

Article

Evaluation of Tropical Tomato for Growth, Yield, Nutrient, and Water Use Efficiency in Recirculating Hydroponic System

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Received: 1 June 2020; Accepted: 22 June 2020; Published: 1 July 2020



Abstract: The issue of low tomato production in the tropics like Ghana has been a long-standing challenge. The advent of greenhouse technology has not significantly improved the yield of tomato compared to Japan and the Netherlands. Immediate technological interventions are needed. Through hydroponics, the low-node order pinching at a high-density planting system has been recommended in some studies. This system was intended to be established in Ghana, and it would be expected to improve the yield and fruit quality of tomato. In effect, a study was carried out in the greenhouse, at Chiba University using this system. A tropical tomato cultivar (Jaguar) was evaluated with Momotaro York at 3.8 m² and pinched at the fourth truss. Data collected were water and nutrient use efficiencies, plant growth rate, dry matter partitioning, and fruit yield and quality, as well as some physiological characteristics. The experiment was laid out in a randomized complete block design with three replications. Results showed that Jaguar cultivar was two times more efficient in water and nutrient use than Momotaro York at first harvest. Root tissue density recorded in Jaguar was significantly lower compared to Momotaro York. The net assimilation rate (NAR) recorded was markedly higher in Jaguar than Momotaro York at last harvest. All the physiological attributes recorded in both cultivars were not significantly different. Plant dry mass (DM) recorded was similar in the two cultivars; however, the DM partitioned to fruits was 55% in Jaguar compared to 46.5% DM for Momotaro York. Fruit yield per area did not differ in the two cultivars. Fruit yields of 28.8 and 30 kg m⁻² per year were recorded in Jaguar and Momotaro York, respectively. In comparison, this yield result is 1.2–1.25 times less and 14.4–15 times higher than current tomato yields recorded in Japan (greenhouse) and Ghana, respectively. Fruit quality, in terms of total soluble solids recorded in Jaguar cultivar being 5.4 %Brix, was within the 3.5–5.6 %Brix recorded in Ghana. This system could effectively enhance the yield and quality of tomato in the tropics as well as economising on the use of resources.

Keywords: hydroponics; high-density; greenhouse; low truss; tomato; yield

1. Introduction

Tomato is highly consumed in Ghana. Ghana national tomato transporters and traders' association [1] reported that the country is the highest consumer of the product in Africa. It was further indicated that 90% of tomato produced in Burkina Faso (a neighbouring country) is consumed in Ghana. However, the production volume in Ghana remains low with an annual yield of 8.6 t ha⁻¹ [2].

Producing enough to meet both local and international demand sustainably is not feasible without the state-of-the-art technology.

In 2014, some greenhouse facilities (tropically customized) were introduced into the country to boost tomato production sustainably. In spite of this, tomato production output has not yet improved significantly in comparison to Japan and the Netherlands. This is an indication that the appropriate cultivation systems at cost-effective levels have not so far been adopted.

Cultivation of tomato under hydroponics conditions for increased yield and quality has been reported. Work on the low-node order pinching at high plant density (LN&HD) cultivation system has been reported to be effective in enhancing productivity and quality of tomato [3]. This system has been defined [4] as, a short cultivation period of 70–120 days, where harvesting is made from 2–4 trusses at high plant-density. This cultivation system has been recommended due to its efficiency in resource utilisation. In contrast to soil cultivation, which has been affected by lots of challenges, this system is efficient in mitigating against such challenges. Efficient use of limited resources to achieve optimum output remains the desire of every rational producer (farmer). The use of water, nutrients, space, and labour is highly efficient with this system [5]. A study was conducted earlier [6] on three tropical tomato cultivars for yield under hydroponic conditions using a sub-irrigated pot cultivation. The study adopted the LN&HD system in recirculating nutrient film techniques (NFT). A yield of 84.9 t ha⁻¹ per year was recorded in Jaguar with just about 50% yield loss to blossom end rot (BER).

Apart from the issue of BER, recirculating sub-irrigation NFT for low substrate culture results in reduced fruit size; hence, yields are consequently compromised. Because of this, it was reported [7] that hydroponics by drip irrigation enhances good yield, higher fertilizer use efficiency, decrease production cost and reduce risk of environmental pollution. The drip method in recirculating hydroponics could also offer a better insight for determining water and nutrient uptake characteristics for a given cultivar under prevailing climatic conditions. The adequate amount with accurate timing of irrigation could influence the yield and quality of tomato [8].

