# EFFECTS OF EARTHING UP AND PRUNING SYSTEMS ON GROWTH AND YIELD OF TOMATO (*Solanum lycopersicum*)

***Keter, I.K.,[1*2] Oloo-Abucheli, G[1]. and Muraya, M.[1]***
[1]*Department of Plant Sciences, Chuka University, P.O. Box 109-60400, Chuka, Kenya*
[2]*Kenya Agricultural and Livestock Research Organization (KALRO), Coffee Research Institute, Koru Subcenter, P.O. Box 15-40104, Koru, Kenya*
**Corresponding author: E-mail: keterkiprop@gmail.com; gabucheli@chuka.ac.ke; moses.muraya@chuka.ac.ke*

**How to cite:**
Keter, I. K., Oloo-Abucheli, G. and Muraya, M. (2021). Effects of earthing up and pruning systems on growth and yield of tomato (solanum lycopersicum). *In: Isutsa, D. K. (Ed.). Proceedings of the 7th International Research Conference held in Chuka University from 3rd to 4th December 2020, Chuka, Kenya, p.8-18*

## ABSTRACT
Tomato (*Solanum lycopersicum*) is an important crop cultivated and consumed worldwide. It provides wide variety of nutrients with many health-related benefits like, protection against cancer, maintains blood pressure and reduces blood glucose level in people with diabetes. Despite the importance of tomato, its growth and yield is limited by choice of cultural practices mainly earthing up and pruning system. There is also limited knowledge on the effect of integrating pruning and earthing up on tomato growth and yield. This study investigated the effect of integration of pruning and earthing up on the growth and yield of tomato. 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. The findings of the study revealed that earthing up and pruning system had a significant ($p < 0.05$) effect on plant height and stem girth diameter at 45, 52, and 59 days after transplanting. The single stem pruning system and earthing up to 30 cm gave the tallest plant height with an average plant height of 69.80 cm in cultivation 1 and 71.50 cm in cultivation 2. Single stem pruning system and earthing up to 30 cm gave the largest stem girth diameter with mean stem girth diameter of 2.16 cm in cultivation 1 and 2.25 cm in cultivation 2. Triple stem pruning system, earthing up to 30 cm had highest marketable fruits with 64500 fruits/hectare in cultivation 1 and 64333 fruits/hectare in cultivation 2. To improve tomato growth and development which consequently improves marketable yields, farmers are encouraged to consider triple stem pruning system with earthing up to level 30 cm.
**Keywords**: Earthing up, Pruning system, Growth, Yield, marketable fruits, Tomato

## INTRODUCTION
The Agriculture sector is the mainstay of the Kenyan economy. The sector 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 [26]. In addition, 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 [26]. The agriculture sector includes 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 [26). [12] studied the performance of the horticultural sub-sector in Kenya and found that increase in horticultural exports led to increased AGDP.

Tomato (*Solanum lycopersicum*), is a popular and extensively cultivated vegetable among the promising commodities in horticultural production in Kenya. It belongs to the Genus Solanum and species, lycopersicum.

It is  a relatively small genus within the extremely large and diverse family Solanaceae [39]. Tomato is native to South America in the Andes Mountains of Peru and Bolivia [31]. It is the fourth most popular fresh-market vegetable after potatoes, cabbages, and onions because of its great yield potential and high nutritive value [36]. Its versatility in  fresh or processed form plays a major role in its spread as an important food commodity. Tomato is an important source of vitamins A (900 IU), C (23 mg) and B2 (0.04 mg), and minerals such as K (244 mg), Fe (0.5 mg), and P (27 mg) per 100 g sample [15]. Tomato contains important compounds that can help protect consumers against cancer, maintains blood pressure, and reduce blood glucose level in people with diabetes. It also contains key carotenoids such as lutein and lycopene that protect the eyes against induced damages [10].

Over the years, tomato production in Kenya has intensified [35]. Yields, however, have remained low due to a myriad of impediments, key among them being poor cultural practices such as improper earthing up level and poor pruning system. Therefore, the production of tomato could be increased through the application of better cultural practices such as proper pruning system and earthing up level, which contribute substantial amount of tomato yields. Earthing up is a technique in horticulture of piling soil around the base of the plant [9]. The technique triggers the initiation of plant roots that come in direct conduct with nutrients through a process of interception as it grows [27].

