Original Article | Open Access

Mutisya and Kere, 2019. 18: 29-37. J Environ Agric Sci (ISSN: 2313-8629)

Thick Grass Mulching Improves Soil Moisture and Weed Control Without Improving Yield and Quality Of Container Grown Tomato (*Solanum lycopersicum* L.) Under Plastic Tunnel Conditions

Beatrice Mwende Mutisya[1], George Mbira Kere[1,*]

Edited by:
Muhammad Ishaq Asif Rehmani,
Ghazi University, D.G. Khan, Pakistan
Reviewed by:
M. Khalil Ur Rehman,
Nanjing Agricultural University, Nanjing, China
Haseeb-Ur-Rehman,
B.Z. University, Multan, Pakistan
Asim Muhammad,
KPK Agricultural University, Peshawar, Pakistan

Received
November 13, 2018
Accepted
January 12, 2019
Published Online
March 28, 2019

Abstract: Mulching is a common practice in tomato production both under protected and field conditions. Container gown tomato production is rapidly gaining popularity among greenhouse tomato growers in Kenya. Although mulching is known to conserve water and reduce weed menace in tomato production, little is currently documented on effect of grass mulching rate on yield and growth of container grown tomatoes under plastic tunnel conditions. The main objective of the study was to investigate the effect of mulching depth on growth and yield of container grown tomatoes under plastic tunnel conditions. The experimental design was randomized complete block design replicated three times. The treatments consisted of four mulching depths; no mulch, 5 cm, 7 cm and 10 cm. Data was collected on growth, yield and yield components and weed density. The data was subjected to analysis of variance at P =0.05 using MINITAB statistical software and significant means separated using Tukeys at P = 0.05. Mulching with grass 7 and 10 cm depths significantly delayed days to 50% flowering. Total tomato yield was highest when no mulch was applied. Fruit quality (total soluble solids, total soluble solids: titratable acidity) were significantly highest with no mulch. The depressed yield and quality of under higher grass mulching rates could be attributed to reduced rhizospheric temperature. Thick grass mulching depth significantly reduced weed density per unit area. Grass mulching depths significantly sustained high and low soil moisture and temperature respectively. The depressed yield Grass mulching above 7 cm depth is detrimental to container grown Cherry tomato under greenhouse conditions. Further investigation is required to understand the interactive effect of mulching depth and irrigation schedule in container grown tomatoes..

Keywords: Water conservation,Cherry tomato, grass mulch, plastic tunnel.

***Corresponding author:** George Mbira Kere:gmbira@kabianga.ac.ke

Cite this article as: Mutisya, B.M. and G.M. Kere. 2019.**Thick grass mulching improves soil moisture and weed control without improving yield and quality of container grown tomato (*Solanum lycopersicum* L.) under plastic tunnel conditions**. Journal of Environmental & Agricultural Sciences. 18:29-37.

1. Introduction

Tomato is an important vegetable crop worldwide grown for its edible fruits (Bashir et al., 2018; Bashir et al., 2019; Gao et al., 2019). Tomato fruit is a rich source of potassium and antioxidants such as β-carotene, lycopene and tocopherols (Chaudhary et al., 2018; Noranjo et al., 2016; Perveen et al., 2015; Petropoulos et al., 2019). Tomato is recommended for healthy diet due to lower fat content and lack of harmful cholesterol (Parveen et al., 2015). Tomato is one of the most important vegetable crops grown in Kenya (Ochilo et al., 2019). It is ranked second after potatoes in terms of production volumes and value in Kenya. Recently production and yield of tomatoes has significantly increased in Kenya (HCD, AFA & KNBS, 2016; Ochilo et al., 2019).

Recent statistics indicate that Kenya is a leading producer of tomtoes in Sub-saharan Africa with annual production of 0.41 million metric tones of tomato fruits (FAO, 2018). Tomato production contributes to 7 and 14 % of total national horticultural and vegetation production, respectively

[1]School of Agriculture and Biotechnology, University of Kabianga, Kericho, Kenya.

(Geoffrey et al., 2014). Tomato crop is therefore an important fruit vegetable in Kenya. Total area under tomato cultivation and its fruit production in Kericho County was 442 ha and 4,159 metric tons while the national hectarage and yield of tomato was 20,111 ha and 341,026 metric tons for the growing season 2015/2016 (HCD, AFA and KNBS (2016). This shows a lower yield performance (45% of the national average) of tomato in Kericho County compared to national average. The reduction in production of tomatoes in the region could be attributed to adverse abiotic and biotic factors, which are characteristics of rainy highlands. The low temperatures and high rainfall in the tropical highlands such as Kericho adversely affect tomato production.

