Thermal and growth indices of cayenne pepper (Nhsmb-F4) under optimal and limited water supply regimes

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ABSTRACT

Thermal indices are veritable tools to summarize thermal stress effects on plant growth and yield. This study assessed thermal and growth indices of screenhouse grown pepper under optimal (everyday-T1) and limited water supply regimes (3, 5 and 7 days; T2, T3 and T4 respectively). The study is a factorial experiment in a Complete Randomized Design (CRD) in three replicates. The pepper specie used was Cayenne pepper. Data were collected on the soil, thermal indices: such as Growing Degree Days (GDD), growth parameters (Plant height), phenological events (Days to First Flowering - (DFFL) and Fruit yield. Data collected were subjected to descriptive and inferential statistics (analysis of variance). Treatments means were separated using Least Significance Difference (LSD) at 95 % confidence level. Results of GDD varietal performance under T2 showed that Cayenne pepper accumulated highest GDD (784 °C/day) followed by T4 (495 °C/day) and the least value was observed under T3 (452 °C/day). The GDD values under T2, T3 and T4 were not significantly different ($p>0.05$) from those obtained under optimal water supply regime (T1). Cayenne pepper plant height under T2 was consistently higher than those under T3 and T4. Phenologically, Cayenne pepper under T3 showed the shortest DFFL. The yield of T2 and T3 were in order of Cayenne pepper (46 and 34 g/pot). The study concluded that, cultivation of Cayenne pepper adapted well to limited water supply regimes of 3, 5 and 7 days without negative effects on the growth and yield in the screenhouse.

Keywords: *Cayenne pepper, Growth indices, Screenhouse, Thermal indices, Water supply regimes.*

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Highlights of this paper

- Cayenne pepper cultivation is feasible under limited water supply regimes of 3, 5, and 7 days without adverse effects on growth and yield in a screenhouse environment.
- Cayenne pepper demonstrated high resilience during extended periods of drought.
- Vegetable farmers in a water-limited environment could adopt cayenne pepper cultivation.

1. INTRODUCTION

In order to feed the world's expanding population, agricultural productivity must rise [1]. Therefore, in order to accomplish sustainable agriculture and feed the world's rising population, it is imperative to understand agricultural water management of plants. According to Yildirim, et al. [2] maintaining adequate soil aeration and meeting crop water requirements are the two primary goals of effective irrigation and water management, which are essential for sustainable agricultural development. According to Ashrae [3] and Parsons [4] thermal indices are helpful tools for describing how thermal environmental stressors interact with plants. Water is a vital component of life and is necessary for all the different physiological and biochemical processes that go into the growth and development of plants. Maximum leaf development, preservation of leaf greenness, assimilate generation and partitioning, and total dry matter yield all depend on adequate moisture availability. Crop development is negatively impacted by water stress; the extent of this effect varies according on the crop's developmental stage and the severity of the water scarcity [5, 6]. According to reports, water stress can impact meristematic processes in the early stages of plant growth and can lead to a decrease in cell turgidity, which is necessary for mitotic cell division, elongation, and enlargement [5, 7]. This, in turn, can hinder plant growth. Due to climate change, which is producing increasingly extreme occurrences like drought and flooding, water scarcity has become a global problem that threatens local agriculture, the environment, and the global economy [8].

Cayenne pepper (Capsicum annuum L.) in Nigeria popularly called atarugu in Hausa, ose in Igbo, ako in Igala and ata in Yoruba is said to be the first spice to have been used by humans [9]. As spices they are usually aromatic and pungent [10] and may be available in various forms such as ground, whole, dried or pre-ground dry. Pepper is the second most important vegetable all over the world just after tomatoes and it is the most grown type of spice providing color and flavor to food while providing essential nutrient requirements at the same time [11]. The distribution of pepper over time in Nigeria has helped in facilitating its availability to areas where it is not heavily produced. Some of the major distribution channels of pepper in Nigeria follow the normal chain of from producers to the wholesalers, retailers and finally the consumers [12]. Red Pepper is usually sold in the markets, marketing of red pepper in big cities of Nigeria is conducted through wholesale to retail markets but much is also sold in small street markets through more informal marketing channels which take place in vacant fields, along roadsides or on mats [13]. In a typical vegetable market, retailers sell both tomato and onion at the same time in addition to other vegetables like hot pepper, sweet pepper, and in some cases, chilies pepper usually sold in heaps, small baskets and metal containers of varying weights. Red pepper is handled for fresh consumption or processed into canned, pickled, frozen, fermented, dehydrated or extracted products [11]. According to Bosland and Votava [11] pepper production has increased worldwide and this could be ascribed partly to its high nutritional value. As explained by Grubben and Tahir [14] Food and Agriculture Organization (FAO) statistics estimated world production of Capsicum peppers in 2001 at 21.3 million tonnes from a harvested area of 1.6 million ha (that is, an average yield of 13.4t/ha). Comparatively, yield in the developing countries is about 10 – 30% of that in developed countries [14]. This work aims to assess the thermal and growth indices of screen house Cayenne pepper under optimal and limited water supply regimes in Abeokuta, Nigeria.

2. MATERIALS AND METHODS

2.1. Experimental Site and Location

The research study was carried out in a screen house at the Federal University of Agriculture, Abeokuta (FUNAAB), which is located behind the College of Environmental Resources Management (COLERM) and extends between Latitude 7.9°N to 7.8°N and Longitude 3°23^{1}E to 3°24^{1}E. Tropical weather with distinct wet and dry seasons characterizes the research area. The dry season is characterized by the continental North Easterly harmattan winds from the Sahara Desert, while the wet season is mostly linked to the moist marine southerly monsoon from the Atlantic Ocean. The 8region where the location is situated has a bimodal pattern of rainfall. The dry season is characterized by the continental North Easterly harmattan winds from the Sahara Desert, while the wet season is mostly linked to the moist marine southerly monsoon from the Atlantic Ocean. The region is situated in the southwest Nigeria's forest-savanna transition zone.