It encourages the development of additional roots and root hair to help improve stem length as well as suckers [37). 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 [7). It also improves the distribution of nutrients, water and air circulation which are important in the soil [32). Proper earthing up level therefore increase tomato fruit yield by creating favorable soil conditions, fruit initiation and development. Removal of unnecessary suckers on the other hand also has a great impact on the tomato fruit yield [34). 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 [33). It also regulates plant growth, flowering, and fruiting responses, [8). 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 as it is considered to be the major photo-assimilate sinker that reduces translocation of food to the fruits [22). However, most of tomato farmers give less regard 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.

## MATERIALS AND METHODS

### 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 0º19’59, N and 0º19’15.85’S. The area lies in the upper midland zone. Daily temperatures in the area range between 22º C to 36º 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
[21] 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.

### Earthing up and Pruning Systems

Transplanting was done on a level ground. Earthing up was done three weeks after transplanting 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.

Figure 1: Showing field Layout and tomato performance

**Data Collection**

***Tomato Stem Girth and Plant Height***

The height of 4 randomly selected and tagged plants per plot were measured using a tape measure every 7 days from 45 days after transplanting and the average height was recorded. The stem girth circumference of 4 randomly selected and tagged plants per plot was measured using a Vernier calliper to find its circumference after every 7 days from 45 days after transplanting and the average stem girth size was recorded in centimetres.

***Total Fruit Yield, Marketable and Unmarketable Yields***

All the fruits harvested per 2.5 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 calliper and categorized according to diameter size. Unmarketable fruits were those <6 cm in diameter and with physiological disorders such as cracks and blossom end rot or other types of blemish if any.

**Data Analysis**

Data were 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.

**RESULTS AND DISCUSSION**

**Effect of Earthing up levels and Pruning Systems on Plant Height**

The height of the plants with earthing up level 30 cm was statistically significant compared to those plants grown under the control treatment. At 45 days after transplanting (DAT), an average height of 41.20 cm and 42.26 cm was recorded in cultivation 1 and 2 respectively while the lowest plant height of 33.68 cm in cultivation 1 and 35.15 cm in cultivation 2 was recorded under the control. This observation was consistent with the results obtained at 52 DAT and 59 DAT which showed that the overall final plant height of 67.96 cm and 69.09 cm under earthing up level 30 cm. Pruning system significantly affected tomato plant height. The single stem at 45 DAT recorded the highest plant height at 39.25 cm in cultivation 1 and 40.22 cm in cultivation 2. Plant height under the triple stem and double stem pruning systems were not statistically different at 52 and 59 days after transplanting as shown in the Table 1.

**Table 1: Means of tomato plant height (cm) at different earthing up levels and pruning systems in two cultivations (2019/2020)**

| Cultivation | EU | 45DAT | 52DAT | 59DAT | PS | 45DAT | 52DAT | 59DAT |
|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 33.68d* | 35.34d | 49.32d | SS | 39.25a | 49.26a | 61.82a |
| | 10 | 36.67c | 48.08c | 55.53c | DS | 37.27b | 48.41b | 57.63b |
| | 20 | 39.26b | 53.33b | 61.93b | TS | 36.59c | 48.19b | 56.60c |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 30 | 41.20a | 57.73a | 67.96a | CV% | 2.10 | 1.62 | 1.46 |
| | CV% | 2.10 | 1.63 | 1.46 | LSD | 0.3211 | 0.3187 | 0.347 |
| | LSD | 0.3707 | 0.368 | 0.400 | | | | |
| 2 | 0 | 35.15d* | 41.87d | 50.65d | SS | 40.22a | 54.96a | 63.45a |
| | 10 | 37.87c | 50.31c | 56.36c | DS | 37.64c | 49.44c | 58.11b |
| | 20 | 39.33b | 54.76b | 62.80b | TS | 38.10b | 49.79b | 57.63c |
| | 30 | 42.26a | 58.65a | 69.09a | CV% | 2.05 | 1.489 | 1.411 |
| | CV% | 2.05 | 1.489 | 1.411 | LSD | 0.321 | 0.309 | 0.340 |
| | LSD | 0.370 | 0.357 | 0.393 | | | | |

*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.