Tomato cultivation in Kenya is predominantly done under open-field and rain-fed conditions. Inspite of recent development in greenhouse technologies, Kenyan farmers prefer open-field tomato cultivation in rain-fed areas of Kenya (Geoffrey et al., 2014). In the recent past, tomato growers have opted for supplementary irrigation during dry season to produce better yields and quality quality, with low disease incidences (Silva et al., 2014). Greenhouse tomato production is an acceptable approach for increased performance of tomatoes in places with suboptimal temperatures. In Kenya, due to lack of availability of indeterminate tomato varieties, farmers were unable to maximize their production under greenhouse conditions. Therefore farmers prefer not to invest for the development of greenhouse structure and grow tomato in open-field (HCD, AFA and KNBS, 2016). Although Cherry tomato is recognized as the ancestor of tomato, it is not considered as an alternative to profitable tomato production in Kenya.

Weeds are considered as one of the major factors limiting crop yields by competing with the crops for various resources. Due to environmental and ecological concerns of chemical control of weed, non-chemical weed management (Arora et al., 2019; Brown et al., 2019; Iqbal et al., 2019). The application of mulching significantly alters plant environment by limiting soil moisture evaporation losses, weed growth suppression and modifications of soil environment including physical (temperature and structure), chemical (fertility, pH) and biological (micro-organisms) properties soil (Kader et al., 2017; Singh et al., 2015).

Grass mulch improves growth and yield of various crops (Iftihar et al., 2011; Manu et al., 2018; Teame et al., 2017). Organic mulches such as grass clippings are known to stabilize soil temperature and soil moisture (Zhang et al. 2015; Bavougian and Reed, 2018). The positive effect of improved soil moisture content and soil temperature leads to better crop performance. The increased growth and yield performance through addition of grass mulch is attributed to improved soil physical properties (Are et al., 2018; Kyere et al.,2018) conservation of soil moisture (Kassahun, 2017) and reduced weed menace (Zhang et al.,2015; Kere et al., 2003). Application of grass mulch caused significant increase in total nitrogen, and availability of macronutrients (nitrogen, phosphorous and potassium), moreover concentration of these nutrients in soil increased with increasing quantity of mulch (Fang et al., 2008; Fang et al., 2010). The effect of grass mulching rate on yield and quality of container grown tomatoes is rarely addressed in literature.

Tomato production in container is gaining popularity especially in urban and peri-urban agriculture. The containers are versatile in growing vegetables using soil or other substrate media transportation of plants to desired points and growing of crops where native biotic or soil factors restrict growing of crops (Nambuthiri et al., 2015).

Plastic containers, perforated with holes at the lower portions, are the common forms of containers used for nursery and vegetable productions both within the greenhouse and field conditions. The plastic containers are beneficial in management of soil borne pests as well as minimizing water requirement. To reduce water evaporative water losses and maintaining root zone temperatures as optimal ranges for increased productivity. Grass mulching is generally known to reduce soil temperatures and conserve soil moisture in conventional cultivation (Tegen et al., 2015; Kere et al., 2003). Little is currently reported in the literature regarding the effect of different rates of grass mulch on the performance of potted cherry tomato under greenhouse conditions is rarely addressed.. The purpose of the study was to investigate the effect of mulching depth on growth, yield and quality of tomatoes grown under container grown under greenhouse conditions of tropical highlands.

2. Materials and Methods

2.1.Experimental Conditions

The study of was conducted at University of Kabianga Demonstration Farm. The Farm is located within the Mau Complex at an altitude of 1700 m above the sea level at Longitude 35.2818 S along

Latitude 0.3661 E. The annual average rainfall and temperature ranges between 1400 to 2000 mm and 16 to 27°C, respectively. The daily temperature during the study period was maintained at an average of 24.8 °C by controlling the ventilation and shading condition of the plastic tunnel.

The experimental design was randomized complete block design replicated three times. The treatment consisted of four grass mulch depths (0, 5, 7 and 10 cm). The weight of grass mulch per container was 0, 19.5, 33.5 and 37.5 g, whereas different mulching depths i.e., 0, 5, 7 and 10 cm, respectively, were used. Potting substrate was prepared by mixing well decomposed poultry manure and top soil in the ratio of (poultry manure: top soil; 1:2 by v/v). The mixture was solarized for 6 weeks with weekly turning) within the plastic tunnel.

The pH (H_2O), air porosity, water porosity of the substrate was 4.52, 8.9 and 49.2%. Plastic bags (25 L; 35.56 × 35.56 × 30.48 cm) were filled with 5.61 kg of the potting substrate leaving 13 cm from the top unfilled. The pots were arranged at a spacing of 50 × 40 within the plastic tunnel and irrigated to pot capacity. Healthy Cherry tomato seedlings (21 days old) were transplanted on 1st March 2017.

