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Effect of Spacing and Topping on the Performance of Hydroponically Grown Tomato Under Tropical Conditions

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Abstract

Production of tomato in the tropics especially in Ghana is beset with lots of setbacks thereby causing low yields per hectare. Greenhouse cultivation systems are promising yet yields of tropical tomato cultivars are hampered by adverse temperature conditions. In order to mitigate this, an experiment was conducted during the extreme summer temperature conditions in the greenhouse at Kashiwanoha Campus of Chiba University, Japan. The study was conducted between May 23, 2018 and September20, 2018. The low substrate volume production system of 500mL in closed recirculated hydroponics (sub-irrigation) method was employed. Three tropical tomato cultivars (Jaguar, Lebombo and Lindo) were evaluated for yields. Plants were spaced at 20cm (4.2 plants m^{-2}) and 30cm (2.8 plants m^{-2}). At 7 and 9WAT, plants were topped at 2nd and 4th nodes respectively. The 3x2x2 factorial in Randomised Complete Block design in three replications was adopted. Some parameter collected were; 1. Morphometrics such as plant height, girth, leaf number and chlorophyll content, days to 50% flowering and fruit set 2. Yield components and fruit quality such as fruit number, marketable yield, yield per area, yield per hectare, percent blossom end rot, fruit TSS, TA, TSS/TA ratio and 3. Dry matter partitioning at last harvest, 11WAT. Results showed that blossom end rot reduced the yields of Jaguar and Lindo almost by 50% while Lebombo recorded less than 1%. Lebombo produced significantly the highest plant dry mass of 125g of which 57.7% was converted to vegetative growth compared to the Jaguar. For Jaguar however, 53.7% of total plant dry mass was allocated to fruits. This in effect was translated to the highest yield of 93tons ha^{-1} $year^{-1}$ for Jaguar plants that were pinched at 4th truss in high density planting of 4.2 plant m^{-2}.

Keywords: Topping; Spacing: Plant density; Dry mass; Substrate volume; Tomato.

1. Introduction

Tomato (Solanum *lycopersicum* L.) has been known as one of the most important crop that is consumed worldwide. It is consumed in diverse dishes in various places.

Growing tomato in the tropical region all year round on sustainable basis is a paramount desire. Tropical areas like Ghana is still striving with abysmal yield of 20tons ha^{-1} $year^{-1}$ compared to the Netherlands, which according to FAOSTAT [1] produces 558.9tons ha^{-1} $year^{-1}$. In all dry seasons, demand for tomato supersedes supply and therefore prices become exorbitantly high. In such circumstance, there is a sole reliance on import of tomato which further increases the price.

Incidentally, growing tomato under tropical conditions is faced with lots of challenges such as; high temperature, drought, flood, pests, diseases, poor production techniques and lack of technical skills. With the advent of greenhouse facility, most of the prevailing challenges are controlled to some extent. Nevertheless, greenhouse control of extremely high temperatures in the tropics as indicated by Mutwiwa, *et al.* [2] is very difficult. Tropical climates are known for high day and night temperatures especially during dry seasons. Air temperatures are usually high and this usually affects reproductive phases of tomato. Report by Sato, *et al.* [3] indicates that high air temperature significantly results in low percent fruit set. Also, Suzuki [4] added that high temperatures especially during summer inhibit fruit production of tomato.

In order to address this challenge, proven techniques under greenhouse conditions could be adopted. Ghana, a tropical country is characterized by more than 90% consumers of tomato which lay more emphasis on quantity. This therefore implies that production techniques that could enhance higher yield of tomato sustainably in the greenhouse should be adopted. In adverse climatic conditions, Watanabe [5] reported that low node-order pinching (LN) at high density planting (HD) has become a practical and widely used technique for year round production and increased

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yields. Under hydroponics techniques, extreme low volume substrate system (ELVS) with LN & HD is useful tools for achieving high tomato yield [6, 7]. In a similar manner, Giacomelli, *et al.* [8] indicated that temperature damage to tomato growth in the summer under high wire cultivation system could be controlled by adopting the single truss tomato system at high plant density. Abdel-Mawgoud, *et al.* [9] reported that plant spacing is one management practice that greatly influences tomato performance especially under hot temperature conditions.