Analysis of the treatment effect showed that the treatment SS3 at 45 DAT recorded significantly the tallest plant height at 43.05 cm and 44.75 cm in cultivation 1 and 2, respectively. Plant height under double and triple stem pruning systems combined with no earthing up level was statistically similar. Single stem pruning combined with earthing up level 30 cm recorded the best performance in plant height. Double stem pruning and earthing up level 30 cm recorded statistically taller plants, followed by a combined treatment of the DS and earthing up level 20 cm and 10 cm. The findings further showed that earthing up level 30 cm in combination with different pruning systems significantly influenced plant height compared to combined treatment of SS, DS and TS with levels 20 cm, 10 cm and the control level. Double stem pruning with no earthing up and triple stem pruning with no earthing up recorded the least plant height and the findings were consistent in both cultivations (Table 2).

**Table 2: Means of tomato plant height (cm) at different treatments in two cultivations (2019/2020)**

| | Cultivation 1 | | | Cultivation 2 | | |
|---|---|---|---|---|---|---|
| Treatment | 45DAT | 52DAT | 59DAT | 45DAT | 52DAT | 59DAT |
| SS0 | 34.65h* | 36.64i | 53.16h | 36.63d | 48.65e | 54.66e |
| SS1 | 37.09f | 50.45e | 59.48f | 38.49c | 53.65d | 60.78d |
| SS2 | 42.22b | 55.98c | 64.85d | 41.02b | 56.98c | 66.85c |
| SS3 | 43.05a | 58.98a | 69.80a | 44.75a | 60.59a | 71.50a |
| DS0 | 32.50i | 37.59g | 47.35j | 34.39e | 38.49f | 48.64g |
| DS1 | 35.34g | 46.85f | 54.66g | 36.64d | 48.65e | 54.66e |
| DS2 | 37.09f | 52.05d | 60.18e | 38.49c | 53.65d | 60.78d |
| DS3 | 41.02c | 57.14b | 68.35b | 41.02b | 56.98c | 68.35b |
| TS0 | 33.90i | 39.79h | 47.45j | 34.40e | 38.49f | 48.65g |
| TS1 | 37.58f | 46.95f | 52.45i | 38.49c | 48.65e | 53.65f |
| TS2 | 38.49e | 51.95d | 60.78e | 38.49c | 53.65d | 60.78d |
| TS3 | 39.52d | 57.09b | 65.73c | 41.02b | 58.39b | 67.43c |
| LSD | 0.6338 | 0.6287 | 0.6987 | 0.6338 | 0.6121 | 0.6803 |
| C.V | 2.0809 | 1.6007 | 1.4653 | 2.0297 | 1.4742 | 1.4101 |

*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 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.

The result revealed that different treatments significantly influenced plant height at different growth stages. The significant plant height recorded from treatment SS3 at different growth stages was because pruning allowed the foliage to receive adequate and uniform sunlight interception [17]. The adequate sunlight interception enabled the plant to photosynthesize more efficiently leading to increase in photoassimilates production which in turn increased the fraction of dry matter partitioned to the stem consequently boosting the growth [23]. The combination of the pruning system and earthing enhanced adequate air circulation and moisture for root extension. The proper root extension improves efficient water and nutrient uptake required for internodes and stem elongation which could have increased plant height ultimately. The current results are in agreement with those of [6] who did research on the effect of nutrient uptake on tomato growth and reported that plant growth vigour and internode length generally increased with the increase in nutrient uptake on tomato seedling. They further reported that plant growth and an increase in the length and number of internodes as a result of increased nutrient uptake led to a progressive increase in plant height. Earthing up also affects soil moisture content leading to better growth. It is worth noting that t availability of moisture determines plant nutrient uptake and that low moisture content reduces root growth and consequently limits the ability of the plant to utilize nutrients in amounts required for optimal growth [25] further observed that soil moisture at an early vegetative growth is one of the determinants of higher growth and yield.

