Yield, marketable fruits, net economic

1.1 Introductions

Agriculture provides sustenance for more than 80% of the Kenyan population in terms of employment and food security [13]. The sector contributes directly up to 24% to the National Gross Domestic Product (GDP) and 27% indirectly through linkages with manufacturing, distribution and other related sectors [20]. Besides, the sector employs more than 40% of the total population and more than 70% of Kenya's rural people and it accounts for 65% of revenue from exports [20]. The agriculture sector comprises of industrial crops, food crops, horticulture, livestock, fisheries and forestry sub sectors. The industrial crops and food crops contribute 17% and 32% of Agricultural Gross Domestic Product (AGDP) while horticulture and Livestock contributes 33% and 17% of AGDP respectively [20]. Studied on the performance of the horticultural sub-sector in Kenya and found that increase in horticultural exports led to increased AGDP [12].

Tomato (*Solanum Lycopersicon*), is a popular and extensively cultivated vegetable. It is among the promising commodities in horticultural production in Kenya. It is the fourth most popular fresh-market vegetable after potatoes, cabbages, and onions because of its great yield potential and high nutritive value [32]. Over the years, tomato production in Kenya has intensified [31]. Yields, however, have remained low due to a myriad of impediments, key among them being poor cultural practices. Therefore, the production of tomato could be increased through the application of better cultural practices such as proper pruning system and earthing up level. Earthing up is a technique in horticulture of piling soil around the base of the plant [11]. The technique triggers the initiation of plant roots that come in direct conduct with nutrients through a process of interception as it grows [21]. It encourages the development of additional roots and root hair to help improve stem length as well as suckers [33]. Plants absorb nutrients primarily through their roots and therefore good growth and proliferation of the roots are essential in partitioning and set of functional equilibrium [9]. It also improves the distribution of nutrients, water and air circulation which are important in the soil [26].

Removal of unnecessary suckers on the other hand also has a great impact on the tomato fruit yield [30]. Suckers would compete to acquire assimilates and removal of the unnecessary suckers would increase transfer of assimilates into the fruiting trusses consequently increasing yield. Pruning contributes to proper partitioning, which is a requirement for plant growth and development [27]. It also regulates plant growth, flowering, and fruiting responses, [10]. Therefore, there is an attempt to increase the yield of tomato through providing good tomato growth and fruiting by combining cultural practices such as pruning system and earthing up levels.

Tomato sucker are less valuable economically in tomato production as it is the most photo-assimilates sinker that reduces translocation of food to the fruits [19]. However, most of tomato farmers pay less attention to combining

earthing up and pruning system. This study aims at contributing and solving some of these constraints by researching to find out appropriate earthing up level and pruning system for tomato production and utilization in the future.

The economic benefit is the biggest concern for commercial tomato growers [42]. In Kenya, the income from tomato plantation is affected by its yield and quality, and especially its ripening time. Regulating the ripening can help the growers to obtain a higher price of tomato in the fierce market competition [38]. Earthing up and pruning system may contribute to uptake and partitioning of cytokinin and auxins growth substances, which theoretically regulates the ripening of crops by their synergistic activity [22]. Earthing up and pruning systems regulate the ripening time by modulating metabolism and catabolism of plant endogenous growth regulators. Moreover, it is reported that efficient nutrient uptake and partitioning through earthing up and pruning system could be a useful method to regulate the ripening dynamics and boost the fruit quality of tomato [2]. Therefore, controlling the ripening time of tomatoes by pruning and earthing up can be a promising measure to increase farmers' income by the way of ensuring tomato yield.

The use of earthing up and pruning systems could potentially aid farmers to attain the utmost achievable yield level. However, most of the tomato farmers frequently give less regard to combining earthing up and pruning system. Most efforts have gone towards improving tomato production through pruning [28]. A missing component in studies on tomato production is the effect of the combination of earthing up and pruning system and determination of their technical efficiency [17]. This study therefore aims at contributing and solving some of these constraints by researching to find out appropriate earthing up level and pruning system for tomato production and utilization in the future.