2.2. Experimental Design and Layout

The National Horticulture Research Institute Cayenne pepper (NIHORT), located in Ibadan, provided Cayenne pepper (NHSMB-F4). The University's FADAMA wetlands provided the top soil, which was then sieved to remove small particles and placed into perforated pots. It is possible for water to drain freely when perforated pots are used. We used 36 pots and measured out 7 kg of sieved soil for each pot. Transplanted into perforated pots, seedlings of Cayenne pepper were irrigated to lessen the environmental suck. The pots were arranged in a complete randomized design (CRD). The pepper specie used in the experiment was Cayenne pepper. The experimental design was totally randomized with three replicates in a factorial system of four water supply regimes (every day, 3 days, 5 days, and 7 days – T1, T2, T3, and T4). Four (4) treatment plots was resulted from the 1×4 factorial experiment with one pepper specie and four water supply regimes.

2.3. Establishment and Planting Techniques

Before planting, all bushes and stubbles were physically removed from the screen house using a cutlass, hoe, mattock, and rake in accordance with farmers' traditional practices. Three weeks later, pesticide was sprayed inside the screen house to protect Cayenne pepper from pests and diseases. Cayenne pepper seed was utilized. Then, in order to promote seed germination, Cayenne pepper seed was submerged in water for five hours. After three days, germinated seeds were sown into seedling trays containing soil. Four weeks after sowing, Cayenne pepper seedlings were transplanted into perforated pots. The pots was filled with the same amount of water to allow the transplants to become acquainted to their new surroundings, later Cayenne pepper were subjected to the water supply regimes treatments

2.4. Data Collection and Analysis

Three categories of data were collected:

Agrometeorological Data: Temperature (Maximum and minimum temperature, relative humidity, soil temperature and light intensity).

Growth Parameters: Plant height (cm), number of leaves, leaf area, leaf length, leaf breath, stem girth / diameter (cm), days to flowering and number of flowers

Yield Parameters: such as Days to fruiting, number of fruits, days to harvest, number of harvests, fruit length (cm), fruit weight and fruit diameter (cm)

2.5. Data Analysis

The data collected were subjected to analyses of variance (ANOVA) using SAS software package 9.1 (SAS Institute, 2003). Mean comparison among the treatments was carried out at 0.05% probability level using Least Significance Difference (LSD). The data collected were analysed using statistical tools such as Descriptive and Inferential Statistics (analysis of variance) and correlation.

2.6. Thermal Unit

The heat units that were determined during the study: Growing Degree-Days (GDD, ºC day), Helio thermal unit (HTU, ºC day) and Heat use efficiency (HUE, Kg/ha/ ºC).

Growing degree-days is the heat unit relating plant growth, development and maturity to air temperature. Hence was estimated using the following equation below

GDD = (Tmax − Tmin) / 2 – Tb .... [15]

Where;

GDD = Growing degree days, Tmax = Maximum temperature Tmin = Minimum temperature Tb= Base temperature (10°C)

Helio thermal unit (HTU, °C day): is the heat unit relating plant growth, development and maturity to sunshine Hours was estimated using the equation below:

HTU = GDD x SSH .... [16]

Where:

GDD= Growing degree days

SSH= Sunshine Hours

Heat use Efficiency (Kg/ha/℃day): is expressed as the ratio of yield of growing degree days

HUE = Yield x GDD…….. [17]

3. RESULTS AND DISCUSSION

3.1. Trends of Temperature (℃) and Relative Humidity (%) in the Screen House during the Growth Period in Abeokuta

The trend of temperature and humidity in the screen house showed that as temperature increase, relative humidity decreases throughout the observed growth period is shown in Figure 1.

The average temperature and average relative humidity in the screen house during the growth of pepper seedlings followed distinct patterns. The patterns showed that the First peak of temperature were observed at 4, 5 and 7 weeks after transplanting (WAT), (37.5, 37 and 35.3 ℃) respectively with their corresponding values of relative humidity (44, 41 and 58 %). Likewise at 8 WAT average temperature of 34.6 ℃ versus relative humidity of 63 %

Furthermore, second peak of temperature was observed at 16, 17, 18 and 19 WAT, (35.4, 34.4, 34.4 and 34.4 ℃) respectively with their corresponding relative humidity values (52, 57, 57 and 55 %) respectively. Finally, the third peak of temperature value was observed at 23 and 24 WAT (34 and 28.5 ℃) with the corresponding relative humidity values (62 and 76 %).

The highest temperature was observed at 4 WAT (37.5 ℃) and the lowest temperature was observed at 9 WAT (24.6 ℃) while the highest humidity was observed at 9 WAT (96 %) and the lowest humidity was observed at 5 WAT (41 %).

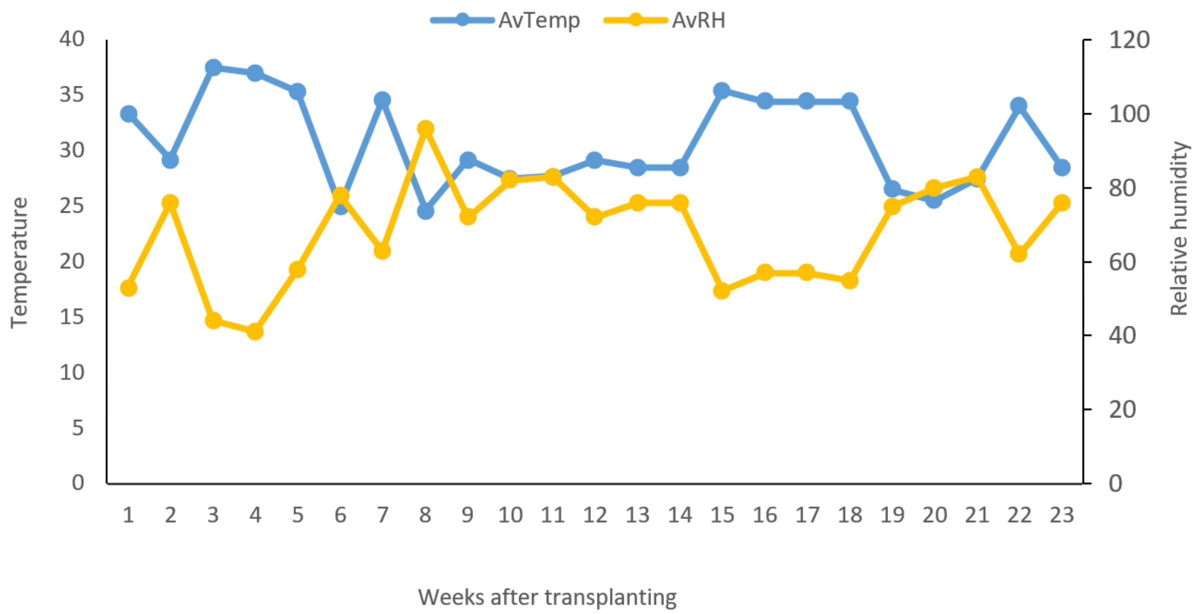

Figure 1. Trends of temperature (℃) and relative humidity (%) in the screen house during the growth period in abeokuta.