The LN&HD using recirculating drip hydroponics could be used to improve the yield of tomato. The system will also enhance water and nutrient use efficiencies, as reported [9]. Plant roots that are involved in water and nutrient uptake are usually restricted in this system due to low substrate volume. These restricted roots are known to produce finer young roots [10], which are efficient in uptake of water and nitrogen [11]. A study on the attributes of water and nutrient uptake in tomato plant is of great importance. This is because the cost of fertilizers is high while water becomes somewhat scarce particularly in the dry seasons. This system will help in the proper use and management of resources at economic levels.

However, studies on most tropical tomato cultivars for growth, yield, water, and nutrient use efficiencies with the LN&HD are not available. In addition, this hydroponic cultivation system has never been reported in Ghana so far as tomato production is concerned. This system was ultimately intended to be established for tomato cultivation in Ghana. The current study sought to evaluate the growth, yield, water, and nutrient uptake attributes of tropical tomato under the LN&HD system using drip recirculating hydroponics in the greenhouse. The system was expected to become the most efficient and economical way of boosting tomato production in the tropics like Ghana.

2. Materials and Methods

The study was conducted in the greenhouse at Kashiwanoha campus of Chiba University, Japan between 29 August 2018, and 14 January 2019.

2.1. Nursery

Cultivars used in the study were Jaguar and Momotaro York. These cultivars were obtained from Techisem, Savanna Seed Company limited, (Longué-Jumelle, France) and Takii Seeds Company Ltd (Kyoto, Japan) respectively.

Seeds were sown in cell trays using cocopeat as the sowing medium. The germinated seeds were kept in an artificial growth chamber. The chamber was equipped with a light intensity of $280 \mu\text{mol m}^{-2} \text{s}^{-1}$ for 16 h, $1000 \mu\text{mol mol}^{-1} \text{CO}_2$ and the day/night temperatures maintained at 23/18 °C. The constitution of the nutrient solution was 0.7 mM $\text{NH}_4\text{-N}$, 8 mM $\text{NO}_3\text{-N}$, 1.3 mM $\text{PO}_4\text{-P}$, 2 mM K, 2 mM Ca, 1 mM Mg, 2 mM $\text{SO}_4\text{-S}$, 3 ppm Fe, 0.5 ppm B, 0.5 ppm Mn, 0.02 ppm Cu, 0.05 ppm Zn, and 0.01 ppm Mo. An ebb and flow hydroponic technique was adopted in supplying the nutrient solution to the seedlings, once a day.

2.2. The Hydroponic System

The system was arranged in benches of 15 m long. Each bench had panels that suspended the planting pot sitting on troughs which served as a channel for draining unabsorbed water back to the return tank. Planting pots of 500 mL volume capacity were 90% filled with cocopeat. Spacing adopted was 0.2 by 1.3 m. The electrical conductivity (EC) of the nutrient solution was 0.12 S m^{-1} , while the pH was maintained between 5.5 and 6.5. The nutrient solution was pumped to the root zone of each plant through drips periodically.

2.3. Transplanting and Treatments

Transplanting of seedlings was carried out at 21 days after germination. Plants were pinched (topped) at 42 and 56 days after transplanting (DAT) respectively for Jaguar and Momotaro after three leaves above the fourth truss were fully developed. The topping was carried out in line with the findings of [12].

Flowers upon full opening were sprayed with 1 mL L^{-1} 4-Chlorophenoxyacetic acid to enhance fruit set.

2.4. Morphometrics

The morphometric parameters such as height, girth, leaf number, and chlorophyll content (SPAD) were measured fortnightly. Additionally, days to 50% flowering and fruiting were determined. Plant height and the girth were measured using a ruler and vernier calipers respectively. Plant girth was initially measured at the first two true leaves and subsequently at the leaf below the succeeding trusses. Chlorophyll content was measured with SPAD 502 plus (Konica-Minolta Inc., Tokyo, Japan). The chlorophyll content was determined on the leaves below the immediate truss as well as the leaves below the succeeding trusses.

2.5. Water and Nutrient Use Efficiencies

Water uptake for the first harvest (70 DAT) was determined as the initial water supplied less the amount of water left (unabsorbed). This parameter was measured periodically when the nutrient solution volume had drastically reduced thereby requiring a renewal. Water use efficiency (WUE) was determined as a ratio of fruit weight to total water uptake per plant at first harvest (70 DAT).