The plants were initially watered at the rate of 300 ml per plant per day. Thereafter watering was increased to 500, 600 and 1000 mL for the 3rd, 4th and rest of the growing periods, respectively.

2.1. Data Collection

To assess the effects of treatments applied data on following parameters were recorded.

2.1.1. Growth and Development

The height of the main stem of 8 plants per treatment was measured using a tape measured at weekly interval. The girth of the main stem measured weekly using vernier caliper. The number of days to 50% flowering and fruiting was also recorded.

2.1.2. Weed density

The weed data was taken at 30 days after transplanting, weeds were uprooted from all the pots. Harvested weed plants were washed and blotted dry and oven dried at 105°C for 10 minutes then reduced to 60°C for 72 hours. The dry weight was then recorded.

2.1.3. Tomato Yield and Yield Components

Tomatoes were harvested four times and terminated thereafter due to serious outbreak of tomato late blight. The cumulative yield was computed as yield per plant or per unit area. The number of fruits per truss was recorded in the first four trusses in all branches and averaged. The individual weight of the fruits at each harvest was computed and treatment averages were recorded at the end of the study.

2.1.4. Soil Moisture and Temperature

Soil moisture was taken at 1.00-2.00 pm during the week days throughout the study period using gravimetric method.The soil and water measutements were taken between 1.00 and 2.00 pm since the period coincided with maximum ambient temperature to allow accurate determination of treatment effect. Soil temperature was taken at a depth 15 cm at the time of moisture data collection using soil thermometer. The average data was computed and analyzed.

2.1.5. Fruit Quality

Tomato nutritional quality (°Brix), taste (titratable acidity) were measured as described by Labate et al. (2010). Briefly, 10 mL of blended fruit juice was diluted with 40 mL of distilled water and vortexed for 10 minutes. Two drops of phenolphthalein indicator was added and vortexed again to attain homogenous mixture. The mixture was then titrated against 0.1 M NaOH. % titratable acidity was estimated using the formula,

% Titratable acidity = [(volume of NaOH used × 0.0064 (acid factor)/volume of blended fruit used] × 100

The appearance quality was estimated by measuring the fruit roundness (ratio of the cross sectional diameter to longitudinal diameter). % fruit defects was estimated by computing the number of fruits with defects divided by the total number of fruits and result multiplied by 100.

Table 1. Effect of grass mulching depth on growth and development parameters of potted cherry tomato in a plastic tunnel

Mulching Depth (cm)	Plant Height (cm)	Stem diameter (cm)	Days to 50% flowering	Days to 50% fruiting
0	89.87	1.03 a	14.33 b	28.33
5	79.33	0.86 ab	14.67 b	32.33
7	75.71	0.81 b	15.33 a	32.33
10	71.97	0.80 b	16.00 a	29.33

Means in a column followed by different letters are significantly different at p = 0.05.

3. Results

3.1. Effect of grass mulching depth on growth and development of cherry tomato

Table 1 illustrates the effect of grass mulching depth on growth and development of potted cherry tomato in a plastic tunnel. Grass mulching depth did not significantly affect height and days to 50% fruiting. Stem diameter significantly decreased with increasing depth of mulching. Thicker mulching depth (7 and 10 cm) significantly delayed flowering.

3.2. Effect of grass mulching depth on yield and yield components of cherry tomato

Table 2 shows the influence of grass mulching depth on yield and yield components of potted tomato plants in a plastic tunnel. Individual fruit weight ranged from 12.3 to 16.0 g. Fruits harvested from mulched pots with grass mulch at 5 cm depth were significantly smallest. The remaining mulch treatments produced fruits with statistically similar weights. Number of fruits per truss followed a similar pattern where 5 cm depth grass mulching produced lowest fruit numbers. In this study, no mulch treatment produced the highest tomato fruit yield per plant. Although not statistically significant, the 7 cm grass mulching depth was second best with respect to total fruit yield.

3.3. Effect of mulching depth on tomato fruit quality

Grass mulching had no significant effect on total soluble solids and fruit shape (Table 3). However, the findings of this study revealed that either no mulch or grass mulching at 5 cm depth had significantly highest and percentage of fruits with physiological defects. The main physiological defects observed were cat face, radial fruit crack and blossom end rot (data not presented). Mulching depth significantly influenced titratable acidity ($p = 0.05$). Titratable acidity was highest with fruits harvested from containers mulched with grass at 5 and 7 cm depths. Interestingly, no mulch or grass mulch at 10 cm registered the lowest total titratable acidity.

Table 2. Influence of grass mulching depth on yield and yield components of cherry tomato

Mulching depth (cm)	Individual fruit weight (g)	Fruits per truss	Yield per plant (g/plant	Yield (kg/m^2)
0	13.92 ab	3.18 ab	230.8 a	0.030 a
5	12.26 b	2.73 b	135.7 b	0.010 b
7	12.53 ab	3.18 ab	166.4ab	0.014 b
10	16.02 a	3.79 a	132.9 b	0.009 b

Means in a column followed by different letters are significantly different at $p = 0.05$.