Janes and McAvoy [10], reported that tomato yield can be increased should the single truss production with high HD be adopted. They further indicated that with this production system, cultivation period is reduced, low labour is required, yields are consistent and it could be automated.

Tamai [11], indicated that the crop could be cultivated 3.5 times per year especially when LN&HD is adopted. This production system as indicated by Kozai [12] is better than the tradition production system which is labour intensive, long production period, variable yields and plants suffer high summer temperature effects. Single truss to three trusses coupled with high density planting have been suggested by several researchers for adoption. Higashide and Heuvelink [13], reported 36kg m^{-2} $year^{-1}$ yield of tomato in Japan using single truss production system at plant density of 10 plants m^{-2}. In similar matter, Zhang, *et al.* [14] reported high tomato yield of 1.74kg/3trusses/plant at 1.2dS m^{-1} EC using ELVS (250mL) with LN & HD.

Reports from several research findings indicate or recommend the single truss system with high density plant. Since shade effect is bound to occur, supplemental lighting has further been recommended Lu, *et al.* [15] but at additional cost. However, it is important to reconsider that prices of seeds for greenhouse production are very high and therefore the need to obtain optimum productivity from such seeds on cultivation. Also there is the need to eliminate the use of artificial light supplement because it is not readily affordable in the tropics. Adequate plant density could be adopted to eliminate the need for supplemental lighting. In view of this, the work sought to evaluate the optimum low node order pinching (truss number) with optimum density planting for optimum yield under tropical conditions like Ghana.

Literature in relation to LN&HD under hydroponic conditions for tomato is scarcely reported in the tropics like Ghana therefore, the need for this study. LN&HD could be used to increase tomato yield in hot tropical conditions. This study was to determine the effect of plant density and topping on yield, fruit quality and dry matter distribution in tomato under hot summer conditions.

2. Materials and Methods

The study was conducted in the greenhouse at Kashiwanoha campus of Chiba University, Japan between May 23, 2018 and September20, 2018 to coincide with the period of summer.

2.1. Nursery

Cultivars used in the study were Jaguar, Lebombo and Lindo. Jaguar and Lindo were obtained from Techisem, Savanna seed limited company while Lebombo was obtained from Proseed company.

Seeds were sown in cell trays using cocopeat as the sowing medium on May 23, 2018. The germinated seeds were kept in artificial growth chamber with lighting of 280 $\mu mol.m^{-2}.s^{-1}$ for 16 hours; 1000 µmol mol^{-1} CO_2; day/night temperatures maintained at 23/18^oC and nutrient solution at EC 1.2dS m^{-1} was supplied as sub-irrigation once a daily.

2.2. The Hydroponic System

The system consisted of 20m long four rolled benches. On each bench was planting troughs laid with white impervious cloth. The impervious cloth with the trough served as a gutter through which unabsorbed nutrient solution flowed from the upper slope of the bench into the return tank (reservoir). Planting panels with 10cm spaced cells were mounted on top of the troughs. Planting pots of 500mL volume capacity were 90% filled with cocopeat. The bases of the planting pots were lined with water permeable net. The net linings allowed for capillary movement of nutrient solution to plants and at the same time filtered the substrate from getting into the nutrient solution.

Nutrient solution was supplied as sub-irrigation by the use of pump. Flow of nutrient solution was automated with a continuous daily supply. The electrical conductivity (EC) and pH of the nutrient solution was automatically regulated by sensors. The pH and EC were automatically maintained within 5.5-6.5 and 1.2dS m^{-1} respectively.

Seedlings were carefully transplanted into the 500mL pot filled with cocopeat. Transplants were trellised using a twine with clips.

2.3. Transplanting and Treatments

Transplanting of seedlings was carried out at 21 days after germination. Plant spacing of 20 and 30cm (4.2 and 2.8 plant/m^2 respectively) were adopted.

Plants were pinched (topped) at 7and 9 weeks after transplanting (WAT) when the fruits of 2nd and 4th truss respectively were fully set.