Nutrient uptake was determined by collecting samples of the nutrient solution at the end of each period. The samples were analysed for nutrients using the Dionex ICS1100 ion chromatography (Thermo Fisher Scientific Inc., Waltham, MA, USA). Nutrient use efficiency (NUE) was expressed as a ratio of the fruit fresh weight to the total nitrogen uptake per plant at first harvest.

2.6. Physiological Characteristics

Physiological attributes such as photosynthetic rate, leaf conductance and transpiration were measured using the LI-6400 (LI-COR, Lincoln, NE, USA). Measurement was carried out on the immediate leaf below the second truss between 1:30 and 2:30 p.m.

2.7. Growth Parameters

Relative growth rate (RGR) expressed as the rate of dry mass increase per unit of plant mass over a given time. Net assimilation rate (NAR) was expressed as dry matter increment per unit leaf area per unit of time. All the leaves were detached, and photo scanned using a camera. The scanned photos were analysed for the leaf area, using the Lia32 (<https://www.agr.nagoya-u.ac.jp/~shinkan/LIA32/author-e.html>) software.

2.8. Dry Matter Partitioning

Distribution of dry mass (DM) was determined by measuring the leaf area, plant dry mass, shoot dry mass, root dry mass, dry mass allocated to fruits, and root-shoot ratio. The DM of leaf, stem, root, and fruit were determined through oven drying at 72 °C for ten days when dry weights of samples became constant. The DM contents were determined fortnightly and used to calculate the growth parameters.

Root tissue density (RTD) is a measure of resource uptake strategies in plants. Plants with higher RTD have more fine roots for the uptake of water and nutrients. RTD influences water and nutrient uptake by the fine roots with a corresponding dry matter investment as reported [13]. Root dry matter concentration (RDMC) as indicated by [14] was used as a proxy to determine RTD in the study. This method has also been recommended by [15], as being relatively cheap, easy, and quick for determining RTD. The RTD was determined as root dry mass per unit root fresh mass.

2.9. Yield Component and Crop Productivity

Yield component was expressed in terms of fruit number per plant, fruit fresh weight per plant, and yield per area. Days to 50% flowering and fruiting were determined. Crop productivity was determined as a ratio of the fruit biomass to the plant biomass.

2.10. Fruit Quality

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

2.11. Data Analysis

Data obtained was analysed using the GenStat (Rothamsted Research, Harpenden, UK) and the least significant difference ($LSD_{0.05}$) was used to separate the means.

3. Results

3.1. Morphometrics

The two cultivars showed similar patterns of growth in terms of height. It was observed at 56 DAT that Momotaro plants grew significantly taller than Jaguar (Table 1a). Momotaro York plants significantly produced thicker stems than Jaguar (Table 1b). Results from Table 1c showed that a larger number of leaves was produced in Momotaro York than Jaguar plants. Chlorophyll content (SPAD) was similar in both cultivars throughout the growth period (Table 1d).

Table 1. Morphological characteristics of tomato as influenced by low-node order pinching at high plant density (LN&HD).

a. Plant height (cm)	Days after transplanting			
	14	28	42	56
Cultivar				
Jaguar	60.2	106.9	128.9	135
Momotaro York	62.1	110.9	136.7	159.4
LSD _{0.05}	2.5	4.85	13.66	21.9
b. Girth (mm)				
Cultivar				
Jaguar	8.4	9.7	10.9	12
Momotaro York	9.7	11.1	12.9	13.9
LSD _{0.05}	1.99	1	1.03	2.69
c. Leaf number				
Cultivar				
Jaguar	10.5	13.4	15.9	17.2
Momotaro York	11.7	15.6	19.5	21.1
LSD _{0.05}	1.58	1.61	1.88	0.25
d. SPAD				
Cultivar				
Jaguar	45.4	47.9	49.9	51.7
Momotaro York	44.3	48.3	50.3	52
LSD _{0.05}	2.28	2.74	2.7	2

SPAD: leaf chlorophyll content; LSD_{0.05}: least significant difference ($p < 0.05$).