According to [20] in their study on soil phosphorus acquisition in the rhizosphere of intercropped plant species, they found that efficient acquisition and uptake of phosphorus and other nutrients significantly increased plant height compared to inefficient nutrient uptake. [42] found that the sesame plant had better growth as a result of higher nutrients availability and uptake due to proper root development. [2] also observed in their study on the effect of micronutrients in presence of different levels of organic manure on growth and yield of tomato that nutrient uptake whether organic or inorganic increase plant growth and development. In tomato production, therefore, earthing up is key in promoting proper tomato root development which enhance efficient nutrient uptake ultimately increasing growth. [33] studied the effect of shoot pruning and inflorescence thinning on growth, yield and fruit quality and they established that few plant sucker densities allows desirable etiolation and causes greater plant growth.

**Effect of Earthing up Levels and Pruning Systems on Tomato Stem Girth**

The largest stem girth diameter at 45 DAT (0.67 cm in cultivation 1 and 0.84 cm in cultivation 2) was recorded from earthing up to 30 cm while the smallest stem girth diameter (0.45 cm in cultivation 1 and 0.57 cm in cultivation 2 (Table 3). The results at 52 DAT and 59 DAT were consistent with those of 45 DAT in both cultivations. Generally, the level earthing up to 30 cm recorded the largest stem girth diameter in both cultivations as shown in Table 3. In the case of the pruning system, single stem recorded the largest stem girth diameter at 0.64 cm in cultivation 1 and 0.78 cm in cultivation 2 as at 45 DAT. The stem girth growth rate was consistent from 45 DAT, 52 DAT and 59 DAT in both cultivations with the single stem recording the overall largest stem girth diameter at 1.74 cm and 1.82 cm in cultivation 1 and 2 respectively as shown in the Table 3.

**Table 3: Means of tomato stem girth size (cm) at different earthing up levels and pruning systems in two cultivations (2019/2020)**

| Cultivation | EU | 45DAT | 52DAT | 59DAT | PS | 45DAT | 52DAT | 59DAT |
|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0.45d* | 0.86c | 1.27d | SS | 0.62a* | 1.16a | 1.74a |
| | 10 | 0.52c | 0.98c | 1.46c | DS | 0.54b | 1.01b | 1.51b |
| | 20 | 0.55b | 1.04b | 1.55b | TS | 0.48c | 0.92c | 1.36c |
| | 30 | 0.67a | 1.25a | 1.88a | CV% | 5.939 | 5.528 | 5.787 |
| | CV% | 5.939 | 5.528 | 5.787 | LSD | 0.013 | 0.023 | 0.036 |
| | LSD | 0.015 | 0.026 | 0.041 | | | | |
| 2 | 0 | 0.57d* | 0.95c | 1.33d | SS | 0.78a* | 1.30a | 1.82a |
| | 10 | 0.65c | 1.08c | 1.52c | DS | 0.67b | 1.13b | 1.58b |
| | 20 | 0.69b | 1.16b | 1.62b | TS | 0.61c | 1.01c | 1.42c |
| | 30 | 0.84a | 1.40a | 1.96a | CV% | 5.804 | 5.804 | 5.804 |
| | CV% | 5.804 | 5.804 | 5.804 | LSD | 0.016 | 0.027 | 0.037 |
| | LSD | 0.018 | 0.031 | 0.043 | | | | |

*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.

Analysis of interaction showed that the treatment SS3 recorded the largest stem girth diameter at 0.77 cm in cultivation 1 and 0.96 cm in cultivation 2 at 45 DAT. The treatment TS0 recorded the smallest stem girth diameter at

0.40 cm in cultivation 1 and 0.49 cm in cultivation 2 (Table 4). These results also showed consistency at 52 and 59 days after transplant. The treatment combinations with earthing level 30 cm recorded the largest stem girth diameter compared to combined treatments of pruning system and earthing up level 20 cm, 10 cm and the control. Stem girth under combined treatment of single stem pruning and earthing up level 20 cm not statistically different from DS30 and TS30. Besides, the results revealed that stem diameter was statistically similar under treatment combination SS10 and DS20, this trend was similar in both cultivations. Stem diameter was statistically similar under SS0 and DS0 although the two treatments were significantly different compared to TS0 that recorded smaller diameter.