Flowers upon full opening were sprayed with 1mL L^{-1} 4-Chlorophenoxyacetic acid to enhance fruit set. The 3x2x2 factorial in Randomized Complete Bock Design in three replications was adopted as the experimental design.

2.4. Morphometrics

The morphometric parameters taken were: height, girth, leaf number and chlorophyll content (SPAD) at 2, 4 and 13 WAT. Also, days to 50% flowering and fruiting were determined. Plant height and girth were measured using ruler and vernier calipers respectively. Plant girth was initially measured at the first two true leaf and subsequently at the leaf below the first truss. Chlorophyll content was measured with SPAD 502 plus. Chlorophyll content was determined in a similar manner.

2.5. Dry Matter Partitioning

Distribution of dry matter was determined by measuring: leaf area, plant dry mass, shoot dry mass, root dry mass, fruit dry mass, root-shoot ratio and percent dry matter partitioned to fruits at 13 WAT. Leaf area was determined using the 'lia320378'photo method. Dry matter of leaf, stem, root and fruit were determined through oven drying at 72^{o}C for ten days after samples showed constant dry weights.

2.6. Yield and yield components

This component comprised fruit number, percent fruit set, percent blossom end rot (BER) affected fruit, marketable yield per plant, yield per area. Percent fruit set was determined as a fraction of total number of fruits to total number of flowers. BER was determined as a fraction of affected fruits to total number of fruits.

2.7. Fruit Quality

Components of fruit quality measured were: total soluble solids (TSS) or Brix%, titratable acidity (TA) and TSS/TA ratio. TSS and TA were measured using K-BA100R spectrophotometer to scan the fruits. TSS/TA was determined as a fraction of TSS to TA.

2.8. Data Analysis

Data obtained were analyzed using the Analysis of Variance (GenStat 32) and the Tukey's honest significant difference was used to separate three or more means that were significantly different.

3. Results

3.1. Morphometrics

From Table 1, results showed that cultivar and spacing did not influence plant height significantly ($p<0.05$) at 2 and 4 weeks after transplanting. However, at 13 WAT result indicates that Lebombo significantly grew taller (141.8cm) than Jaguar (116.3cm) and Lindo (117.1cm). Plants pinched at 4th truss were significantly 30.9cm taller than those pinched at 2nd truss. Cultivar x spacing interaction had no significant influence on plant height at 13 WAT. Cultivars pinched at different truss number significantly affected plant height at 13 WAT. The tallest plants of 162.4cm was recorded in Lebombo pinched at 4th truss while the shortest; 92.6cm was recorded in Jaguar pinched at two trusses. No significant interaction effect was recorded for cultivar, spacing and pinching at 13 WAT.

Plant girth was not affect by cultivar and spacing at 2 WAT. At 4 and 13 WAT, Jaguar recorded significant ($p<0.05$) thinner stem diameter than the other two cultivars (Table 1). Spacing and pinching on the other hand had no influence on stem diameter throughout the growing period. No significant interactions effects were observed.

Results from Table 2 showed that cultivar, spacing and cultivar x spacing interaction did not significantly affect leaf number throughout the growing period.

Table 2 indicates that Jaguar recorded significantly ($p<0.05$) the highest chlorophyll content at 2 and 4 WAT than the other cultivars. Similar trend was observed in 13 WAT however, Jaguar and Lindo recorded similar results. At 13 WAT, plants grown at 30cm apart recorded 3.1 chlorophyll content, significantly higher than those grown at 20cm. Lebombo spaced at 20cm recorded the lowest chlorophyll content (52.6) compared to other treatments; although not significantly different from some treatments. Cultivars topped at different truss numbers recorded similar chlorophyll content at 13WAT.

Table 1 showed that Jaguar and Lebombo respectively set flowers in 2 and 3 days earlier than Lindo. In a similar trend, the two cultivars set fruits in 9 and 3 days respectively earlier than Lindo.