3.2. Water and Nutrient Use Efficiencies

Figure 1a showed that the peak of water uptake for both cultivars was recorded between 37 and 39 DAT. Water uptake from the peak period to the first harvest was relatively higher in Momotaro compared to Jaguar. However, results from Table 2 showed that Jaguar recorded two times significantly higher WUE and NUE than Momotaro York at first harvest. Results from Figure 1b,c indicated that the highest nutrient uptake in the two cultivars occurred at 37 DAT for K and NO_3^- . Moreover, the uptake of Ca in Jaguar plants was higher than observed in Momotaro. Uptake of NO_3^- in Jaguar was twice that of Momotaro York at 43 DAT. Similarly, the uptake of Ca was relatively higher in Jaguar than Momotaro York. Absorption of NH_4^+ was the lowest in the two cultivars. The trend in terms of nutrient uptake (for all the major nutrients) was similar in both cultivars.

Table 2. Water and nutrient use efficiencies of tomato at 70 days after transplanting (DAT) (first harvest).

Cultivar	Fruit Weight (kg plant ⁻¹)	WUE (kg kg ⁻¹)	NUE (kg kg ⁻¹)
Jaguar	0.658	0.033	221.1
Momotaro York	0.353	0.015	111.9
LSD _{0.05}	0.116	0.004	34.9

WUE: water use efficiency; NUE: nutrient use efficiency; LSD_{0.05}: least significant difference ($p < 0.05$).