2.1 Materials and Methods

2.1.1 Site Description and Experimental Design

The study was conducted at Chuka University Research and teaching farm for cultivation 1 while cultivation 2 was carried out on a farm at Ndagani within the University neighbourhood. The first cultivation was carried out in November 2019 and ended in January 2020. The second cultivation commenced in February 2020 and ended in May 2020. The site is situated at 0^0 19'59, N and 0^0 19'15.85'S. The area lies in the upper midland zone. Daily temperatures in the area range between 22 ^{o}C to 36 ^{o}C. The annual rainfall is 1599 mm distributed bi-modally with the longest rains experienced in November. The climate is favourable for the cultivation of tea, coffee, maize, cowpeas, pigeon peas, tobacco and a variety of other food crops. Soils in this area are classified as humic nitisols [18] and they are of volcano origin with basic and ultrabasic igneous rocks.

The study used a split-plot experiment arranged in a randomized complete block design (RCBD) and replicated three times. Each subplot had six plants. There were two factors, the pruning system and earthing up. The pruning system was allocated to the main plot, while the earthing up was allocated to the sub-plot. There were four levels of earthing up (no earthing up, earthing up to 10 cm, earthing up to 20 cm and earthing up to 30 cm) and three levels of pruning system (single stem or control level, double stem and triple stem) the treatment were made up by a combination of factor levels resulting to 12 treatments in this study. The plant spacing was 0.6 m by 0.45 m, row spacing and within the row respectively.

2.1.2 Earthing up and Pruning Systems

Transplanting was done on a level ground. Earthing up was done three weeks after transplanting by hilling the soil around the plant as follows: No earthing up 0 cm (EU0), earthing up to 10 cm (EU1), earthing up to 20 cm (EU2), and earthing up to 30 cm (EU3). Double stem and triple stem suckers below the first pair of the true leaves were maintained. The plants were trained into; Single Stem (SS), Double Stem (DS), and Triple Stem (TS). Where; SS=Single Stem, DS=Double Stem, TS=Triple Stem, DAT=Day after transplant, EU=Earthing Up, PS=Pruning System.

2.2 Data Collection

3.4.3 Tomato Fruit Size

The fruit size was determined by measuring the fruit at the widest part, starting from the attachment of the fruit to the plant to the blossom end, and then at the diameter of the fruit. All measurements were made using a Vernier caliper. Fruits were categorized into small (<6 cm), medium (6–8 cm) and large (>8 cm) according to the diameter size [29]. Low-quality fruits were those measuring less than 6 cm and high quality were those measuring above 6 cm as per the marketing quality. The fruits category >6 cm in diameter were counted and considered marketable.

2.2.1 Total Fruit Yield, Marketable and Unmarketable Yields

All the fruits harvested per 2.5 m x 2 m area were counted and weighed separately on each harvesting date. The average fruit weight was calculated for each treatment in tonnes per hectare. Fruits were separated into two lots of marketable and unmarketable fruits. Marketable fruits were picked at the breaker stage. The size was determined using a Vernier caliper and categorized according to diameter size. Unmarketable fruits were those <6 cm in diameter with physiological disorders such as cracks and blossom end rot or other types of blemish.

2.2.2Economic analysis

Net return was obtained by subtracting total expenditure (cost per hectare) from the gross return (revenue). Cost referred to the major component of the net return. It was determined by calculating expenses on the land preparation, purchase of seeds and its application, farmyard manure, chemical fertilizers, pesticides and harvesting. Gross return per hectare was determined by tomato sales based on prevailing farm gate prices according to [28].
Net Return = Gross Return-Expenditure

2.3 Data Analysis

Data was subjected to the Analysis of Variance using Statistical Analysis System version 9.4 at a probability level of 5 % and where the F-test was significant, Least Significant Difference was used in mean separation.