**Table 4: The means of tomato stem girth size (cm) at different combined effect of earthing up and pruning systems (Treatment effects) in two cultivations (2019/2020)**

| | Cultivation 1 | | | Cultivation 2 | | |
|---|---|---|---|---|---|---|
| Treatment | 45DAT | 52DAT | 59DAT | 45DAT | 52DAT | 59 DAT |
| SS0 | 0.52d* | 0.99d | 1.48d | 0.66d | 1.10d | 1.54d |
| SS1 | 0.58c | 1.08c | 1.62c | 0.72c | 1.20c | 1.69c |
| SS2 | 0.62b | 1.15b | 1.74b | 0.77b | 1.29b | 1.81b |
| SS3 | 0.77a | 1.43a | 2.16a | 0.96a | 1.61a | 2.25a |
| DS0 | 0.43f | 0.83f | 1.22f | 0.54f | 0.91f | 1.27f |
| DS1 | 0.52d | 0.99d | 1.48d | 0.66d | 1.10d | 1.54d |
| DS2 | 0.58c | 1.08c | 1.62c | 0.72c | 1.20c | 1.69c |
| DS3 | 0.62b | 1.15b | 1.73b | 0.77b | 1.29b | 1.81b |
| TS0 | 0.40g | 0.77g | 1.13g | 0.49g | 0.84g | 1.18g |
| TS1 | 0.45ef | 0.86ef | 1.27ef | 0.57ef | 0.95ef | 1.33ef |
| TS2 | 0.47e | 0.88e | 1.31e | 0.58e | 0..95e | 1.37e |
| TS3 | 0.62b | 1.16b | 1.74b | 0.78b | 1.30b | 1.82b |
| LSD | 0.026 | 0.047 | 0.073 | 0.033 | 0.055 | 0.076 |
| C.V | 6.023 | 5.630 | 5.901 | 5.912 | 5.912 | 5.917 |

*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 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.

The results indicate that different treatments significantly influenced stem girth at different growth stages. Earthing up in this case, coincided with the active tomato growth stage and improved soil condition which encouraged strong root growth and proper absorption of more nutrients leading to an increase in stem diameter. The results of this study are also similar to those found by [11] and [19] in their study on shoot-to-root coordination on plant carbon and nitrogen acquisition, they found that the stem diameter of proper roots developed plants was larger than the equivalent component in the poor-rooted plants. The result of the current study is also in agreement with the findings
[28] who found in their various study on the effects of root zone nutrient concentration on the growth and nutrient uptake of tomato that improved nutrient uptake and partitioning increase growth components in plants.

Improper nutrient uptake and partitioning cause a decrease in stem diameter and total dry matter [38], and that the severe nutrient deficit was found to delay stem elongation in tomato according to the study by [5]. It is also possible that pruning and earthing up during active tomato growth enhanced efficient nutrient and partitioning to stem ultimately increasing stem girth. In line with the current findings, [14**]** who researched on the effects of pruning location on growth and fruiting of three tomatoes, found that pruning enhances efficient partitioning of nutrients which ultimately enhances stem growth. [24] who did research on the photosynthetic rate of the vegetative sink in tomato indicated that change in stem diameter reflect changes in stem tissue nutrient partitioning. The strong stem may be a useful indicator of the potential of the plant to produce high final yield.

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

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 5).

**Table 5: 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 6 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 tends 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 10 cm, 20 cm to 30 cm. as shown in table 6. 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 6

**Table 6: 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 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.

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 6). 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 [29]. 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 [18] 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 present results are also in agreement with those of [30] 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. [16] 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 [40] 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.

**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 7).

**Table 7 Means of tomato total yield hectare at different earthing up levels and pruning system in two cultivations (2019/2020)**

| Cultivation | EU | ton/ha | PS | ton/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 was affected by earthing up and pruning. There were significant effects 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 8. 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 8.