3.2. Response of Cayenne Pepper Thermal Indices Under Optimal and Limited Water Supply Regimes in Abeokuta

The response of Cayenne pepper thermal indices such as Growing degree days, Helio- thermal unit and Heat use efficiency under optimal and limited water supply regimes in Abeokuta is shown in Table 1.

Growing Degree Days (GDD) to Vegetation: Cayenne pepper under the 3 days water supply regime takes 784.25 days to reach the vegetative stage. Following closely is the everyday (Optimal) water supply regime with 775.25 days, then, the 7 days water supply8 regime takes 494.83 days, and the 5 days water supply regime has the lowest days to vegetation at 457.33 days after transplanting.

Growing Degree Days (GDD) to First flower: Cayenne pepper under the everyday (Optimal) water supply regime leads with 853.17 days to reach the first flowering stage. The 3 days water supply regime follows with 844.08 days, then, the 7 days water supply regime takes 533.67 days, and the 5 days water supply regime has the lowest days to first flower at 495.00 days after transplanting.

Growing Degree Days (GDD) to First Fruit: Cayenne pepper under the 7 days water supply regime exhibits the highest GGD to first fruit at 1593.50 days, followed by the 3 days water supply regime with 1539.92 days, then, the 5 days water supply regime takes 1352.92 days, and the everyday (Optimal) water supply regime reaches first fruit at 1280.75 days after transplanting.

Growing Degree Days (GDD) to First Harvest: Cayenne pepper under the 7 days water supply regime leads in GDD to first harvest at 2242.00 days, followed by the 3 days water supply regime with 2183.03 days, then the everyday (optimal) water supply regime takes 2077.08 days, and the 5 days water supply regime has the lowest GDD to first harvest at 1967.58 days after transplanting.

Helio - Thermal Unit (HTU) to Vegetation: Cayenne pepper under the everyday (Optimal) watering regime accumulates 3161.34 HTU to reach the vegetative stage. The 3 days watering regime follows with 3138.11 HTU, then, the 7 days watering regime accumulates 2044.02 HTU, and the 5 days watering regime has the lowest HTU to vegetation at 1906.85 HTU weeks after transplanting.

Helio - Thermal Unit (HTU) to First Flower: Cayenne pepper under the everyday (optimal) water supply regime leads with 3483.12 HTU to reach the first flowering stage. The 3 days water supply regime follows with 3348.04

HTU, then the 7 days water supply regime accumulates 2166.65 HTU, and the 5 days water supply regime has the lowe88st HTU to first flower at 1999.90 HTU weeks after transplanting.

Helio - Thermal Unit (HTU) to First Fruit: Cayenne pepper under the 7 days water supply regime exhibits the highest HTU to first fruit at 6119.40 HTU, followed by the 3 days water supply regime with 5955.63 HTU, then, the 5 days water supply regime accumulates 5320.25 HTU, and the everyday (optimal) water supply regime reaches first fruit at 5104.43 HTU weeks after transplanting.

Helio - Thermal Unit (HTU) to First Harvest: Cayenne pepper under the 7 days water supply regime leads in HTU to first harvest at 7895.73 HTU, followed by the everyday (optimal) water supply regime with 7473.43 HTU, then, the 3 days water supply regime accumulates 7724.03 HTU, and the 5 days water supply regime has the lowest HTU to first harvest at 7202.96 HTU weeks after transplanting.

Heat Use Efficiency: Cayenne pepper heat use efficiency varies among water supply regimes, ranging from 0.00057 to 0.00180. Cayenne pepper under the 5 days water supply regime demonstrates the highest efficiency at 0.00180 HUE, followed by the everyday (optimal) water supply regime with 0.00137 HUE, then, the 7 days water supply regime with 0.00120 HUE, and the 3 days water supply regime with 0.00057 HUE weeks after transplanting.

3.3. Phenological and Yield Characters of Cayenne Pepper Under Optimal and Limited Water Supply Regimes in Abeokuta

The response of Cayenne pepper phenological and yield characters under optimal and limited water supply regimes in Abeokuta is shown in Table 2. During the observed periods Cayenne pepper shows varying response in phenological characters.

Days to Vegetation: Cayenne pepper under 3 days water supply regime also shows highest days to vegetation at 47.33 days, followed by the everyday (optimal) water supply regime, taking 46.67 days, then, the 7 days water supply regime with 30.00 days, and the 5 days water supply regime had the lowest duration to first harvest with 27.67 days after transplanting.

Days to First Flowering: Cayenne pepper under everyday (optimal) and the 3 days water supply regime had the highest value, taking 51.00 days to reach the first flowering stage, followed by the 7 days water supply regime, taking 32.33 days, and the 5 days water supply regime had the lowest days to first flowering with 30.00 days after transplanting.

Days to First Fruiting: Cayenne pepper under 7 days water supply regime exhibits the longest duration to first fruiting at 96.50 days, followed by the 3 days water supply regime, taking 93.00 days, then, the 5 days water supply regime with 81.33 days, and the everyday (optimal) water supply regime had the lowest 8duration to first fruiting with 76.67 days after transplanting.

Day to First Harvest: Cayenne pepper under 7 days water supply regime also results in the highest days to first harvest at 138.50 days. Followed by the 3 days water supply regime, taking 135.00 days then, the everyday water supply regime with the value of 128.00 days, and the 5 days water supply regime had the lowest duration to first harvest with 121.00 days after transplanting.