3.1 RESULTS AND DISCUSSION

4.2.1 Effect of Earthing up levels and Pruning Systems on Number of Tomato Fruits under Different Size Categories

The distribution of fruit size at harvest appeared to respond to earthing up. Earthing up to level 30 cm recorded the highest number of tomato fruits under the size category (<6 cm) at an average of 71381 fruits per hectare in cultivation 1 and 77393 fruits per hectare in cultivation 2 (Table 1). Control (no earthing up) on the other hand recorded the fewer number of fruits at an average of (38049 fruits and 44051 fruits) per hectare in cultivation 1 and 2, respectively. Findings from size category (6 - 8 cm) and (>8 cm) showed earthing up to 30 cm recorded the highest proportional number of fruits in both cultivations. The results from the pruning system showed that triple stems pruning system recorded the highest number of fruits in category (<6 cm) at an average of 77708 fruits per hectare in cultivation 1 and 83734 fruits in cultivation 2. Whereas the smallest number were obtained from single stem pruning system with an average of 32625 fruits and 38600 fruits per hectare in both cultivation 1 and 2, respectively. Triple stems recorded the highest results under category (6-8 cm) and (>8 cm) in both cultivations. Single stem recorded the smallest number of fruits in both cultivations (Table 1).

Table 1: Tomato fruit size at different earthing up levels and pruning systems in cultivations 1 and 2

	Earthing up				Pruning system			
Cultivation	EU	<6 cm	6-8 cm	>8 cm	PS	<6 cm	6-8 cm	>8 cm
1	EU0	38049d*	52279d	26055d	SS	32625c	45158c	21199c
	EU1	49556c	63021c	34753c	DS	54042b	67599b	37900b
	EU2	60168b	74281b	41257b	TS	77708a	92586a	54370a
	EU3	71389a	84279a	49998a	CV%	4.59	3.87	4.43
	CV%	4.59	4.38	4.43	LSD	1017	1071	677.26
	LSD	1174.9	1237.4	782.04				
2	EU0	44056 d	44275d	22056d	SS	38600c	37163c	17125c
	EU1	55554c	55000c	30770c	DS	60042b	59625b	33917b
	EU2	66167b	66301b	37276b	TS	83734a	84583a	50375a
	EU3	77393a	76278a	45111a	CV%	4.14	4.38	4.95
	CV%	4.14	4.38	4.95	LSD	1018	1070.6	678.19
	LSD	1175.5	1238.1	781.93				

*Means followed by the same letter(s) along the column for earthing up and pruning systems are not significantly different at 5 % probability level. Mean separation was done within each cultivation. Where; SS=Single Stem, DS=Double Stem, TS=Triple Stem, EU=Earthing UP, PS=Pruning system

In both cultivations, the distribution of fruits in different size categories appeared to respond to earthing up and pruning system treatments. The analysis showed that the treatment TS3 recorded the highest proportion of tomato fruits under category (<6 cm) with an average of 95834 fruits per hectare in cultivation 1 and 101833 in cultivation 2 respectively. The number of fruits was high under TS3, followed by TS2 and TS1; this trend indicates that the triple stem pruning system resulted in a higher proportion of fruits with higher earthing up level. Additionally, under the same pruning system and varied earthing up levels it was noted that more medium-size fruits (6-8 cm) were recorded under high earthing up level 30 cm (Table 2). The treatment SS0 recorded the smallest proportions of

fruits under size categories **(**<6 cm), **(**6-8 cm) and **(**>8 cm) in both cultivations as shown in Table 2. The analysis of variance showed that the number of fruits under TS1 and DS3 were not significant ($p<0.05$) in size categories (6-8 cm) and >8 cm in both cultivations (Table 2).

Table 2: Tomato fruit number under different size categories and earthing up levels and pruning systems per hectare in cultivations 1 and 2.

Cultivation 1				Cultivation 2		
Treatment	<6 cm	(6-8) cm	(>8) cm	<6 cm	(6-8) cm	(>8) cm
SS0	15668i*	28336i	15000k	21664i	20333i	11000k
SS1	28663h	42000h	19500j	34667g	34000h	15500j
SS2	37000f	50000g	22333i	43000f	42010g	18332i
SS3	48167e	60332f	27669g	54164e	52333f	23659g
DS0	38000f	61330g	25003h	44000f	43334g	21000h
DS1	48166e	60000f	33659f	54166e	53009f	29669f
DS2	60835d	75170e	41833d	66833d	67155e	37833d
DS3	70167c	84000d	51167c	76168c	78008d	47167c
TS0	61500d	77162e	38161e	67500d	69161e	34164e
TS1	71835c	87000c	51167c	77833c	79010c	47168c
TS2	81661b	97669b	59666b	87665b	89672b	55663b
TS3	95834a	108500a	68513a	101833a	100500a	64500a
LSD	2036.9	2151.3	1354.7	2036.9	2155.2	1353.6
C.V	4.6028	3.8908	4.4328	4.1485	4.4057	4.9573