Table-1. Influence of topping and spacing on height, girth, days to 50% flowering and fruit set

	Height (cm)			Girth (mm)				
Treatment	**2 WAT**	**4 WAT**	**13 WAT**	**2 WAT**	**4 WAT**	**13 WAT**	**Days to flowering**	**Days to fruit set**
Cultivar (C)								
Jaguar	54.4a	111.4a	116.3a	8.7a	10.1a	11.2a	36a	41.5a
Lebombo	55.4a	115.3a	141.8b	8.9a	11.2b	12.9b	35.8a	47.3b
Lindo	51.1a	108.8a	117.1a	9.50a	11.2b	12.5b	38.9b	50.9c
Spacing (S)								
20cm	55.3	112.4	122.3	8.9	10.8	12.0	36.9	46.4
30cm	51.9	111.3	119.2	9.1	10.9	12.4	36.9	46.7
lsd(0.05)	3.89	4.42	4.30	0.57	0.19	0.85	0.59	0.65
Truss number (T)								
2			105.3			12.4		
4			136.2			11.9		
lsd(0.05)			4.33			0.650		
Interactions								
Cultivar x spacing	NS	NS	NS	NS	**	NS	NS	NS
Cultivar x truss			**			NS		
Spacing x truss			**			NS		
C x S x T			NS			NS		

NS = no significance; ** = significant difference; Same letters in same column are not significantly different at ($p<0.05$) according to Tukey's HSD

Table-2. Leaf number and chlorophyll content of tomato as influenced by topping and spacing

	Leaf number			Chlorophyll content		
Treatment	2 WAT	4 WAT	13 WAT	2 WAT	4 WAT	13 WAT
Cultivar (C)						
Jaguar	10.4a	15.6a	15.6a	43.4b	56.34b	59.4b
Lebombo	10.6a	16.7a	16.7a	36.3a	52.32a	55.2a
Lindo	10.9a	15.8a	15.8a	38.3a	52.70a	57.5ab
Spacing (S)						
20cm	10.7	16.2	16.2	39.3	53.8	55.8
30cm	10.6	16.9	16.9	39.4	53.7	58.9
lsd(0.05)	0.39	0.93	0.93	2.71	1.72	*2.27*
Truss number (T)						
2						
4						57.7
lsd(0.05)						57.1
Interactions						1.99
Cultivar x spacing	NS	NS	NS	NS	NS	**
Cultivar x truss			NS			**
Spacing x truss			NS			NS
C x S x T			NS			NS

3.2. Yield Components

Results from Table 3 shows that Jaguar and Lebombo respectively recorded fruit set of 94.9% and 97.6% significantly ($p<0.05$) higher than Lindo which recorded 88.7%. Spacing of plant did not significantly influence fruit set. Plants topped at 2nd truss recorded 97.9% fruit set which was significantly higher than those topped at 4th truss which recorded 89.5%. Lindo topped at 4th truss recorded 81.5% fruit set as the lowest compared to other treatments.

Results from Table 3 indicated that Lebombo significantly produced 14.4 fruits per plant which was twice that of Jaguar and five fruits greater than Lindo. Spacing had no significant influence on fruit number. Topping of plants at 2nd truss significantly produced 4 four fruits less than those topped at 4th truss. Fruit number per plant was significantly ($p<0.05$) influenced by cultivar, plant density and topping interactions. Lebombo plants topped at 4th truss produced the highest fruit number of 16.2 and 17.8 at spacing of 20cm and 30cm respectively. The smallest fruit number of 5.5 and 5.7 was recorded in Jaguar plants topped at 2nd truss with spacing of 30cm and 20cm respectively.

Results from Table 3 showed that Jaguar significantly ($p<0.05$) produced 0.68kg as highest yield followed by 0.483kg per plant for Lebombo. Lindo produced the lowest yield of 0.375kg per plant. Spacing did not significantly influence yield per plant. Topping of node had no significant effect on marketable yield. There was no interaction effect on yield per plant.

The highest yield, 2.4kg m^{-2} according to Table 3 was recorded in Jaguar and followed by 1.7kg m^{-2} for Lebombo. Lindo on the other hand produced the lowest yield of 1.3kg m^{-2}. Plants spaced at 20cm produced 2.2 kg m^{-2} which was significantly higher than 1.4 kg m^{-2} for plants spaced at 30cm. Topping of plants did not significantly affect yield per area.