Regarding the ratio of total soluble solids to total titratable acid, treatment without mulch was ranked first and statistically at par with mulching (at depth of 10 cm). The effect of grass mulching depth on fruit shape was not detected in this study.

3.4. Effect of different mulching depth on weed density

At 30 days post transplanting, grass mulching significantly reduced the weed density of potted tomato plants at varying degrees. The effectiveness of grass mulching depth on weed density was in the order 10 cm > 7cm > 5 cm > no mulch (Table 4). However, at 60 days after transplanting weed data was not collected as previously planned since negligible number of weeds emerged after weeding at 30 days after transplanting. Mulching depth at 7 or 10 cm had the best effect with respect to weed control.

3.5. Effect of grass mulch depth on substrate temperature and moisture

Table 5 summarizes the effect of mulching depth on substrate moisture and temperature levels. The level of soil moisture increased with increase in grass mulch depth. 10-cm grass mulching depth maintained substrate moisture about 3-fold relative to no mulch treatment. Grass mulching at 10 cm depth reduced soil temperature by about 8.9°C (34.2%) compared no mulch treatment. With increasing mulching rates substrate temperature decreased while moisture content increased.

Table 3. Effect of grass mulching depth on potted cherry tomato fruit quality in a plastic tunnel

Grass mulching depth (cm)	Total soluble solids (% brix)	Total titratable acidity	Total soluble solids/acid ratio	Ratio of lateral and longitudinal diameter	% fruit defects
0	5.00	0.54 b	9.32 a	0.86	1.97 a
5	4.83	0.75 a	6.47 c	0.81	2.50 a
7	5.00	0.73 a	6.83 bc	0.85	0.87 b
10	4.83	0.59 b	8.28 ab	0.81	0.46 b

Means in a column followed by different letters are significantly different at $p = 0.05$

Table 4. Effect of mulching depth on weed density in potted tomato in plastic tunnel

Mulching depth (cm)	Weed density (g/m^2)	% Reduction in weed biomass
0	15.26 a	-
5	6.42 b	57.93 b
7	2.21 c	85.52c
10	1.20 c	92.14c

Means in a column followed by different letters are significantly different at p = 0.05.

4. Discussion

4.1. Growth and yield

The yield obtained in this study was lower as compared to other studies on cherry tomato (Santamaria et al., 2003) that reported an average of 2 kg per plant as harvesting was only done four times. The highest yield recorded under no mulch treatment is probably due to conducive rhizospheric temperatures coupled with adequate soil moisture. This study revealed that the thick grass mulch reduced soil temperature while it improved soil moisture compared to without mulch treatment. The two factors are expected to reduce movement of oxygen in the root zone. The induced hypoxic condition as a result of supraoptimal levels of soil moisture.

Waterlogged conditions are already repoted to increase rate of respiration while decreasing photosynthetic rate (Araki et al., 2012; Manik et al., 2019; Velasco et al., 2019; Ziska, 1998). Kawasaki et al. (2014) demonstrated that increased root zone temperature of tomatoes resulted in higher yield and improved uptake of phosphorus and potassium while lowering the uptake of nitrogen. However, reduced root zone temperature reduced uptake of nitrogen, phosphorus and potassium of tomatoes grown hydroponically under greenhouse conditions (Yan et al., 2012). In another study, Li et al. (2015) reported that post-soil aeration increased growth and yield of potted tomatoes.

Table 5. Effect of grass mulching depth on substrate temperature and soil moisture of potted Cherry tomato fruit quality in a plastic tunnel

Grass mulching depth (cm)	% gravimetric soil moisture	Soil temperature (^oC)
0	14.61 d	26.2 a
5	22.38 c	23.4 b
7	35.22 b	19.0 c
10	45.73 a	17. 3 d

Means in a column followed by different letters are significantly different at p = 0.05.

This tend to support our finding that thick grass mulch probably reduced oxygen levels of the pot media by maintaining low temperatures and high moistures. The high soil moisture and low temperature induced reduction in diffusion of oxygen to the plant roots (Walter et al., 2004).

4.2. Fruit quality

Fruit quality of tomatoes is based on physical and nutritional attributes. Tomato shape is one of the most physical qualities of tomatoes in the fresh market (Kays, 1999). In the current study, fruit shape was not affected by grass mulching depth indicating that the fruit roundness as estimated by the ratio of lateral and longitudinal diameter is largely controlled by genetic factors. Fruit size as indicated by weight was comparable to values obtained in previous studies (Coyago-Cruz et al., 2018).The maximum brix value obtained in our study was 5 lower than the one reported by previous studies (Santamaria et al., 2003) but similar to those reported by Klunklin and Savage (2017).