*Means followed by the same letter(s) along the column for earthing up and pruning systems are not significantly different at $P<0.05$. Mean separation was done within each cultivation. Where; SS0=Single Stem x no Earthing Up (Control), SS1=Single Stem x Earthing up to 10 cm, SS2=Single Stem x Earthing up to 20 cm, SS3=Single Stem x Earthing up to 30 cm, DS0=Double Stem x no Earthing up, DS1=Double Stem x Earthing up to 10 cm, DS2=Double Stem x Earthing up to 20 cm DS3=Double Stem x Earthing up to 30 cm, TS0=Triple Stem x no Earthing up, TS1=Triple Stem x Earthing up to 10 cm, TS2=Triple Stem x Earthing up to 20 cm, TS3=Triple Stem x Earthing up to 30 cm.

Earthing up and pruning systems significantly affected the number of fruits in different size categories. Since nutrients especially nitrogen are the most important growth and yield determinants. One of the major factors related to its expected uptake by the tomato is the availability of moisture in the root zone. Irrespective of pruning system, earthing up level 30 cm could have promoted substantial moisture availability in the root zone thus increasing root hair development consequently increasing nutrient uptake posing potential increase in fruit development. The treatment TS3 recorded the largest number of fruits of the three fruit size categories. This shows that earthing up and pruning enhanced satisfactory nutrient uptake and partitioning hence reducing nutrient competition between all potential bearing suckers and trusses. The increase in the number of tomato fruits observed under TS3 agreed with observations made by [24] and [5] who reported that increase in nutrient uptake and partitioning to each sucker was accompanied by an increase in the number of fruits and total yield per unit area. [35] found that nutrient uptake and assimilate competition between fruits during the cell division period affect fruit development. [34] mentioned that the number of fruits and size per plant is affected by nutrient uptake efficiency and pruning. They also mentioned that the number of fruits per plant is increased with an increase in tomato productive suckers and trusses. [8] showed that the size of fruits was influenced by plant nutrient uptake efficiency. According to [43], plants having sufficient nutrient uptake, form bigger fruits and at the same time get more fruits per plant, thus fruit quality and number increase. The findings of this study are also in agreement with [4] who observed that improved water and nutrient capture considerably increases the average size fruit. They suggested that a raised bed (equivalent to earthing up) in this case enables plants to set many fruits because of improved mineral intake resulting in large fruits

Physiological responses of the tomato to pruning showed that triple stem plants which were earthed up to level 30 cm produced more fruits in different size categories. This is because there was a balance between the root system and the aboveground plant structure which increased satisfactory nutrient partitioning prioritizing on the fruiting sites. In this trial, pruning system focused on the removal of unnecessary water suckers to maintain the ideal number of suckers considered as productive. The current results are similar to those of [24] on the effect of plant population, fruit and stem pruning on yield and quality of tomato. They reported that pruning tomato to two stems obtain more fruits than single stem pruned plants. The results were also similar to those by [6], who observed that two stem pruning gave the highest number of fruits per plant as compared to single stem pruned plants.

3.1.3 Effect of Earthing up levels and Pruning Systems on Marketable Tomato Fruit Numbers

The analysis of the results showed that, earthing up to level 30 cm had a significantly greater proportion of marketable fruits at 44833 fruits in cultivation 1 and 44614 fruits in cultivation 2 as compared to no earthing up (control) which recorded the smallest proportions of marketable fruits at an average of 22389 fruits and 22333 in cultivation 1 and 2 respectively. In both cultivations, the distribution of marketable fruits at harvest also appeared to respond to the pruning system. After grading, the triple stem pruning system record the highest proportion of marketable fruits at an average of 50248 fruits in cultivation 1 and 50250 fruits in cultivation 2 as compared to the single stem pruning system which recorded the smallest averages of 17000 fruits in cultivation 1 and 17042 fruits in cultivation 2 (Table 3).