Number of Flowers: Cayenne pepper under 3 days water supply regime yields the highest number of flowers at 32.03, followed by the everyday (optimal) water supply regime, taking 25.77, then, the 5 days water supply regime with the value of 20.47, and the 7 days water supply regime yield the lowest number of flowers with the value of 19.37 weeks after transplanting.

Table 1. The response of cayenne pepper thermal indices under optimal and limited water supply regimes in Abeokuta.

Variety	Watering	GDDVEG	GDD_FFL	GDD_FFR	GDD_FH	HTU_VEG	HTU_FFL	HTU_FFR	HTU_FH	HUE
NHSMB-F4	3 days	784.25	844.08	1539.92	2183.08	3138.11	3348.04	5955.63	7724.03	0.0057
	5 days	457.33	495.00	1352.92	1967.58	1906.85	1999.90	5320.25	7202.96	0.00180
	7 days	494.83	533.67	1593.50	2242.00	2044.02	2166.65	6119.40	7894.73	0.00120
	Everyday	775.25	853.17	1280.75	2077.08	3161.34	3483.12	5104.43	7473.48	0.00137
	LSD	548.17 ns	575.46 ns	535.56 ns	507.53 ns	2156 ns	2118.9 ns	1657.8 **	1351.8 ns	0.0023 ns

Where GDD_VEG is Growing Degree Days to Vegetation HTU_VEG is Helio _Thermal unit to Vegetation

GDD_FFL is Growing Degree Days to First Flower HTU_FFL is Helio _Thermal unit to First Flower

GDD_FFR is Growing Degree Days to First Fruit HTU_FFR is Helio_Thermal unit to First Fruit

GDD_FH is Growing Degree Days to First Harvest HTU_FH is Helio_Thermal unit to First Harvest

HUE is Heat Use Efficiency, ns is Not Significant, ** is Significant at 0.05

Table 2. Phenological and yield characters of Cayenne pepper under optimal and limited water supply regimes in Abeokuta.

Variety	Watering	DFFL	DFFR	DFH	DVEG	NOF	FD (cm)	FL (cm)	FW (g)	NOF	NOH
NHSMB-F4	3 days	51.00	93.00	135.00	47.33	32.03	0.77	2.52	8.39	14.67	46.33
	5 days	30.00	81.33	121.00	27.67	20.47	2.73	5.28	25.24	7.43	33.67
	7 days	32.33	96.50	138.50	30.00	19.37	1.22	4.96	18.52	4.95	17.50
	Everyday	51.00	76.67	128.00	46.67	25.77	1.11	4.63	20.47	27.87	86.00
	LSD	34.17 ns	33.45 ns	32.72 ns	32.36 ns	16.06 ns	1.38 **	2.95 ns	34.24 ns	19.24 **	53.23 **

Where: DFFL is Days to First Flowering NOFL is Number of Flowers NOF is Number of Fruits

DFFR is Days to First Fruiting FD is Fruits Diameter NOH is Number of Fruits harvested

DFH is Days to First Harvest FL is Fruits Length

DVEG is Days to Vegetation FW is Fruits Weight

ns is Not Significant, ** is Significant at 0.05

Fruit Diameter: Cayenne pepper under 5 days water supply regime results in the highest values for fruit diameter (2.73 cm), followed by the 7 days water supply regime with the value of 1.22 cm, then, the everyday (optimal) water supply regime with the value of 1.11 cm, and the 3 days water supply regime had the lowest value of 0.77 cm weeks after transplanting.

Fruit Length: Cayenne pepper under 5 days water supply regime results in the highest values for fruit length (5.28 cm), followed by the 7 days water supply regime with the value of 4.96 cm, then, the everyday (optimal) water supply regime with the value of 4.63 cm, and the 3 days water supply regime had the lowest value of 2.52 cm weeks after transplanting.

Fruit Weight: Cayenne pepper under the 5 days water supply regime results in the highest values for fruit weight (25.24 g), followed by the everyday (optimal) water supply regime with the value of 20.47 g, then, the 5 days water supply regime with the value of 18.52 g, and the 3 days water supply regime had the lowest value of 8.39 g 888uhweeks after transplanting.

Number of Fruits: Cayenne pepper under the everyday (optimal) water supply regime yields the highest number of fruits at 27.87, followed by the 3 days water supply regime, taking 14.67, then, the 3 days water supply regime with the value of 7.43, and the 7 days water supply regime yield the lowest number of fruits with the value of 4.95 weeks after transplanting.

Number of Harvests: Cayenne pepper under everyday (optimal) water supply regime yields the highest number of fruits at harvest with the value of 86.00, followed by the 3 days water supply regime, taking 46.33, then, the 5 days water supply regime with the value of 33.67, and the 7 days water supply regime yield the lowest number of fruits harvested with the value of 17.50 weeks after transplanting.

3.4. Growth Characters of Cayenne Pepper Under Optimal and Limited Water Supply Regimes in Abeokuta

Plant Height : The response of Cayenne pepper plant height under optimal (everyday) and limited water supply regimes in Abeokuta is shown in Figure 2. Limited water supply regimes of 3, 5 and 7 days watering regimes did not significantly influenced Cayenne pepper plant height at all sampling occasions except at 5 WAT under everyday (optimal) water supply regimes. At 2 WAP, Cayenne pepper plant height varied from 14.73 to 16.17 cm under everyday (optimal) and 3 days water supply regimes respectively. At 3 WAP, Cayenne pepper plant height varied from 17.44 to 22.44 cm under 5 and 3 days water supply regimes respectively. Also, at 4 WAP it was unveiled that Cayenne pepper plant height varied from 23.78 to 28.17 cm under 7 and 5 days water supply regimes respectively. The figure further unveiled that at 5 WAP Cayenne pepper plant height varied from 23.17 to 32.50 cm under 7 days and everyday (optimal) water supply regimes respectively. At 6 WAP, Cayenne pepper plant height ranged from 28.50 to 33.61 cm under 7 and 3 days water supply regimes respectively. Finally, at 7 WAP Cayenne pepper plant height ranged from 30.22 to 36.00 cm under 7 to 3 days water supply regimes respectively.