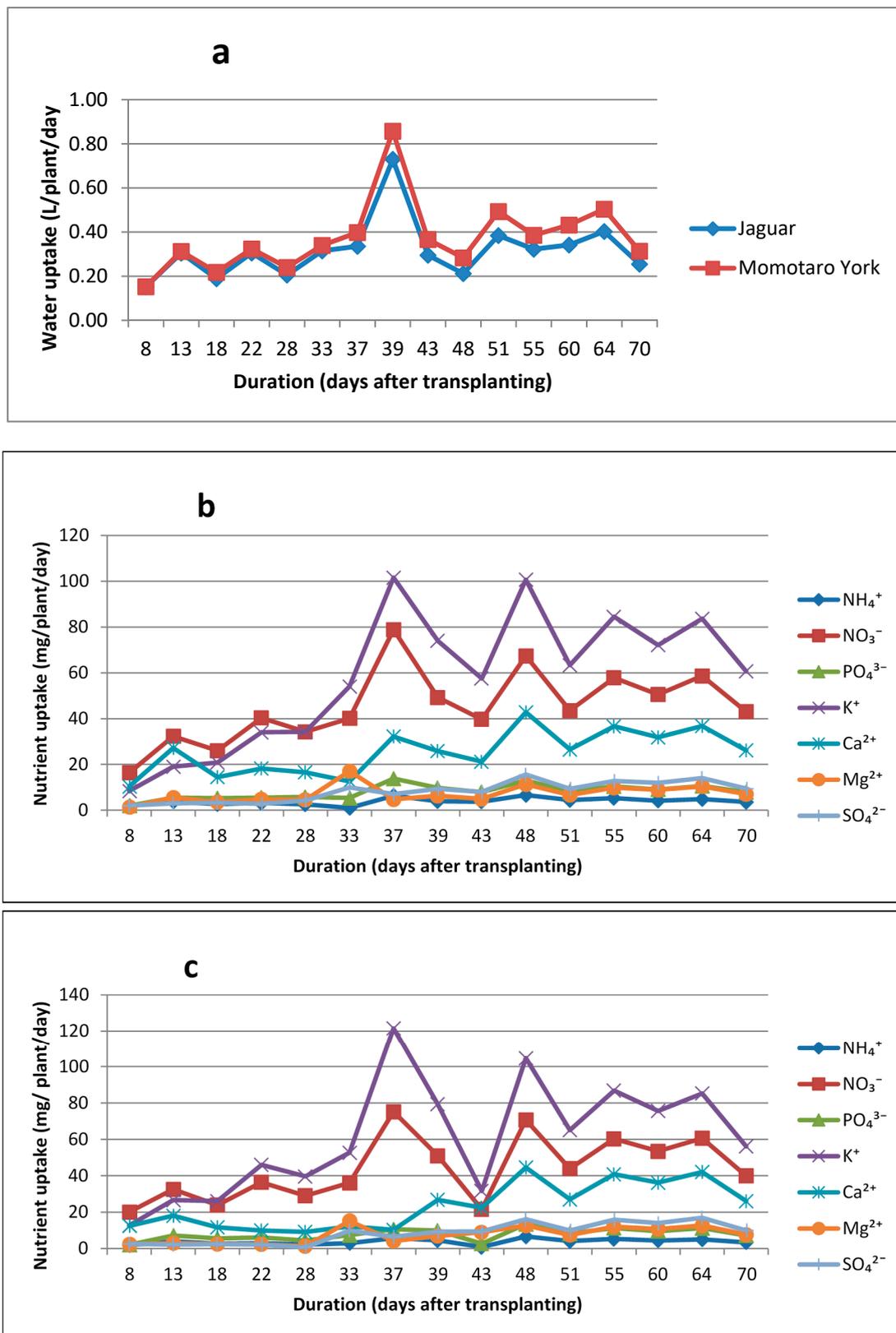


Figure 1. (a) Water uptake characteristics of Jaguar and Momotaro York, (b) nutrient uptake characteristics of Jaguar, and (c) nutrient uptake characteristics of Momotaro York.

3.3. Physiological Characteristics

The photosynthetic rate, conductance as well as the transpiration rate recorded was similar in the two cultivars (Table 3).

Table 3. Physiological response of tomato to LN&HD at 42 DAT.

Cultivar	Photosynthesis ($\mu\text{mol cm}^{-2} \text{s}^{-1}$)	Conductance ($\text{mol cm}^{-2} \text{s}^{-1}$)	Transpiration ($\text{mmol cm}^{-2} \text{s}^{-1}$)
Jaguar	14.8	0.59	5.7
Momotaro	13.5	0.44	4.9
LSD _{0.05}	7.06	0.313	1.99

3.4. Growth Parameters

Between flowering and fruit set, the RGR recorded was significantly higher in Momotaro York than in Jaguar (Table 4). On the other hand, the NAR recorded between the first and the last harvests was significantly higher in Jaguar than Momotaro York. A higher leaf area was recorded in Momotaro York than Jaguar almost throughout the growth period.

Table 4. Dry matter partitioning and growth rate of tomato as influenced by LN&HD.

Growth/DM		Days after Transplanting				
		14	28	42	56	140
Leaf area (m^2)	Jaguar	12.8	16.5	23.1	25.9	31.7
	Momotaro	14.7	24.1	27.3	36.1	48.2
	LSD _{0.05}	3.7	4.2	5.5	2.3	3.1
Plant DM (g plant^{-1})	Jaguar	16.6	31.5	68.9	88.3	215.5
	Momotaro	15.6	32.3	69.3	98.5	214.3
	LSD _{0.05}	3.9	6.6	9.9	11.5	40.2
Leaf DM (g plant^{-1})	Jaguar	6.2	12.7	16.2	19.7	41.6
	Momotaro	6.4	14.5	18.9	23.5	52.2
	LSD _{0.05}	1.4	2.5	1.9	2.3	9.9
Stem DM (g plant^{-1})	Jaguar	2.8	7.3	10.1	12.7	19.9
	Momotaro	3.1	8.7	13.4	14.8	28.9
	LSD _{0.05}	0.42	0.6	1.7	1.8	3.1
Root DM (g plant^{-1})	Jaguar	7.6	11.6	16.6	14.6	32.9
	Momotaro	6	9.1	14.9	14.6	32
	LSD _{0.05}	2.5	5.5	4	3.3	9.8
Root tissue density (g cm^{-3})	Jaguar					0.16
	Momotaro					0.18
	LSD _{0.05}					0.006
DMFr (g plant^{-1})	Jaguar			25.8	40.7	119.2
	Momotaro			23.0	46	99.6
	LSD _{0.05}			0.24	12.7	25.4
Root/Shoot ratio (g g^{-1})	Jaguar	0.84	0.58	0.62	0.47	0.56
	Momotaro	0.63	0.39	0.48	0.39	0.39
	LSD _{0.05}	0.19	0.25	0.03	0.2	0.07
RGR ($\text{g g}^{-1} \text{d}^{-1}$)	Jaguar		0.046	0.056	0.018	0.0064
	Momotaro		0.052	0.055	0.025	0.0056
	LSD _{0.05}		0.03	0.02	0.0045	0.0021
NAR ($\text{g m}^{-2} \text{d}^{-1}$)	Jaguar		0.073	0.14	0.057	0.032
	Momotaro		0.063	0.1	0.067	0.019
	LSD _{0.05}		0.05	0.006	0.012	0.01

DM: dry mass; DMFr: dry matter allocated to fruits; RGR: relative growth rate; and NAR: net assimilation rate.