Table 3: Means of marketable tomato fruits at different levels of earthing up and pruning systems in two cultivations (2019/2020)

Cultivation	EU	Fruits/Ha	PS	Fruits/Ha
1	0	22389d*	SS	17000c
	10	30889c	DS	34167b
	20	37111b	TS	50248a
	30	44833a	CV%	5.047
	CV%	5.047	LSD	689.26
	LSD	795.89		
2	0	22333d	SS	17042c
	10	30722c	DS	33958b
	20	37333b	TS	50250a
	30	44614a	CV%	3.241
	CV%	3.241	LSD	441.97
	LSD	510.35		

*Means followed by the same letter(s) along the column for earthing up and pruning systems are not significantly different at 5 % probability level. Mean separation was done within each cultivation.

The results in Table 4 show that earthing up levels and pruning system significantly affected the total marketable yields. This result shows that increasing both earthing up and pruning system levels tended to increase marketable tomato fruit yield per hectare. The average mean progressively increased from (SS1, DS1, TS1), (SS2, DS2, TS2) to the highest average means from (SS3, DS3, TS3) in terms of individual treatments. However, the lowest in all treatments was obtained from controls (SS1, DS1, and TS1). This implies that marketable yield progressively increased from single stem, double stem, and finally to triple stem in terms of pruning systems. In terms of earthing up, marketable yields increased from control, level 10cm, 20 cm to 30 cm. as shown in table 4. A comparison of the means shows that values from TS0 (control) were not significantly higher overall, although it was significantly higher than DS2, DS1, DS0, SS3 SS2, SS1 and SS0 treatments because of its increased bearing area (suckers and trusses). It was also noted that although DS3 was not significantly higher its overall average means, it was higher than TS0, in this case, root development, water and nutrient uptake was the key factor. In general, the treatment TS3 recorded the highest number of marketable tomato fruits at an average of 64500 fruits in cultivation 1 and 64333 fruits in cultivations 2 respectively. Whereas the treatment SS0 (control) in both cultivations recorded the smallest proportions of marketable tomato fruits as shown in Table 4

Table 4: Means of marketable tomato fruits at different levels of earthing up and pruning systems treatments in two cultivations (2019/2020)

	Cultivation 1	Cultivation 2
Treatment	Means	Means
SS0	11500j*	11503k
SS1	15330i	15661j
SS2	18333h	18167i
SS3	21500g	22835g
DS0	22834g	21333h
DS1	30167f	29833f
DS2	37835d	38000d
DS3	47167c	46667c
TS0	34171e	34167e
TS1	47163c	46667c
TS2	55164b	55828b
TS3	64500a	64333a
LSD	1379.6	892.69
C.V	5.0526	3.2784

*Means followed by the same letter(s) along the column for earthing up and pruning systems are not significantly different at 5 % probability level. Mean separation was done within each cultivation. Where; SS0=Single Stem no Earthing Up (Control), SS1=Single Stem Earthing up to 10 cm, SS2=Single Stem Earthing up to 20 cm, SS3=Single Stem Earthing up to 30 cm, DS0=Double Stem no Earthing up (control), DS1=Double Stem Earthing up to 10 cm, DS2=Double Stem Earthing up to 20 cm DS3=Double Stem Earthing up to 30 cm, TS0=Triple Stem no Earthing up (control), TS1=Triple Stem Earthing up to 10 cm, TS2=Triple Stem Earthing up to 20 cm, TS3=Triple Stem Earthing up to 30 cm.

The result indicates that different treatments significantly influenced the total number of marketable fruits. There were highly significant differences between treatments concerning the total number of marketable fruits per hectare, with the highest number of fruits per hectare observed in TS3 (Table 4). This could be attributed to more fruits produced due to an increase in productive tomato suckers and trusses. Dry matter accumulations in the bearing trusses is ultimately a product of resource partitioning determined by the interaction between the pruning system and earthing up levels as well as competition driven by source-sink relationships [23]. These interactions were the most consequential to the development of crop load (fruits). As the number of tomato suckers and trusses increase, marketable fruits per plant increased asymptotically. This is the evidence that the total marketable fruits were higher in TS3. The current results are similar with those of [15] in their study on the effect of shoot pruning, observed that tomato plants which were pruned to a single stem gave the lowest number of marketable fruits per plant as compared to double and triple stem.