**Table 8: 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 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.

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 [45]. In this context, it will be expected that any positive growth impact of increasing earthing levels improved soil aeration and consequently root hair development [43]. 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 [41] who showed that an increase in root surface area enhances nutrient uptake leading to increased total yields and the number of fruits per plant. [6] also reported the highest crop yield per hectare after earthing up potato 15 days after complete plant emergence. Similarly, [44] 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. [4], 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

## CONCLUSION AND RECOMMENDATIONS OF THE STUDY

Combined treatment of single stem pruning system and earthing up level 30 cm gave the highest plant growth and development. 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 in the final yields per hectare. It is therefore worthwhile investing in optimizing growth conditions, i.e. earthing up to level 30 cm in combination with a triple pruning system. Based on the findings of the study, the following recommendations were made. To improve tomato growth and development which consequently improves marketable yields, farmers are encouraged to consider triple stem pruning system and earthing up to level 30 cm.

## ACKNOWLEDGEMENT

I wish to extend my sincere gratitude to Chuka University Internal Research Funds for partially sponsoring my research. I am very grateful to Chuka University through the Department of Plant Science for providing facilities to run the experiments for this study. I would like to express my sincere thanks and appreciation to my supervisors Dr. Grace Abucheli, and Dr. Moses Muraya for their guidance and support throughout the study period.

**REFERENCES**

Abbasi NA, Zafar L, Khan HA, Qureshi AA. Effects of naphthalene acetic acid and calcium chloride application on nutrient uptake, growth, yield, and post-harvest performance of tomato fruit. *Pak. J. Bot*. 2013; *45*(5): 1581-1587.

Afsun J, Khatun K, Mostarin T, Haq ME, Islam MN, Biswas BR, Ahmed M. Effect of Micronutrients in Presence of Different Levels of Organic Manure on Growth and Yield of Tomato (*Solanum Lycopersicum* L.). *Asian Journal of Agricultural and Horticultural Research*. 2019; 1-13.

Ahmad H, Yeasmin S, Rahul S, Mahbuba S, Uddin AJ. Influence of sucker pruning and old leaves removal on growth and yield of cherry tomato. *Journal of Bioscience and Agriculture Research*. 2017; *12*(02): 1048- 1053.

Amundson S, Deyton DE, Kopsell DA, Hitch W, Moore A. Sams, CE. Optimizing plant density and production systems to maximize the yield of greenhouse-grown 'Trust'Tomatoes. *HortTechnology*. 2012; *22*(1): 44- 48.

Antisari LV, Carbone S, Gatti A, Vianello G, Nannipieri P. Uptake and translocation of metals and nutrients in tomato grown in soil polluted with metal oxide (CeO 2, Fe 3 O 4, SnO 2, TiO 2) or metallic (Ag, Co, Ni) engineered nanoparticles. *Environmental Science and Pollution Research*. 2015; *22*(3): 1841-1853.

Azarmi R, Hajieghrari B, Giglou A. Effect of Trichoderma isolates on tomato seedling growth response and nutrient uptake. *African Journal of Biotechnology*. 2011; *10*(31): 5850-5855.

Benjamin JG, Nielsen DC, Vigil MF. Quantifying effects of soil conditions on plant growth and crop production, Geoderma. 2003; 116:137–148.

Bertin N, Genard M. Tomato quality as influenced by pre-harvest factors. Scientia Horticulturae. 2018; 233: 264- 276.

Bertolino S, Asteggiano L, Saladini MA, Giordani L, Vittone G, Alma A. Environmental factors and agronomic practices associated with Savi's pine vole abundance in Italian apple orchards. *Journal of Pest Science*. 2015; 88 (1): 135-142.

Bhowmik D, Kumar KS, Paswan, S, Srivastava S. Tomato-a natural medicine and its health benefits. *Journal of Pharmacognosy and Phytochemistry*. 2012; *1*(1): 33-43.

Chen C, Xu F, Zhu JR, Wang RF, Xu ZH, Shu LZ, Xu WW. Nitrogen forms affect root growth, photosynthesis, and yield of tomato under alternate partial root-zone irrigation. *Journal of Plant Nutrition and Soil Science*. 2016; *179*(1): 104-112.