The variation may be explained differences in growing conditions and varieties of tomato cultivated (Coyago-Cruz et al., 2018). Fruit taste and flavor are largely determined by total soluble solids, titratable acidity and the ratio of total soluble solids to titratable acidity (Opiyo and Ying, 2005; Tigist et al., 2013). Stress in growing conditions induces biosynthesis of organic acids in plants (Mardi et al., 2002; Klunklin and Savage, 2017). The current study therefore indicates that the stress levels in the growing conditions was within tolerable regimes and could not significantly reduce the TSS: TA ratios. It remains to be investigated the reasons for superior taste quality under no mulch. Titratable acidity decreases as the tomato fruit ripens (Li et al., 2015). However, Li et al. (2015) argued that the positive effect of post-infiltration aeration on total soluble solids and fresh fruit yield is attributed to increased rhizospheric aeration of potted tomato plants which promoted stomatal conductance hence increased carboxylation. The rate of ripening of tomato fruits could be slower in plants mulched with grass under pot conditions. The levels of titratable acidity obtained in this study are similar to previous ones reported by (Li et al., 2015).

4.3. Soil moisture and temperature

The lowest soil moisture obtained was 45.73% under no mulch treatment. This treatment did not significantly lower the yield and quality of tomato fruits. This indicates that at current irrigation regime and growing conditions the moisture level did not pose water deficit stress. This agrees with findings of Sibomana et al. (2013) who demonstrated that severe water stress of container grown tomatoes was detected at 40% pot capacity. The findings of this study show that thicker grass mulching improves soil moisture conservation of potted cherry tomato due to reduced evapoprative losses and reduced rhizopheric tempertature. the findings agrees with other studies that showed that organic mulches like grass or wood mulches are superior in soil moisture conservation (Xue et al., 2016; Bavougian and Reed, 2018).

Hurd and Graves (1985) showed that the optimum root zone temperature for tomatoes is 15 °C. This implies that temperatures obtained under 7 and 10-cm grass mulch was near normal range. In contrast, the values were suboptimal according to Jones (2008). The peak root zone temperature for nutrient uptake in tomatoes is 26 °C. The root zone buffering capacity of soil temperature depends on the growing conditions. This explains the varying responses in different studies. This study confirmed that thicker the grass mulch the higher the soil moisture. Soil water conservation and tomato yield was better under grass mulch as compared to without mulch (Marinari et a., 2015; Moreno et al., 2016; Ogundare et al., 2015; Zhang et al., 2019). In the current study, root zone temperatures and soil moistures were taken between 1.00-2.00 pm when ambient temperatures were highest. It is therefore expected the night rhizospheric temperatures and moisture of containerized tomatoes were lowest and highest, respectively. These conditions could have worsened root hypoxia and hence reduced photosynthetic capacity of the crop.

4.4. Weed density

Recently nonchemical weed control is gaining importance due to environmental and health concerns (Jabran and Chauhan, 2018; Lowry et al., 2018; Moss, 2019; Pannacci et al., 2017). The findings of the study indicate that thick grass mulch density greatly lowers weed density. The observation may be ascribed to light exclusion or strong physical barrier to emergence of germinating weed seedlings. In a study conducted by Kosterna (2014), thicker straw mulch straw was found to be effective on weed management. Since grass mulch depth of 7 cm did not significantly differ with that of 10 cm it will be wise to select the former in order to reduce weed menace without causing yield and quality penalty of container grown cherry tomato. Weed density at 60 days after transplanting could be explained by the robust vegetative growth of the tomato plants that effectively covered the pot surfaces hence no light penetration for the underneath weed seedlings.

5. Conclusion

Thick grass mulch is effective in controlling weeds, conserving water in pot grown tomatoes. The low root temperatures under thick grass mulch adversely affect yield performance. It would be prudent to investigate the influence of irrigation scheduling and mulching rate on yield and quality of pot grown cherry tomatoes. In this study 7 cm thick grass application appeared best for potted cherry tomato under plastic tunnel. From this study we can propose that thick grass mulch should be combined with low irrigation water application. Thick grass mulch may also be applicable during periods of high ambient greenhouse temperatures.

List of Abbreviations: HCD, Horticultural Crops Directorate; AFA, Agriculture Food Authority; KNBS, Kenya National Bureau of Statistics; TSS, Total Soluble Solids; TA, Tritable acidity.

Competing Interest Statement: The authors declare that they have no competing interest.

Author's Contribution: GBK designed the experiment, guided the study and did data analysis and proof read the manuscript. BMM executed the experiment, collected the data and wrote the manuscript.

Acknowledgments: The authors are thankful to Mr. Jonah Rotich for the acquisition of the seeds and management of the experiment.