These current results are also in agreement with those of [24] who in their study on the effect of plant population, fruit and stem pruning on yield and quality of tomato, showed that total yields increased with increases in productive suckers per plant. They pointed out that, increase in sucker density generally with proper nutrient uptake increases both early and total yields per hectare. [14] observed that earthing up of potato crop during the active plant growth period improved the soil condition, which enabled proper root growth. They indicated that Proper root growth enhanced efficient nutrients absorption that facilitated better growth and development consequently increasing marketable yield. The current results are also in line with the work of [36] who confirmed that earthing up potato after complete plant emergence resulted in better plant performance and yields. Tomato plants with high marketable fruits are more desirable to farmers because they will be able to sell more hence obtaining high net economic return.

3.1.4 Effect of Earthing Up levels and Pruning System on Tomato Yields (tonne/ha)

In cultivation 1 and 2, the earthing up level 30 cm showed a tendency of higher yield at an average of 17.03 tonnes per hectare in cultivation 1 and 17.03 tonnes per hectare in cultivation 2 relative to control (no earthing up) which recorded significantly the smallest average yields. On the other hand, the pruning system showed significant difference with triple stem pruning system tendency of higher average yields (18.67 tonnes in cultivation 1 and 18.64 tonnes in cultivation 2) as compared to control (single stem) in both cultivations (Table 5).

Table 5 Means of tomato total yield hectare at different earthing up levels and pruning system in two cultivations (2019/2020)

Cultivation	EU	tonne/ha	PS	tonne/ha
1	0	11.05d*	SS	8.81c
	10	12.97c	DS	14.52b
	20	14.96b	TS	18.67a
	30	17.03a	CV%	1.83
	CV%	1.83	LSD	0.10
	LSD	0.11		
2	0	10.99d	SS	8.78c
	10	12.96c	DS	14.49b
	20	14.91b	TS	18.64a
	30	17.03a	CV%	1.74
	CV%	1.74	LSD	0.09
	LSD	0.11		

*Means followed by the same letter(s) along the column for earthing up and pruning systems are not significantly different at 5 % probability level.

Tomato fruit production in terms of average yield in tonnes per hectare was also substantially affected by the combination of earthing up and pruning system treatments. There were significant effects of treatment on average total yield in both cultivations. This result shows that increasing both earthing up and pruning system levels tended to increase total fruit yield in tonnes per hectare. The average mean progressively increased from (SS1, DS1, TS1),

(SS2, DS2, TS2) to the highest average means from (SS3, DS3, TS3) in terms of individual treatments. However, the lowest in all treatments was obtained from controls (SS0, DS0, TS0). This implies that total yield progressively increased also from single stem, double stem, and finally to triple stem in terms of pruning systems. In terms of earthing up, marketable yields increased from control, level 10 cm, 20 cm to 30 cm. similar to marketable yields as shown in table 12. A comparison of the means shows that TS1 was not significantly different from DS3, because of its increased bearing area (suckers and trusses) and nutrients uptake respectively. It was also noted that TS0 was not significantly different from DS2, in this case, root development, water and nutrient uptake was the key factor. Generally, the analysis showed that the treatment TS3 recorded the highest fruit yield (21.82 tonnes and 21.84 tonnes) per hectare in cultivations 1 and 2 respectively. Whereas the treatment SS0 (control) recorded the smallest average yield at 6.21 tonnes/hectare in cultivation 1 and 6.12 tonnes per hectare in cultivation 2 as shown in table 6.