3.5. Dry Matter Partitioning

According to Table 4, Momotaro York recorded a higher leaf area, leaf DM and stem DM than Jaguar over the growth period. However, the DM allocated to root was similar in both cultivars. Root-shoot ratio differed significantly in the two cultivars. In the last growth period, Momotaro recorded a lower root-shoot ratio than Jaguar. Dry matter allocated to fruit increased progressively in both cultivars over the growth period. However, Jaguar recorded a higher dry mass of 2.8 g allocated to fruit than Momotaro York at 42 DAT. The RTD observed was significantly higher in Momotaro York than Jaguar.

3.6. Yield Components and Crop Productivity

Results from Table 5 showed that Jaguar flowered and fruited in three and five days, respectively, earlier than Momotaro York. However, the two cultivars were not significantly different in terms of fruit number, or fruit weight per plant recorded. The fruit yield per area and crop productivity were not significantly different in both cultivars.

Table 5. Yield components of tomato as affected by LN&HD.

Cultivar	DTF	DTFr	Fruit Number per Plant	Fruit Weight (kg plant ⁻¹)	Yield per Area (kg m ⁻²)	Crop Productivity (g g ⁻¹)
Jaguar	11	17	15.8	2.5	9.6	1.4
Momotaro	14	22	16.2	2.6	10	1.3
LSD _{0.05}	2.9	1.4	7.01	0.6	2.12	0.25

DTF = days to 50% flowering; DTFr = days to 50% fruiting.

3.7. Fruit Quality

According to Table 6, the total soluble solids recorded was significantly higher in Momotaro York than in Jaguar. However, titratable acidity and TSS/TA ratio were similar in both cultivars.

Table 6. Fruit quality of tomato as influenced by LN&HD.

Cultivar	Total Soluble Solids (%Brix)	Titratable Acidity (g L ⁻¹)	TSS/TA Ratio
Jaguar	5.4	0.36	15.1
Momotaro	6.5	0.42	15.5
LSD _{0.05}	0.43	0.075	2.13

TSS: total soluble solids; TA: titratable acidity.

4. Discussion

4.1. Morphometrics

Plant height at 56 DAT in Momotaro York was significantly higher than Jaguar probably due to longer internode length in the former. Leaf numbers, as well as stem girth recorded in Momotaro plants were markedly higher compared to the Jaguar plants. This may be due to an allocation of significantly higher plant biomass of 13.5% to stem in Momotaro as against 9.2% recorded in Jaguar. A similar observation has been reported where 12–13% dry mass was allocated to stem [16].

4.2. Water and Nutrient Use Efficiencies

The peak of water uptake in both cultivars between 37 and 39 DAT was due to a very high solar radiation in that period. This confirms that environmental factors could influence the uptake of water as [17,18] have reported. Uptake of water in Momotaro was higher probably due to higher leaf area and RTD. Tissue growth such as larger leaf area, thicker stems, and more young finer roots

probably induced higher demand for water in Momotaro York than Jaguar. However, water use was less efficient in Momotaro than in Jaguar. This was because more of the resource (water) was consumed towards vegetative growth at the expense of yield in Momotaro plants. Nutrient uptake in Momotaro York was significantly higher due to the more young finer roots recorded. High water and nutrient uptake especially K^+ and NO_3^- could also be due to an increase in fruit load, which has been reported by [19]. At the peak of water uptake, a corresponding peak in nutrient uptake was observed as may be influenced by solar radiation. This implies that environmental factors strongly influence the uptake of K and N. Under a low substrate volume condition, plants recorded a preferential uptake characteristic for nutrients as might be influenced by environmental factors. This attribute could also be strongly influenced by crop variety. Plant uptake of NH_4^+ was the lowest compared to the other nutrients. This might be due to its initial low concentration in the nutrient solution, which was formulated purposely to check against BER. The order of preferential nutrient uptake characteristics in both cultivars was similar. Similar nutrient uptake characteristics have been reported by [20,21]. Plants of Jaguar recorded higher Ca uptake than Momotaro York. This might be due to the higher root-shoot ratio recorded in Jaguar since the transpiration rate was similar in both cultivars. Absorption of Ca is dependent on water potential gradient and confirmed to be influenced by transpiration and growth rate of tissues [22]. Additionally, Ca absorbed in Jaguar plants might have been used in producing much firmer fruits than Momotaro York (data not shown).