References

Araki, H., M. A. Hossain. Takahashi. 2012. Waterlogging and hypoxia have permanent effects on wheat root growth and respiration .J. Agron. Crop Sci. 198(4): 264-275.

Are, K.S., S.O. Oshunsanya and G.A. Oluwatosin. 2018. Changes in soil physical health indicators of an eroded land as influenced by integrated use of narrow grass strips and mulch. Soil and Tillage Research. 184: 269-280.

Arora, S., M. Sehgal, D.S. Srivastava and S.K. Sarkar. 2019. Rice pest management with reduced risk pesticides in India. Environ. Monit. Assess. 191(4): 241.

Bashir, M.A., A.M. Alvi, K.A. Khan, M.I.A. Rehmani, M.J. Ansari, S. Atta, H.A. Ghramh, T. Batool and M. Tariq. 2018. Role of pollination in yield and physicochemical properties of tomatoes

(*Lycopersicon esculentum*). Saudi J. Biol. Sci. 25: 1291-1297.

Bashir, M.A., A.M. Alvi, M.I.A. Rehmani, T.B. Qasirani, S. Mahpara and M. Tariq. 2019. Pollinators diversity for tomatoes crop under agro-forest ecosystem of Dera Ghazi Khan Punjab Pakistan. Pure Appl. Biol. 8(2): 1487-1493.

Bavougian, C.M. and P.E. Reed. 2018. Mulch and ground cover effects on soil temperature and soil moisture, surface reflectance and vine yard weed management. Peer J. 6:e5082.

Brown, B., A.K. Hoshide and E.R. Gallandt. 2019. An economic comparison of weed management systems used in small-scale organic vegetable production. Organic Agric. 9(1): 53-63.

Chaudhary, P., A. Sharma, B. Singh and A.K. Nagpal. 2018. Bioactivities of phytochemicals present in tomato. J. Food Sci. Technol. 55(8): 2833-2849.

Coyago-Cruza, E., C. Mireia , A. Morianaad, D. Hernanze , A. M. Benítez-Gonzálezb, C. M. Stinco and A. J. Meléndez-MartínezMartínez. 2018. Antioxidants (carotenoids and phenolics) profile of cherry tomatoes as influenced by deficit irrigation, ripening and cluster. Food Chem 240(1):870-884.

Fang, S., B. Xie and J. Liu. 2008. Soil nutrient availability, poplar growth and biomass production on degraded agricultural soil under fresh grass mulch. Forest Ecol. Manage. 255(5): 1802-1809.

Fang, S., J. Liu, D. Liu and B. Xie. 2010. Enzymatic activity and nutrient availability in the rhizosphere of poplar plantations treated with fresh grass mulch. Soil Sci. Plant Nutr. 56(3): 483-491.

FAO, 2018. Food and Agriculture Organisation of the United Nations. http://www.fao.org/faostat. Accessed on April 2019.

Gao, L., I. Gonda, H. Sun, Q. Ma, K. Bao, D.M. Tieman, E.A. Burzynski-Chang, T.L. Fish, K.A. Stromberg, G.L. Sacks, T.W. Thannhauser, M.R. Foolad, M.J. Diez, J. Blanca, J. Canizares, Y. Xu, E. van der Knaap, S. Huang, H.J. Klee, J.J. Giovannoni and Z. Fei. 2019. The tomato pan-genome uncovers new genes and a rare allele regulating fruit flavor. Nat. Genet. 51(6): 1044-1051.

Geoffrey, S.K., N.K. Hillary, M.A. Kibe, M. Mariam, M.C. Mary. 2014. Challenges and strategies to improve tomato competitiveness along the tomato value chain in Kenya. Int. J. Bus. Manag. 9(9): 205.

Horticultural Crop Directorate, Agriculture Food Authority and Kenya National Bureau of Statistics (HCD, AFA, KNBS). 2016**.** Horticulture Validated Report for 2015-16. www.agricultureauthority.go.ke/. (Accessed on June 2017).

Hurd, R.G. and C. J. Graves. 1985. Some effects of air and root temperatures on yield and quality of glasshouse tomatoes. J. Hort. Sci. 60(3):359-371.

Iftikhar, A., H. Zahoor, R. Shuaib, M. Noor-Un- Nisa and A. N. Summar. 2011. Response of vegetative and reproductive components of chilli to inorganic and organic mulches. Pak Journal Agr Sci 48(1): 19-24.

Iqbal, J., A. Ditommaso, M.I.A. Rehmani, K. Jabran, S. Hussain, W. Nasim, S. Fahad, M.A. Shehzad, A. Ali. 2019. Purple nutsedge (*Cyperus rotundus*) control through interference by summer crops. Int. J. Agric. Biol. 21(5): 1083-1088.