Dube AK, Ozkan B, Govindasamy R. Analyzing the export performance of the horticultural sub-sector in Ethiopia: ARDL bound test cointegration analysis. *Horticulturae*. 1018; *4*(4), 34.

Faling M. Framing agriculture and climate in Kenyan policies: a longitudinal perspective. *Environmental Science & Policy*. 2020; *106*: 228-239.

Falodun EJ, Ogedegbe SA. Effects of pruning location on growth and fruiting of three tomatoes (Lycopersicon esculentum Mill) varieties in the rainforest zone of Nigeria. *Agro-Science*. 2019; *18*(3), 1-4.

Gastélum-Barrios A, Bórquez-López RA, Rico-García E, Toledano-Ayala M, Soto-Zarazúa GM. Tomato quality evaluation with image processing: A review. *African Journal of Agricultural Research*. 2011; *6*(14): 3333- 3339.

Getachew T, Belew D, Tulu S. Combined Effect of Plant Spacing and Time of Earthing up on Tuber Quality Parameters of Potato (*Solanum tuberosum* L.) at Degem District, North Showa Zone of Oromia Regional State. *Asian Journal of Crop Science*. 2012; 5(1): 24-32.

Glanz-Idan N, Wolf S. Upregulation of photosynthesis in mineral nutrition-deficient tomato plants by reduced source-to-sink ratio. *Plant Signaling & Behavior*. 2020; *15*(2): 1712543.

Goda Y, Mohamed AA, Helaly AA, and El-Zeiny OAH. Effect of shoot Pruning on Growth, Yield, and Fruit Quality of Husk Tomato (*Physalis pubescens* L.). *Journal of American Science*. 2014; 10(1): 5-10.

Gupta S, Shi X, Lindquist I E, Devitt N, Mudge J, Rashotte AM. Transcriptome profiling of cytokinin and auxin regulation in tomato root. *Journal of Experimental Botany*. 2013: *64*(2), 695-704.

Hinsinger P, Betencourt E, Bernard L, Brauman A, Plassard C, Shen J, Zhang F. P for two, sharing a scarce resource: soil phosphorus acquisition in the rhizosphere of intercropped species. *Plant Physiology*. 2011; *156*(3): 1078-1086.

Jaetzold R, Schmidt H, Hornetz B, Shisanya C. Farm management handbook. *Vol II, Part C, East Kenya. Subpart C*, *1*; 2007

Ji Y, Nuñez Ocaña, D, Choe D, Larsen DH, Marcelis LF, Heuvelink E. Far-red radiation stimulates dry mass partitioning to fruits by increasing fruit sink strength in tomato. *New Phytologist*. 2020

Johannes F, Max J, Schmidt L, Urbanus, Mutwiwa N, Kahlen K. Effects of shoot pruning and inflorescence thinning on plant growth, yield, and fruit quality of greenhouse tomatoes in a tropical climate. *Journal of Agriculture and Rural Development in the Tropics and Subtropics*. 2016; 117(1): 45–56.

Kanai S, Moghaieb RE, El-Shemy HA, Panigrahi R, Mohapatra PK, Ito J, Fujita K. Potassium deficiency affects water status and photosynthetic rate of the vegetative sink in greenhouse tomato prior to its effects on source activity. *Plant Science*. 2011; *180*(2): 368-374

Khan MZ, Ahmed H, Ahmed S, Khan A, Khan RU, Hussain F, Sarwar S. Formulation of humic substances coated fertilizer and its use to enhance K fertilizer use efficiency for tomato under greenhouse conditions. *Journal of Plant Nutrition*. 2019; 42(6): 626-633.

Kogo BK, Kumar L, Koech R. Climate change and variability in Kenya: a review of impacts on agriculture and food security. *Environment, Development and Sustainability*, 2020; 1-21.

Kudoyarova GR, Dodd IC, Veselov DS, Rothwell SA, Yu, Veselov S. Common and specific responses to availability of mineral nutrients and water. *Journal of Experimental Botany*. 2015; 66(8): 2133-2144.