4.3. Growth Parameters

The leaf area recorded in Momotaro York was higher than in Jaguar. The difference in the leaf area might be attributed to more leaf numbers recorded in Momotaro York as well as the higher RTD. This, in effect, enhanced a higher uptake of water in Momotaro York. Also, the higher dry mass partitioned to fruits in Jaguar might have restricted the leaf area, as indicated in the findings of [23]. Plants of Momotaro produced longer internode stems with a more significant number of leaves. This in effect, showed that Momotaro was more vegetative in growth than Jaguar. The higher root–shoot ratio in Jaguar showed an indication of better plant health and capacity for water and nutrient uptake.

In contrast, the lower root–shoot ratio recorded in Momotaro York could be due to relatively a higher uptake of nitrogen which probably favoured shoot growth. Allocation of higher plant dry mass to Jaguar fruit might also be due to the higher root–shoot ratio, which subsequently had a positive influence on the yield. Comparatively, Jaguar recorded a higher investment of dry matter into generative growth than Momotaro York. This result confirmed the findings of [24] that regardless of maximum photosynthetic rate with elevated CO_2 , the dry mass component distributed to fruit in Momotaro York reduced markedly. NAR differed significantly in the two cultivars at last harvest. NAR was higher in Jaguar than Momotaro York in the same period. In that period, there was little fruit load in Jaguar due to an almost complete harvest. This, in turn, might have induced more partitioning of resources into vegetative growth in Jaguar; hence, the higher NAR. Additionally, the larger number of leaves in Momotaro York might have induced inter-leaf shading. Momotaro plants recorded a higher RGR than Jaguar at 56 DAT due to a higher investment of resources towards vegetative growth.

4.4. Yield and Yield Components

Although Jaguar flowered and fruited earlier than Momotaro York, their yield characteristics were similar. Fruit yields of 28.8 and 30.0 kg m⁻² per year were recorded in Jaguar and Momotaro York, respectively. This implies that Jaguar (with four months cultivation period) could be cultivated three times a year with a yield of 288 t ha⁻¹ per year. This result is somewhat close to the yield of 360 t ha⁻¹ per year reported by [25] as tomato yield in Japan under greenhouse condition. In comparison, this yield result is 1.2–1.25 times less and 14.4–15 times more than current tomato yields recorded in Japan (greenhouse) and Ghana, respectively.

4.5. Fruit Quality

Plants of Momotaro York recorded significantly higher TSS compared to Jaguar plants. This difference might be due to the genetic attributes between the two cultivars. Results from a previous study on Jaguar recorded a TSS value of 1.5 %Brix higher than that obtained in the present study. This difference might be attributed to the different hydroponic systems employed in the two studies. The sub-irrigated hydroponic system induced a higher osmotic gradient; thus, resulting in an increase in the TSS. In contrast, the present study instead recorded a larger fruit size at the expense of TSS. The TSS value recorded in Jaguar agrees with [26], which reported the TSS of 3.5–5.6 %Brix for tomato grown in Ghana.

5. Conclusions

The adoption of LN&HD cultivation system was very promising and efficient for increasing tomato production at cost-effective levels. The system will afford farmers the opportunity to cut down the use of resources such as water, nutrient, substrate, and space, especially with the recirculating drip hydroponic system. Furthermore, it should be possible to cultivate tomato in the tropics like Ghana sustainably using this system. A similar yield to that reported in Japan is achievable when plants are grown at 3.8 plants m⁻² and pinched at the fourth truss.

Author Contributions: Conceptualization, A.W.A., S.T. and K.M.; Data curation, N.L.; Formal analysis, A.W.A., G.O.N., N.L. and K.M.; Funding acquisition, S.T.; Investigation, A.W.A., S.T. and K.M.; Methodology, A.W.A., S.T., G.O.N. and K.M.; Project administration, K.M.; Resources, S.T. and N.L.; Software, A.W.A. and N.L.; Supervision, S.T.; Validation, S.T. and G.O.N.; Writing—original draft, A.W.A. and K.M.; Writing—review & editing, A.W.A., S.T. and G.O.N. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: We (Alex Williams Ayarna, Satoru Tsukagoshi, George Oduro Nkansah, Na Lu and Kazuya Maeda) declare that there is no conflict of interest as far as our work is concerned.

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