Cultivar and spacing as well as cultivar and truss number interactions did not significantly influenced yield per area. Yield per area was significantly ($p<0.05$) affected by cultivar, plant density and truss number interactions. Jaguar at high plant density and topped at 4th truss produced 3.1kg m^{-2} as the highest yield per area. The lowest (0.86kg m^{-2}) was recorded in Lindo grown at low density and topped at 2nd truss.

Results from Table 3 showed that Jaguar and Lindo significantly lost 44.1 and 47.1% respectively of fruits to BER. Lebombo on the other hand recorded less than 1% of BER incidence.

Plant density did not significantly influence BER. Plants topped at 2nd truss suffered 6% BER more than those topped at 4th truss. Cultivars topped at different truss numbers were significantly affected by BER. Jaguar pinched at 2nd truss suffered 51.7% BER while Lebombo pinched at 2nd truss recorded no BER. All other interactions had no significant influence on BER.

3.3. Fruit Quality

Cultivar and plant density showed no significant effect on TSS (Table 3). Plants topped at 4th truss recorded 0.2% significantly higher Brix than that of plants topped at 2nd truss. No significant interaction effect was observed on TSS.

Cultivar and spacing showed no significant effects on titratable acidity (Table 3). Plants pinched at 4th truss were 0.3g g^{-1} significantly higher than those pinched at 2nd truss in terms of TA. Lebombo spaced at 20cm recorded the highest TA (0.6g g^{-1}) while the least (0.5g g^{-1}) was recorded in the same cultivar spaced at 30cm. No other significant interaction effect on TA was observed.

Cultivar, spacing and topping had no significant effects on TSS/TA ratio. Similarly, no significant interaction effect on TSS/TA ratio was observed.

Table-3. Yield, blossom end rot and fruit quality of tomato as influenced by topping and spacing

Treatment	Percent fruit set	Fruit number/ plant	Marketable yield/plant (kg)	Yield/area kg/m^2	BER incidence (%)	TSS (brix%)	TA (g/g)	TSS/TA
Cultivar (C)								
Jaguar	95.0b	7.6a	0.68c	2.4b	44.1b	6.8a	0.5a	13.5a
Lebombo	97.6b	14.4b	0.48b	1.7a	0.2a	6.7a	0.5a	13.6a
Lindo	88.71a	9.08a	0.38a	1.3a	47.1b	6.9a	0.5a	14.0a
Spacing (S)								
20cm	93.9	10.3	0.53	2.2	29.8	6.9	0.5	13.5
30cm	93.6	10.4	0.49	1.4	31.1	6.7	0.5	13.9
lsd(0.05)	5.03	2.77	0.11	*0.39*	3.80	0.24	0.03	0.90
Truss number (T)								
2	97.9	8.4	0.47	1.7	33.6	6.7	0.49	13.8
4	89.5	12.3	0.56	2.0	27.3	6.9	0.52	13.6
lsd(0.05)	*4.02*	*2.32*	0.103	*0.48*	*3.81*	*0.2*	*0.02*	0.91
Interactions								
Cultivar x spacing	NS	**	NS	NS	NS	NS	**	NS
Cultivar x truss	**	NS	NS	NS	**	NS	NS	NS
Spacing x truss	NS	NS	NS	NS	NS	NS	NS	NS
C x S x T	NS	**	NS	**	NS	NS	NS	NS

3.3. Dry Matter Partitioning

According to Table 4, Lebombo recorded significantly ($p<0.05$) the highest leaf area of 17.22m^2 followed by 12.78m^2 for Jaguar. Lindo recorded 11.23m^2 as the lowest leaf area at 13 WAT. Spacing did not significantly influence leaf area. Plants topped at the 4th truss recorded 3.7m^2 leaf area significantly greater than those topped at the 2nd truss. In terms of interactions, only spacing and truss number significantly affected leaf area. Plants pinched at the 4th truss with 20 or 30cm spacing recorded 14.74 and 16.44m^2 respectively. These were significantly higher than the leaf area recorded in plants subjected to other treatments.