Kumar P, Edelstein M, Cardarelli M, Ferri E, Colla G. (2015). Grafting affects growth, yield, nutrient uptake, and partitioning under cadmium stress in tomato. *HortScience*. 2015; *50* (11): 1654-1661.

Li T, Heuvelink E, Marcelis LFM. Quantifying the source–sink balance and carbohydrate content in three tomato cultivars. Frontiers in Plant Science 2015; 6:1–10.

Maboko MM, Du Plooy CP, and Chiloane S. Effect of plant population, fruit and stem pruning on yield and quality of hydroponically grown tomato. *African Journal of Agricultural Research*. 2011; *6*(22), 5144-5148.

Maleka KG. Determination of yield and yield components of selected tomato varieties in soil with different levels of cattle manure application. Theses and dissertations (agriculture). 2012; 199.

Mattar MA, El-Abedin TKZ, Alazba AA, Al-Ghobari HM. Soil water status and growth of tomato with partial root- zone drying and deficit drip irrigation techniques. *Irrigation Science*. 2020; *38*(2), 163-176.

Max JFJ, Schmidt L, Mutwiwa UN, Kahlen K. Effects of shoot pruning and inflorescence thinning on plant growth, yield, and fruit quality of greenhouse tomatoes in a tropical climate. *Journal of Agriculture and Rural Development in the Tropics and Subtropics (JARTS)*. 2016; *117* (1): 45-56.

Mondal MMA, Puteh AB, Razzaque AHM. De-branching improves morpho-physiological characters, fruit quality, and yield of tomato. *Pakistan J. Bot*. 2016; *46*, 2249-2253.

Ochilo WN, Nyamasyo GN, Kilalo D, Otieno W, Otipa M, Chege, F. Lingeera EK. Characteristics and production constraints of smallholder tomato production in Kenya. *Scientific African*, 2019; *2*.

Parr B, Bond JK, Minor T. *Vegetables and Pulses Outlook, April 2018* (No. 1495-2018-3227).

Pokhrel B, Sorensen JN, Petersen KK. Effect of plant-based organic fertilizers and chicken manure extract on plant growth and root zone activities of tomato. *In III International Symposium on Organic Greenhouse Horticulture*. 2016; 1164: 173-180.

Ronga D, Zaccardelli M, Lovelli S, Perrone D, Francia, E, Milc J, Pecchioni N. Biomass production and dry matter partitioning of processing tomato under organic vs conventional cropping systems in a Mediterranean environment. *Scientia horticulturae*, 2017; *224*: 163-170.

Sibomana MS, Workneh TS, Audain K. A review of postharvest handling and losses in the fresh tomato supply chain: a focus on Sub-Saharan Africa. *Food Security*. 2016; 8(2): 389-404.

Tafi M, Siyadat S, Radjabi R, Mojadam M. The effects of earthing up on the potato yield in Dezful (Khouzestan, Iran) weather condition. *Middle-East Journal of Scientific Research*. 2010; *5*(5): 392-396.

Tracy SR, Black CR, Roberts JA, Mooney SJ. Exploring the interacting effect of soil texture and bulk density on root system development in tomato (*Solanum lycopersicum* L.). *Environmental and Experimental Botany*. 2013; *91*: 38-47.

Tripathy S, Bastia DK. Irrigation and nutrient management for yield augmentation of summer sesame (Sesamum indicum L.). *Journal of Crop and Weed*. 2012; *8*(2): 53-57.

Wang J, Li Y, Niu W. Deficit Alternate Drip Irrigation Increased Root-Soil-Plant Interaction, Tomato Yield, and Quality. *International Journal of Environmental Research and Public Health*. 2020; *17*(3): 781.

Wang Y, Liu F, Richardt Jensen C. Comparative effects of partial root-zone irrigation and deficit irrigation on phosphorus uptake in tomato plants. *The Journal of Horticultural Science and Biotechnology*. 2012; *87*(6), 600-604.

Zakaria NI, Ismail MR, Awang Y, Megat Wahab PE, Berahim Z. Effect of Root Restriction on the Growth, Photosynthesis Rate, and Source and Sink Relationship of Chilli (*Capsicum annuum* L.) Grown in Soilless Culture. *BioMed Research International*, *2020*.

**********