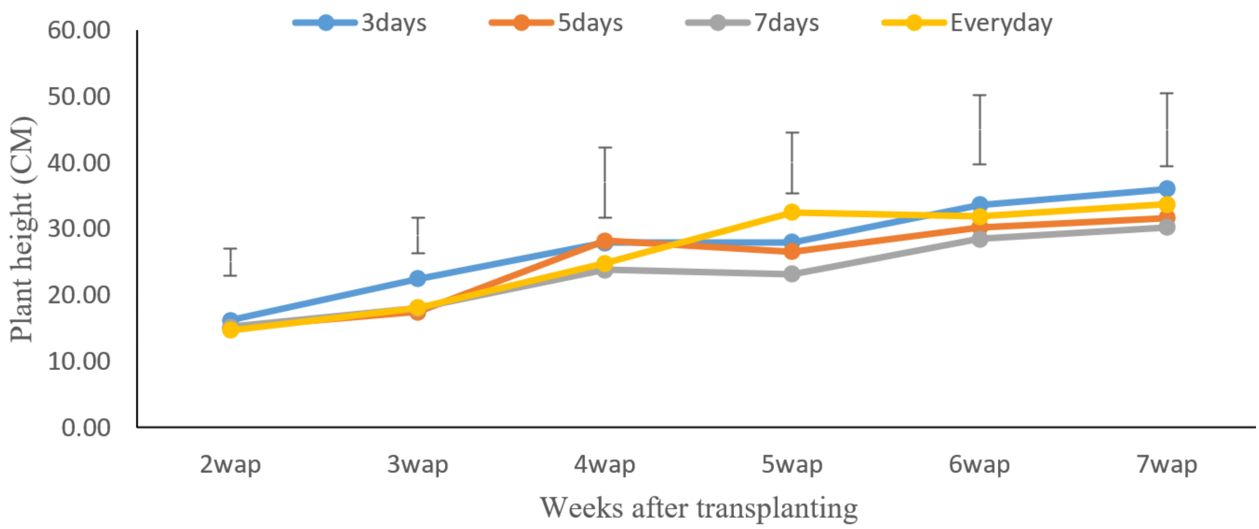

Figure 2. The response of plant height under optimal and limited water supply regimes in Abeokuta.

Stem Girth: The response of Cayenne pepper stem girth under optimal (everyday) and limited water supply regimes in Abeokuta is shown in Figure 3. Limited water supply regimes of 3, 5 and 7 days and that of optimal (everyday) water supply regime did not significantly (P>0.05) influenced the stem girth of Cayenne pepper at all sampling occasions except at 3 WAP under limited water supply regime of 3 days. At 2 WAP, Cayenne pepper stem girth varied from 2.54 to 4.18 cm under 7 days and everyday (optimal) water supply regimes respectively. At, 3 WAP, Cayenne pepper stem girth varied from 2.99 to 5.03 cm under 7 and 3 days water supply regimes respectively. Also, at 4 WAP, it was unveiled that Cayenne pepper stem girth varied from 4.40 to 5.61 cm under everyday (optimal) and 3 days wate supply regimes respectively. Further exploration at 5 WAP demonstrated that Cayenne pepper stem girth varied from 4.33 to 5.76 cm under 5 and 3 days water supply regimes respectively. At 6 WAP, Cayenne pepper stem girth varied from 4.53 to 5.95 cm under 7 and 3 days water supply regimes respectively. Finally, at 7 WAP, Cayenne pepper stem girth varied from 4.90 to 6.35 cm under 7 and 3 days water supply regimes respectively.

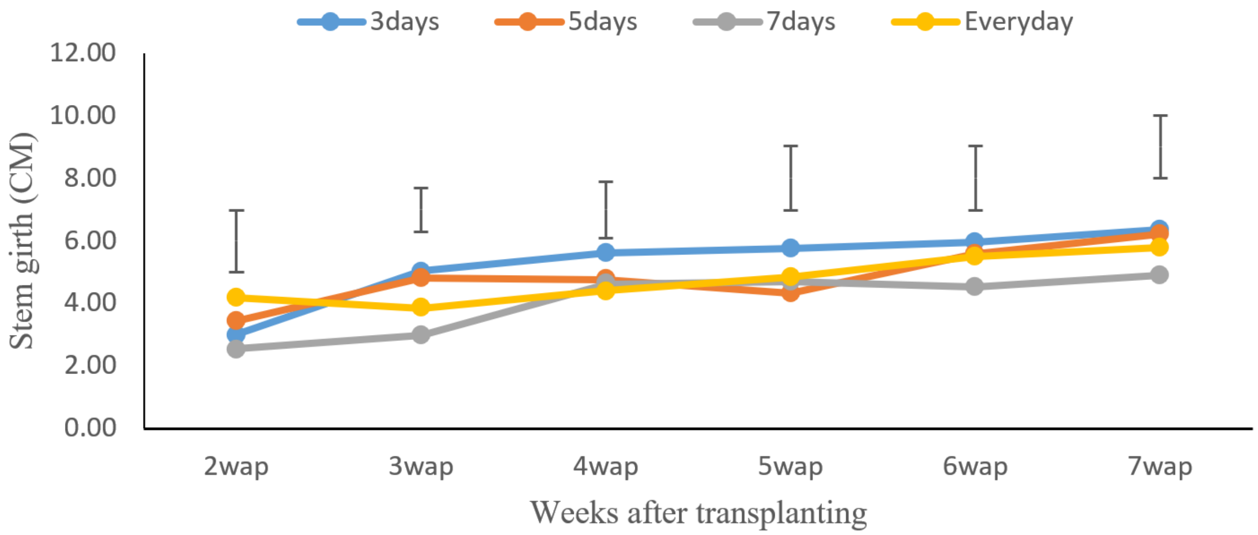

Figure 3. The response of Stem girth under optimal and limited water supply regimes in Abeokuta.