From Table 4, Lebombo significantly ($p<0.05$) produced 13g dry mass more than the other cultivars. Spacing did not affect plant dry mass significantly. Plant dry matter was 16.9g higher in plants pinched at 4th truss than those pinched at 2nd truss. Plant dry matter was significantly affected by cultivar and spacing interaction. Lebombo planted at 30cm spacing recorded the highest plant dry mass (127.0g) though not significantly higher than some treatments. Lindo planted at 30cm spacing recorded the lowest plant dry mass of 104.2g. Cultivar and node pinching interaction significantly affected plant dry matter production. Pinching Lebombo at 4th truss recorded significantly higher plant dry mass (139.5g) relative to other treatments. No other interactions effected were observed on plant dry mass.

According to Table 4, dry matter partitioned to shoot at 13 WAT significantly differed in cultivars. Lebombo produced the highest (54.59g), followed by 44.3g for Lindo. Jaguar recorded the lowest dry matter (36.32g) partitioned to the shoot. Plant spacing did not significantly influence dry matter portioning to the shoot. Plants pinched at the 4th truss significantly produced 6.44g more shoot dry mass than those pinched at the 2nd truss. No significant interaction effect was observed for dry matter production to shoot.

Dry matter partitioning to root among cultivars differed significantly. Lindo partitioned 5.05 and 3.68g more dry matter to roots than Jaguar and Lebombo respectively. Plant spacing had no significant influence on dry matter distribution to roots. Pinching of plants did not affect root dry matter significantly. There was no significant interactions effect on dry matter partitioned to root.

From Table 4, results showed that Lindo and Jaguar respectively recorded Root/shoot ratio of 0.17 and 0.12 significantly higher than that of Lebombo. Plant spacing and node pinching showed no significant effect on Root/shoot ratio. No significant interaction effect was observed on Root/shoot ratio.

Dry matter partitioned to fruit was significantly influenced in cultivars (Table 4). Jaguar recorded the 60.22g fruit dry mass which represent the highest (53.68%) of total plant dry mass. Dry matter allocated to Lebombo and Lindo fruits respectively were 53.52 and 47.24g which represent 42.26% and 41.65% of their total plant dry mass. Dry matter allocated to fruits was not significantly influenced by spacing. High node pinched plants (four trusses) significantly partitioned 12.6g more dry matter in fruits than those that received low node pinching.

Cultivar and spacing interaction influenced fruit dry mass partitioning significantly. Jaguar spaced at 20cm partitioned the highest dry matter of 61.7g (54.22% of total plant dry matter) to fruit. Dry matter allocated to fruit was significantly influenced by cultivar and pinching interaction. The highest dry matter of 63.1g and 64.3g were partitioned to fruits produced by Jaguar and Lebombo respectively pinched at the 4th truss. The lowest dry matter of 42.7g and 42.0g allocated to fruit were recorded in Lebombo and Lindo pinched at 2nd truss.

Table-4. Dry matter partitioning of tomato as influenced by truss number and spacing at 13 WAT

Treatment	**Leaf area (m^2)**	**Plant dry mass (g)**	**Shoot dry mass (g)**	**Root dry mass(g)**	**Fruit dry mass (g)**	**Root/shoot ratio**	**Percent dry mass to fruits**
Cultivar (C)							
Jaguar	12.78b	112a	36.3a	15.5a	60.2b	0.43b	53.7b
Lebombo	17.22c	125b	54.6c	16.9a	53.5ab	0.31a	42.3a
Lindo	11.23a	112.1a	44.3b	20.5b	47.2a	0.47b	41.7a
Spacing (S)							
20cm	13.3	118.8	44.5	18.1	56.2	0.42	47.3
30cm	14.2	113.9	45.7	17.1	51.1	0.39	44.5
lsd(0.05)	2.52	9.82	6.20	2.4	8.38	0.073	5.31
Truss number (T)							
2	11.9	107.9	41.9	18.7	47.4	0.46	43.8
4	15.6	124.8	48.3	16.5	60	0.35	47.9
lsd(0.05)	2.165	7.93	5.77	2.26	7.28	0.06	5.19
Interactions							
Cultivar x spacing	NS	**	NS	NS	**	NS	**
Cultivar x truss	NS	**	NS	NS	**	NS	NS
Spacing x truss	**	NS	NS	NS	NS	NS	NS
C x S x T	NS	NS	NS	NS	NS	NS	NS

4. Discussion

4.1. Morphometrics

Plants of Lebombo cultivar were characterized by higher internode length and that might have made the cultivar grow taller than the other cultivars. Higher truss number in cultivars might have induced much taller plants than those with lower truss number.