Table 6: Means of tomato yield in tonnes per hectare at different treatments in two cultivations (2019/2020)

	Cultivation 1	Cultivation 2
Treatment	Means	Means
SS0	6.21i*	6.12i
SS1	7.74h	7.73h
SS2	9.64g	9.60g
SS3	11.65f	11.64f
DS0	11.66f	11.62f
DS1	13.53e	13.53e
DS2	15.29d	15.24d
DS3	17.62c	17.58c
TS0	15.29d	15.24d
TS1	17.65c	17.58c
TS2	19.93b	19.89b
TS3	21.82a	21.84a
LSD	0.206	1.196
C.V	1.8212	1.7364

*Means followed by the same letter(s) along the column for earthing up and pruning systems are not significantly different at 5 % probability level. Mean separation was done within each cultivation. Where; SS0=Single Stem no Earthing Up (Control), SS1=Single Stem Earthing up to 10 cm, SS2=Single Stem Earthing up to 20 cm, SS3=Single Stem Earthing up to 30 cm, DS0=Double Stem no Earthing up (control), DS1=Double Stem Earthing up to 10 cm, DS2=Double Stem Earthing up to 20 cm DS3=Double Stem Earthing up to 30 cm, TS0=Triple Stem no Earthing up (control), TS1=Triple Stem Earthing up to 10 cm, TS2=Triple Stem Earthing up to 20 cm, TS3=Triple Stem Earthing up to 30 cm.

The result revealed that different treatments significantly influenced total tomato yield per plant at different earthing up levels and pruning system. It is possible that earthing up resulted in the distribution of air in the tomato root zone. The distribution of air increased the level and availability of oxygen, which is continuously needed to act as an electron acceptor in the tricarboxylic acid metabolic cycle, ATP production and normal root cell activity. An increase in the circulation of oxygen in the root zone enhances the development of mitochondria and proteins in the root cell leading to an increase in plant growth and development [43]. In this context, it will be expected that any positive growth impact of increasing earthing levels improved soil aeration and consequently root hair development [39]. Proper root promotes efficient nutrient uptake and partitioning to the productive suckers and trusses in tomatoes. This led to the development of more flowers and fruits resulting in higher tomato fruit yield per plant. It should be noted that nutrient uptake affects the tomato production by increasing mineral contents, flower clusters, fruit set percentage, and reducing physiological disorders leading to higher yield. The current results are in agreement with the findings of [39] who showed that an increase in root surface area enhances nutrient uptake leading to increased total yields and the number of fruits per plant. [7] also reported the highest crop yield per hectare after earthing up potato 15 days after complete plant emergence. Similarly, [40] also reported that tomato fruit yield increases with increased nutrient uptake. [1] also found that nutrients not only increase the yield of tomato by reducing the flower drop but also increase the fruit retention.

Overall, production (tonnes/hectare) was directly related to the number of productive suckers and trusses that affected fruit loads. The crop load was on average higher within the triple stem pruning system with treatment TS3 averaging higher than those from a single stem pruning system. The effect of triple stem pruning earthing up level 30 cm resulting in the production of greater fruit weight may be explained by not only an increase in bearing area (trusses and suckers) but also exposure of the tomato to increased nutrient uptake due to an increase in root hairs development after earthing up. According to [3], who did a study on the influence of sucker pruning and old leaves removal on the growth and yield of tomato, they found that growth, flowering, and fruiting responses are regulated by pruning. [5], indicated that the increase in plant bearing area (suckers and trusses) lead to an increase in total

yield. They further explained that pruning limits vegetative growth and allows more light which increases photosynthesis efficiency hence increased fruit yield.

4.4.1 Effect of Earthing up levels and Pruning System on Net Economic Benefit per hectare

The results from the analysis of variance for the effect of earthing up and pruning system and their combined effect showed that there was a significant effect on the net economic benefit in both cultivations. The study also showed that the treatment had a significant effect on the net economic benefit in both cultivations. This shows that triple stem pruning system gave the highest average net economic benefit as compared to the double stem and single stem pruning system (Table 7).

Table 7: Net economic benefit at different earthing up and pruning system levels in cultivation 1 and 2

	Earthing up		Pruning system	
Cultivation	EU	Kshs/Ha	PS	Kshs/Ha
1	EU0	240445d*	SS	144833c
	EU1	266056c	DS	311461b
	EU2	324101b	TS	432458a
	EU3	384389a	CV%	2.57
	CV%	2.57	LSD	3079.4
	LSD	3555.8		
2	EU0	245222d*	SS	173292c
	EU1	308500c	DS	358708b
	EU2	372278b	TS	493000a
	EU3	440667a	CV%	2.34
	CV%	2.34	LSD	3236.7
	LSD	3737.4		