Number of Leaves: The response of Cayenne pepper number of leaves to optimal and limited water supply regimes in Abeokuta is shown in Figure 4. Limited water supply regimes of 3, 5 and 7 days and that of optimal (everyday) water supply regime did not significantly (P>0.05) influenced the Cayenne pepper number of leaves at all sampling occasions except at 2 WAP under limited water supply regime of 3 days. At 2 WAP, Cayenne pepper number of leaves varied from 12.51 to 23.44 under everyday (optimal) and 3 days water supply regimes respectively. At 3 WAP Cayenne pepper number of leaves aves varied from 14.22 to 35.78 under everyday (optimal) and 3 days water supply regimes respectively. Also, at 4 WAP it was also unveiled that Cayenne pepper number of leaves varied from 27.11 to 46.89 under everyday (optimal) and 3 days water supply regimes respectively. The figure further unveiled that at 5 WAP Cayenne pepper number of leaves varied from 37.56 to 53.89 under 7 days and everyday (optimal) water supply regimes respectively. At 6 WAP, Cayenne pepper number of leaves varied from 49.89 to 60.33 under 7 days and everyday (optimal) water supply regimes respectively. Finally, at 7WAP Cayenne pepper number of leaves varied from 58.33 to 70.45 under 7 and 5days water supply regimes respectively.

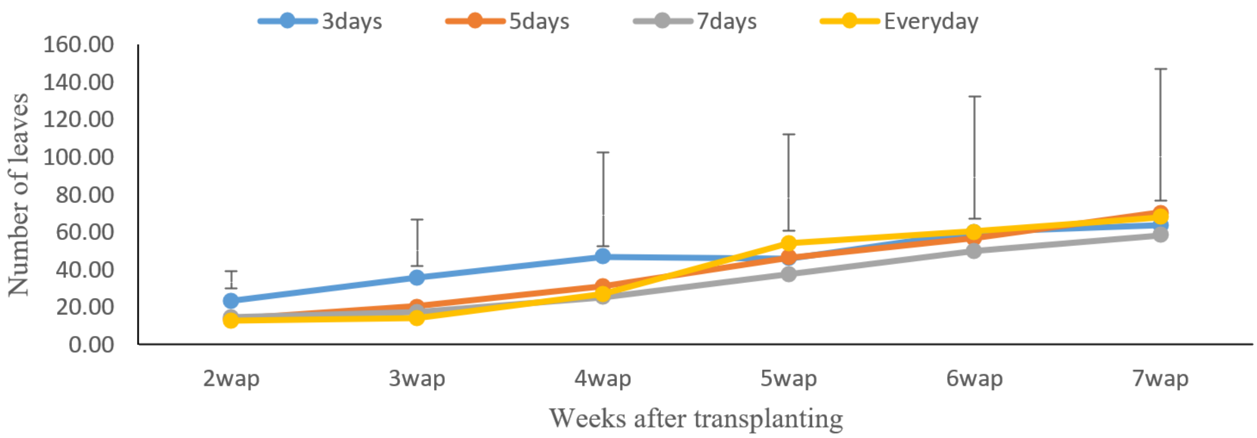

Figure 4. The response of Number of leaves under optimal and limited water supply regimes in Abeokuta.

Leaf Area: The response of Cayenne pepper leaf area to optimal (Everyday) and limited water supply regimes in Abeokuta is shown in Figure 5. Limited water supply regimes of 3, 5 and 7 days and that of optimal (everyday) water supply regime did not significantly (P>0.05) influenced the Cayenne pepper leaf area at all sampling occasions. At 2 WAP, Cayenne pepper leaf area varied from 7.79 to 10.46 cm under 7 and 3 days water supply regimes respectively. At 3 WAP Cayenne pepper leaf area varied from 9.68 to 13.13 cm under 7 and 3 days water supply regimes respectively. Also, at 4 WAP Cayenne pepper leaf area varied from 16.00 to 18.23 cm under 7 and 5 days water supply regimes respectively. The figure further unveiled that at 5 WAP Cayenne pepper leaf area varied from 17.85 to 21.96 cm under 7 and 3 days water supply regimes respectively. Cayenne pepper leaf area at 6 WAP varied from 18.69 to 19.56 cm under 3 days and everyday (optimal) water supply regimes respectively. Finally, at 7 WAP Cayenne pepper leaf area varied from 19.94 to 25.09 cm under 7 and 3 days water supply regimes respectively.

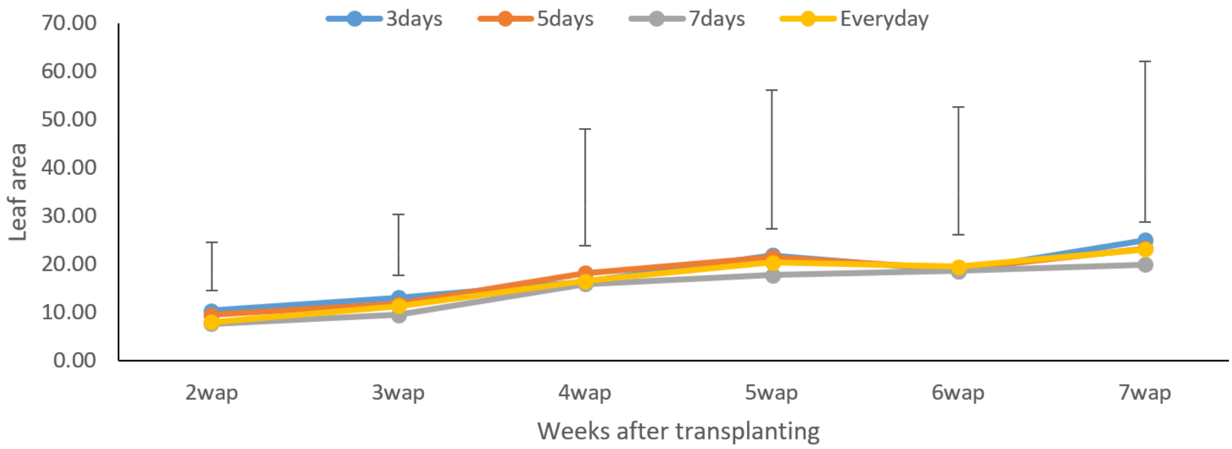

Figure 5. The response of leaf area under optimal and limited water supply regimes in Abeokuta.