Jabran, K. and B.S. Chauhan. 2018. Overview and Significance of Non-Chemical Weed Control. In: Jabran, K., Chauhan, B.S. (Eds.), Non-Chemical Weed Control. Academic Press, p. 1-8.

Kader, M.A., M. Senge, M.A. Mojid and K. Ito. 2017. Recent advances in mulching materials and methods for modifying soil environment. Soil Tillage Res. 168: 155-166.

Kassahun, A. 2017. Evaluation of deficit irrigation and mulching on water productivity of tomato (Lycopersicon esculentum Mill) at Kalu Woreda, South Wollo, Ethiopia, Msc. Thesis Submitted to Haramaya University, Ethiopia.

Kawasaki, Y., S. Matsuo, Y. Kanyama and K. Kanahama. 2014. Effect of root zone heating on growth and activity, nutrient uptake, fruit yield of tomato at low air temperatures. J. Japan Soc. Hort. Sci. 83(4):295-301.

Kays, S.J. 1999. Preharvest factors affecting appearance. Postharvest Biol. Technol. 15(3):233-247

Kere, G.M., M. O**.** Nyanjage and G. Liu., S. P. O. Nyalala. 2003. Influence of drip irrigation schedule and mulching material on yield and quality of tomatoes (*Lycopersicon esculentum* MILL, 'Money Maker'). Asian J. Plant Sci. 2(14): 1052-1058.

Klunklin W. and G. Savage. 2017. Effect on quality characteristics of tomatoes grown under well-watered and drought stress conditions. Foods. 6(8):56.

Kosterna, E.2014. The effect of soil mulching with organic mulches, on weed infestation in broccoli and tomato cultivated under polypropylene fibre and without a cover. J Plant Prot Res. 54(2): 188-198.

Kyere, K., K. Agyarko and B.O. Yaw. 2018. Influence of grass mulch on soil physical attributes of a luvisol and water requirement of cowpea (*Vigna unguiculata*) in the transition zone of Ghana. Asian Soil Res. J. 1(2): 1-13.

Labate, J.A., S.M. Sheffer and L. Robertson. 2010. Optimized work flow for assaying tomato fruit quality: vitamin A, titratable acids, brix and lycopene. North Eastern Branch of Crop Science, Soil and Agronomy Societies of America 2010 Conference, Ithaca NY

Li, Y., Z. Jia, W. Niu,J. Wang., M. Zhang. 2015. Effect of post-infiltration soil aeration at different growth stages on growth and fruit quality of drip irrigated potted tomato plants (*Solanum lycopersicum*). PLoS ONE 10(12): e0143322

Lowry, C.J. and R.G. Smith. 2018. Chapter 5 - Weed Control Through Crop Plant Manipulations. In: Jabran, K., Chauhan, B.S. (Eds.), Non-Chemical Weed Control. Academic Press, pp. 73-96.

Manik, S.M.N., G. Pengilley, G. Dean, B. Field, S. Shabala and M. Zhou. 2019. Soil and crop management practices to minimize the impact of waterlogging on crop productivity. Front. Plant Sci. 10: 140.

Manu, V., A. Whitbread and G. Blair. 2018. Effects of vegetative mulches on growth of indigenous crops in the Kingdom of Tonga. Soil Use Manag. 34(1): 147-153.

Mardi. D, B. Janet and W. Paul. 2002. Organic Greenhouse Tomato Production. ATTRA Horticultural Guide. 16 Pp.

Marinari, S., R. Mancinelli, P. Brunetti and E. Campiglia. 2015. Soil quality, microbial functions and tomato yield under cover crop mulching in the Mediterranean environment. Soil and Tillage Research. 145: 20-28.

Moreno, M.M., A. Cirujeda, J. Aibar and C. Moreno. 2016. Soil thermal and productive responses of biodegradable mulch materials in a processing tomato (<i>Lycopersicon esculentum</i> Mill.) crop. Soil Research. 54(2): 207-215.

Moss, S. 2019. Integrated weed management (IWM): why are farmers reluctant to adopt non-chemical alternatives to herbicides? Pest Manage. Sci. 75(5): 1205-1211.

Nambuthiri, S., A. K. Koeser., R. Geneve,N. Genhua. 2015. Moving Toward Sustainability with Alternative Containers for Greenhouse and Nursery Crop Production: A Review and Research Update. Horttechnology, 25(1):8-16

Naranjo, R.D.D.P., S. Otaiza, A.C. Saragusti, V. Baroni, A.D.V. Carranza, I.E. Peralta, E.M. Valle, F. Carrari and R. Asis. 2016. Hydrophilic antioxidants from Andean tomato landraces assessed by their bioactivities in vitro and in vivo. Food Chem. 206: 146–155.