Higher chlorophyll content in Jaguar might be due to cultivar genetic difference. Plants that were grown in low density recorded higher chlorophyll content. The result might be attributed to higher interception of light because such plants had wider spacing compared to plants grown in high density.

4.2. Yield Components

The higher fruit set recorded in Jaguar and Lebombo indicates that both cultivars possess good attributes of heat tolerance. Plants with higher truss number recorded lower fruit set due to adverse effect of extreme summer temperatures as stressed by Sato, *et al.* [3]. However, lower fruit number was recorded in 2nd truss topped plants due the incidence of BER.

Marketable yields per plant for all cultivars were low in comparison with 1.73kg plant^{-1} for plants topped at 3rd truss as reported by Zhang, *et al.* [14]. However, this study recorded high incidence of blossom end rot which accounted for high yield loss. In addition, plant density adopted by this study was much lower than that reported by the researchers.

Plants with closer spacing had higher (density) number of plants per area and that accounted for the higher yield. It implies that at high density with pinching at 4th truss, Jaguar produced 93tons ha^{-1} year^{-1}. Lower yield per area in comparison with the 360tons ha^{-1} year^{-1} yield reported by Higashide and Heuvelink [13] may be due to cultivar genetic diversity, difference in plant density and yield loss to blossom end rot.

Plants of Jaguar and Lindo were highly susceptible to BER compared to Lebombo which showed high level of resistance. Lebombo might have probably possessed a stronger xylem network at the blossom end than the other cultivars. This has been suggested by Ho, *et al.* [16] that tomato genotypes possessing a stronger xylem network have been found to be less susceptible to BER. Yield loss of almost 50% in the two susceptible cultivars confirmed report by Taylor, *et al.* [17] that BER may reduce tomato marketable yield up to about 50%. Plants topped at 2nd truss recorded BER more than those topped at 4th truss. This might probably be due to the fact that first fruit emergence coincided with the incidence of extreme high summer temperatures. This incidence is in agreement with Watanabe [5], which reported that tomato under high temperatures result in blossom end rot.

4.3. Dry Matter Partition

The higher leaf area recorded in Lebombo might be due to difference in genetic attributes among the cultivars. Higher number of leaves in plants pinched at 4th truss might have accounted for the higher leaf area compared to plants pinched at 2nd truss. Irrespective of spacing, higher truss number produced more leaves hence the higher leaf area.

Lebombo plants were better producers of photosynthates relative to the other cultivars. Spacing did not affect plant dry mass significantly. Due to higher photosynthetic area, Lebombo topped at 4th truss were better producers of dry mass compared to the other cultivars.

Lebombo cultivar partitioned more of its photosynthates towards vegetative growth while Jaguar recorded more of partitioning towards reproductive growth. Plants pinched at the 4th truss were higher in shoot mass and therefore produced more shoot dry mass than those pinched at the 2nd truss.

There was more investment of photosynthates in root at the expense of fruit in Lindo compared to other cultivars. This might have account for the low yield in the same cultivar.

Dry matter distribution in Jaguar was more geared towards yield and this might have accounted for the higher yield compared to the other cultivars. Due to more photosynthetic area available to plants topped at 4th truss, more photosynthates were partitioned into fruit. However, percent dry mass partitioned into fruit for the 2nd and the 4th truss topped plants were similar.

5. Conclusions

In adverse temperature conditions, the low substrate volume production system could effectively enhance yield of tropical tomato cultivars. Cultivation of Jaguar hydroponically at low substrate volume production, pinched at 4th truss in high density planting could produce yield of 93.0tons ha^{-1} year^{-1} or more. Drip irrigation nutrient film technique may better improve the potential yield of Jaguar should high density planting with 4th truss topping be adopted.

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