3.5. Response of Soil Temperature Patterns at A 5 Cm Depth for Cayenne Pepper Under Optimal and Limited Water Supply Regimes in Abeokuta

The response of soil temperature patterns at a 5 cm depth for Cayenne pepper under optimal (everyday) and limited water supply regimes in Abeokuta is shown in Figure 6. Limited water supply regimes of 3, 5 and 7 days and that of optimal (Everyday) water supply regime did not significantly ($P>0.05$) influenced the soil temperature of Cayenne pepper at all sampling occasions. At 2 WAP, soil temperature patterns at a 5 cm depth for Cayenne pepper varied from 34.49 to 35.20 ℃ under 3 and 5 days water supply regimes respectively. At 3 WAP soil temperature patterns at a 5 cm depth for Cayenne pepper varied from 29.51 to 30.57 ℃ under 7 and 5 days water supply regimes respectively. Also, at 4 WAP soil temperature patterns at a 5 cm depth for Cayenne pepper varied from 31.47 to 32.69 ℃ under 3 and 5 days water supply regimes respectively. At 6 WAP soil temperature patterns at a 5 cm depth for Cayenne pepper varied from 36.81 to 37.60 ℃ under 7 and 5 days water supply regimes respectively. Finally, at 7 WAP soil temperature patterns at a 5 cm depth for Cayenne pepper varied from 34.85 to 35.67 ℃ under 5 and 7 days water supply regimes respectively.

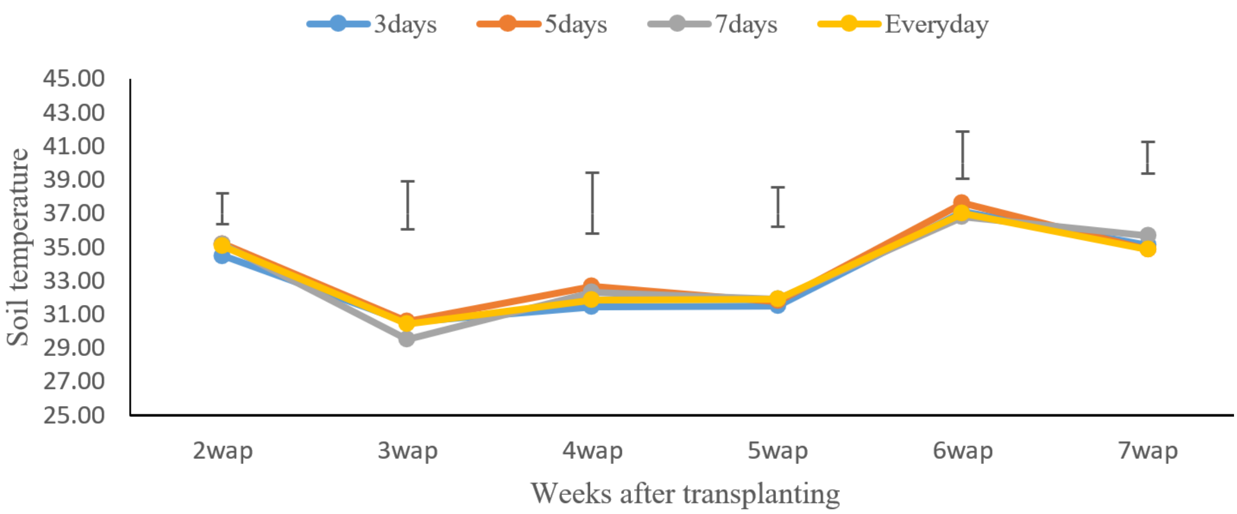

Figure 6. The response of soil temperature patterns at a 5 cm depth for Cayenne pepper under optimal and limited water supply regimes in Abeokuta.

3.6. Response of Soil Temperature Patterns at A 10 Cm Depth for Cayenne Pepper Under Optimal and Limited Water Supply Regimes in Abeokuta

The response of soil temperature patterns at a 10 cm depth for Cayenne pepper under optimal (everyday) and limited water supply regimes in Abeokuta is shown in Figure 7. Limited water supply regimes of 3, 5 and 7 days and that of optimal (Everyday) water supply regime did not significantly (P>0.05) influenced the soil temperature of Cayenne pepper at all sampling occasions. At 5 WAP, soil temperature patterns at a 10 cm depth for Cayenne pepper varied from 31.17 to 32.54 ℃ under 3 and 5 days water supply regimes respectively. Also, at 6 WAP soil temperature patterns at a 10 cm depth for Cayenne pepper varied from 36.48 to 37.33 ℃ under 7 and 5 days water supply regimes respectively. Finally, at 7 WAP soil temperature patterns at a 10 cm depth for Cayenne pepper varied from 34.48 to 35.36 ℃ under everyday (optimal) and 7 days water supply regimes respectively.

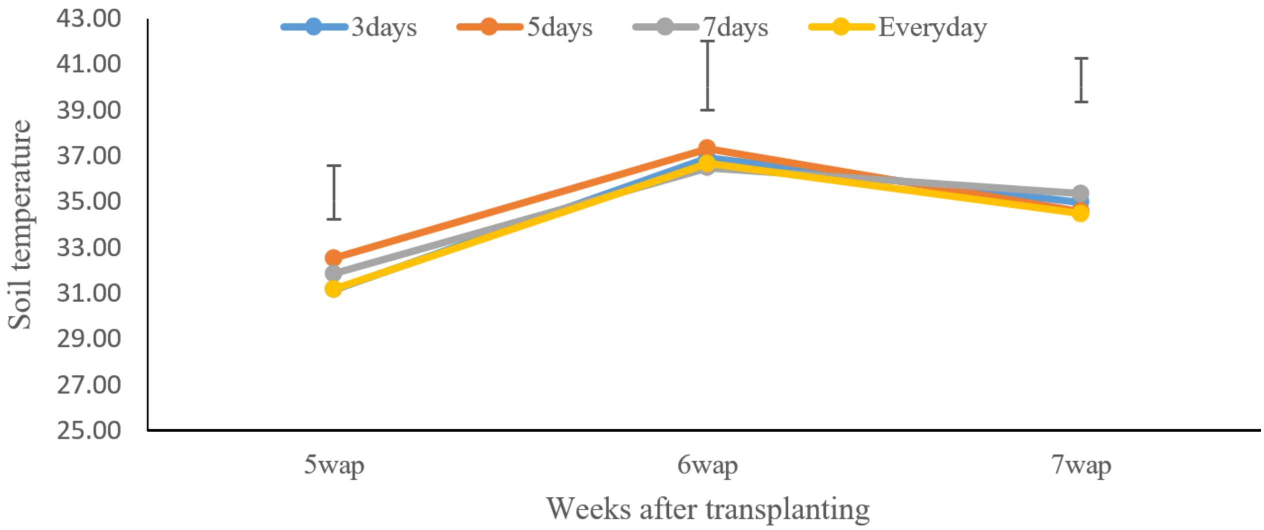

Figure 7. The response of soil temperature patterns at a 10 cm depth for Cayenne pepper under optimal and limited water supply regimes in Abeokuta.