*Means followed by the same letter(s) along the column for earthing up and pruning systems are not significantly different at 5 % probability level. Mean separation was done within each cultivation. Where; SS=Single Stem, DS=Double Stem, TS=Triple Stem, EU=Earthing UP, PS=Pruning System

Analysis of the treatment effect showed that the treatment TS3 recorded the highest average net economic benefit per hectare (Kshs 524000 in cultivation 1 and Kshs 596000 in cultivation 2) as compared to treatment SS0 (control) which recorded the smallest average net economic benefit per hectare at Ksh 69000 in cultivation 1 and Ksh 87157 in cultivation 2 (Table 8).

Table 8: Tomato net economic benefits (Kshs/Ha) at different treatments levels in cultivation 1 and 2

	Cultivation 1	Cultivation 2
Treatment	Means	Means
SS0	69000i*	87157i
SS1	113500h	139168h
SS2	169000g	200333g
SS3	227833f	266500f
DS0	228167f	266500f
DS1	282333e	327333e
DS2	334000d	383000d
DS3	401333c	490000c
TS0	334167d	383000d
TS1	402334c	459000c
TS2	469333b	533500b
TS3	524000a	596500a
LSD	6102.9	6424.8
C.V	2.5018	2.3281

*Means followed by the same letter(s) along the column for earthing up and pruning systems are not significantly different at 5 % probability level. Mean separation was done within each cultivation. Where; SS0=Single Stem x no Earthing Up (Control), SS1=Single Stem x Earthing up to 10 cm, SS2=Single Stem x Earthing up to 20 cm, SS3=Single Stem x Earthing up to 30 cm, DS0=Double Stem x no Earthing up, DS1=Double Stem x Earthing up to 10 cm, DS2=Double Stem x Earthing up to 20 cm DS3=Double Stem x Earthing up to 30 cm, TS0=Triple Stem no x Earthing up, TS1=Triple Stem x Earthing up to 10 cm, TS2=Triple Stem x Earthing up to 20 cm, TS3=Triple Stem x Earthing up to 30 cm.

In this study, an increase in yield was dependent on the earthing up level and pruning system used. In cultivation 1, the average marketable yields obtained from the treatment TS3 were 21.82 tonnes per hectare and 21.84 tonnes per hectare in cultivation 2 as opposed to the average yield from treatment controls (TS0, DS0 and SS0) as shown previously in Table 8. As a result, the projected total net economic return was higher in treatment TS3 as compared to all other treatments with SS0 being the least in both cultivations. The highest average net economic benefit in cultivation 1 and 2 were Kshs 524,000 and Kshs 596,500, respectively as compared to the lowest net economic return from treatment SS0 (Table 7). These values indicate that increase in marketable yield contributed to the significant improvement of gross income, which could offset the increased cost of production and even make tomato enterprise more profitable. In this study use of triple stem pruning systems appeared to be more productive as compared to single stem and double stem because of higher marketable yields.

The current results are in agreement with findings from [24] who observed that an increase in the number of productive stems led to an increase in yield and sales. This observation is further supported by [16] who found that a single stem pruning system gave the lowest marketable fruit number that ultimately reduced the economic return per plant. They also found that triple stem pruning system gave the highest number of marketable fruits per plant translating to higher yield and higher net economic return. According to [15], [28] and [30], tomatoes with more productive suckers and trusses gave higher net returns as compared to tomatoes with few productive suckers.

4.1 Conclusion and Recommendations of the study

From the results, it can be concluded that combinations of triple stem pruning system and earthing up to level 30 cm produced the highest number of the best quality fruit size (medium and large size fruits), it also gave the highest number of marketable fruits which reflected the final yields per hectare. It is therefore worthwhile investing in optimizing growth conditions, i.e. earthing up level 30 cm in combination with triple pruning system. Based on the benefit-cost ratio, it can be concluded that a combination of triple stem pruning system and earthing up to level 30 cm gave the best net return. Based on the findings of the study, the following recommendations were made. To improve tomato fruit size which consequently improves marketable yields and net economic benefits, farmers are encouraged to consider triple stem pruning system and earthing up to level 30 cm.

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