Ochilo, W.N., G.N. Nyamasyo, D. Kilalo, W. Otieno, M. Otipa, F. Chege, T. Karanja, E.K. Lingeera. 2019. Characteristics and production constraints of smallholder tomato production in Kenya. Scientific African. 2: e00014.

Ogundare, S.K., I. J. Babatunde, and O.O Etukudo. 2015. Response of tomato variety (Roma F) yield to different mulch materials and staking in Kabba, Kogi State, Nigeria. J. Agric. Sci.: 3(No.2).

Opiyo, A.M. and T. J. Ying. 2005. The effects of 1-methylcyclopropene treatment on the shelf life and quality of cherry tomato (Lycopersicon esculentum var. cerasiforme) fruit. Int J Food Sci 40(6): 665–673.

Pannacci, E., B. Lattanzi and F. Tei. 2017. Non-chemical weed management strategies in minor crops: A review. Crop Protect. 96: 44-58.

Perveen, R., H.A.R. Suleria, F.M. Anjum, M.S. Butt, I. Pasha and S. Ahmad. 2015. Tomato (*Solanum lycopersicum*) carotenoids and lycopenes chemistry; Metabolism, absorption, nutrition, and allied health claims—A comprehensive review. Crit. Rev. Food Sci. Nutrit. 55(7): 919-929.

Petropoulos, S.A., Â. Fernandes, N. Katsoulas, L. Barros and I.C. Ferreira. 2019. The effect of covering material on the yield, quality and chemical composition of greenhouse-grown tomato fruit. J. Sci. Food Agric. 99(6): 3057-3068.

Santamaria, P., G. Campanile, A. Parente and A. Elia. 2003. Subirrigation vs dripirrigation: Effects on yield and quality of soilless grown cherry tomato. J. Hortic. Sci. Biotechnol. 78(3): 290-296.

Sibomana, I.C., J.N. Aguyo and A.M Opiyo. 2013. Water stress affects growth and yield of container grown tomato (*Lycopersicon esculentum* Mill) plants. G.J.B.B.2 (4): 461-466

Silva, B.A, A. R. Silva and L. G. Pagiuca. 2014. Cultivo protegido. Em busca de mais eficiência produtiva. Hortifruti Brasil, n.132, 10-18.

Singh, V.P., K.K. Barman, R. Singh, A.R. Sharma. 2015. Weed Management in Conservation Agriculture Systems. In: Farooq, M., Siddique, K.H.M. (Eds.), Conservation Agriculture. Springer International Publishing, pp. 39-77.

Teame, G., A. Tsegay and B. Abrha. 2017. Effect of organic mulching on soil moisture, yield, and yield contributing components of sesame (*Sesamum indicum* L.). Int. J. Agron. 2017: 6.

Tegen, H., W. Mohammed and Y. Dessalegn. 2015. Effects of mulching materials on soil temperature under polyhouse condition. J. Biol. Agric. Healthcare. 5:164-168.

Tigist, M., T.S. Workneh and K. Woldetsadik. 2013. Effect of variety on quality of tomato stored under ambient conditions. J. Food Sci. Technol.50 (3): 477-486

Velasco, N.F., G.A. Ligarreto, H.R. Díaz and L.P.M. Fonseca. 2019. Photosynthetic responses and tolerance to root-zone hypoxia stress of five bean cultivars (*Phaseolus vulgaris* L.). S. Afr. J. Bot. 123: 200-207.

Walter, S., H. Heuberger and W.H Schitzler. 2004. Sensibility of different vegetables to oxygen deficiency and aeration with H_20_2 in the rhizosphere. Acta Hortic. 659:499-508

Xue, N., W. T. Song, H.C. Zhang, X. Yang and L.D. Wang. 2016. Effects of mulching on soil properties and growth of tea olive (*Osmathus fragrance*I. PlosOne 11(8):e0158228.

Yan, Q, Zq. Duan, Jd. Mao, X. Li and F. Dong. 2012. Effects of root zone temperature and N, P and K supplies on nutrient uptake of cucumber seedlings in hydroponics. J. Soil Sci. Plant Nutr. 58(6): 707-717.

Zhang, P., W. Ting, . H.X. Wang, W. Min, X.P. Meng, M. Siwei,, Z. Rui, J. Zhikuan and H. Qingfang. 2015. Effects of straw mulch on soil water and winter wheat production in dryland farming. Sci. Rep. 5:10725

Zhang, X., S. You, Y. Tian and J. Li. 2019. Comparison of plastic film, biodegradable paper and bio-based film mulching for summer tomato production: Soil properties, plant growth, fruit yield and fruit quality. Scientia Horticulturae. 249: 38-48.

Ziska, L.H. 1998. The influence of root zone temperature on photosynthetic acclimation to elevated carbon dioxide. Ann.Bot. 81(6):717-721.