4. DISCUSSION

The research findings underscore the critical role of water management in optimizing pepper growth and yield, this is consistent with González-Dugo, et al. [18] and Flexas, et al. [19] who highlighted the high sensitivity of pepper species to water stress. The response of Cayenne pepper under optimal (everyday) and limited water supply regimes. Thermal indices are veritable tools to summarize thermal stress effects on plant growth and yield. Ashrae [3] and Parsons [4]. The Heat Use Efficiency (HUE) values show how well Cayenne pepper use heat to achieve more yield. Higher HUE values mean they use heat better, which can lead to more yield. Cayenne pepper showed a remarkable adaptability, particularly evident in its expedited progression to the vegetative stage under the 5 days watering regime. This finding highlights the various temperature based indices like growing degree days (GDD), photo-thermal units (PTU) and helio-thermal units (HTU) can be successfully used for describing phenological behavior and other growth parameters like plant growth development, biomass production and yield e.t.c. Neog and Chakravarty [20]. The observed Heat Use Efficiency (HUE) values further emphasize the pepper specie efficient utilization of available resources, promising prospects for mitigating limited water regimes and enhancing agricultural productivity, these research shed light on the dynamic relationship between Cayenne pepper and water management strategies, emphasizing the importance of the use of specific methods such as limited water supply regimes of 3, 5, and 7 days to make sure vegetable crops grow well and can handle different environments. These findings align with the research of Alvino and Zerbi [21] who demonstrated the importance of heat use efficiency in crop performance under stress conditions. Cayenne pepper higher adaptability and notable responses across the different phenological stages under varied water supply regimes underline the findings according to Jones [22] there are three main physiological processes that plants use to adapt to conditions of water stress: i) avoiding plant water deficit, ii) tolerating plant water deficit, and iii) efficiency mechanisms. Plants use a variety of strategies to prevent water deficits, including developing drought escape mechanisms (such as shortening their growth cycles and establishing dormant periods during dry seasons); creating small leaves, reducing their leaf area, and stomatal enclosures; and optimizing water uptake through the development of strong root systems. Phenological and yield characters as well as weather parameters observed across screen house pepper Cayenne pepper under optimal and limited water supply regimes. The phenological stage and yield characters were examined from days to first flowering, fruiting, and harvest. Yield character such as fruits length, fruits diameter and weight, this findings have also been reported to vary with change in site, location and topography and environment. Weather parameters have significant impact on the phenology of agricultural, horticultural and flower crops [23] alongside parameters such as fruit diameter, length, weight, and the number of fruits at various stages. The phenological responses for Cayenne pepper under 5 days water supply regimes sped up the plant's development to the first flowering stage aligning with findings by Yaghi, et al. [24] on the impact of irrigation frequency on pepper growth stages. Cayenne pepper's robust growth under the 5 days watering regime aligns with the observed stomatal enclosure mechanisms and osmotic adaptations reported by Wang, et al. [25] and Sanders and Arndt [26] suggesting effective physiological responses to moderate water stress. The results showed distinct responses among the varieties to different water supply regimes. For instance, Cayenne pepper displayed the shortest duration to first fruiting and harvest under 5 days water supply regime while, the longest duration to first fruiting and harvest was under the 7 days water supply regime. Also Cayenne pepper exhibited the highest number of fruits and number of harvest under 3 days water supply regime, echoing the findings of Dorji, et al. [27] on the influence of irrigation frequency on fruit yield and quality. The findings on growth parameters, including plant height, stem girth, and number of leaves. Despite variations in water supply regimes, certain trends emerged, indicating the resilience of some growth parameters to changes in water availability. For instance, Cayenne pepper under 3 days water regime showed consistent increases in plant height and stem girth, highlighting its adaptability to varying water conditions. Similarly, Cayenne pepper under 3 days water regime exhibited distinct responses in number of leaves and leaf area, emphasizing the importance of understanding how different plant species cope with water stress. These observations are consistent with the findings of Kang, et al. [28] who explored the effects of different irrigation strategies on plant growth parameters. Overall, the comprehensive examination of thermal indices, phenological and yield characters as well as growth parameters sheds light on the dynamics relationship between plant growth and water availability. These findings contribute valuable insight for agricultural practices, informing strategies to optimize crop productivity under varying environmental conditions as also highlighted by Jones [22].

5. CONCLUSION

Cayenne pepper (NHSMB-F4) accumulated more heat under limited water supply regimes of 5 and 7 days as revealed by higher GDD, HTU and HUE values. Cayenne pepper (NHSMB- F4) cultivation maximize heat use efficiency under limited water supply regimes. Among the Limited water supply regimes, Cayenne pepper (NHSMB-F4) under 5 days regime show the shortest days to first flowering and first harvest, indicating relatively faster development compared to 3 and 7 days watering regimes. Limited water supply of 5 and 7 days regimes produces higher fruits yield for the Cayenne pepper (NHSMB-F4). Generally Cayenne pepper (NHSMB-F4) has the highest stem girth and number of leaves under 3 days regime compared

5.1. Recommendations

In environment where there is limited water supply, vegetable farmers are encouraged to adopt limited water supply regimes such as 3 and 5 days watering regimes. To reduce water crisis, vegetables farmer could adopt limited water supply regimes of 3, 5 and 7 days without any adverse effects on the their vegetable. For efficient water use, vegetable farmers can use recommended water regimes to manage their plants in dry conditions. Cayenne pepper (NHSMB-F4), perform well under all limited water supply regimes, its cultivation is therefore recommended in a water limited conditions without any adverse effect on the final yield.

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