Hindawi
Journal of Engineering
Volume 2023, Article ID 9970714, 9 pages
https://doi.org/10.1155/2023/9970714

Research Article

Optimization of Water Management for Green Pepper Production in a Water-Limiting Tropical Savanna Agroecological Zone Based on Crop Water Productivity

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Received 16 May 2022; Revised 13 April 2023; Accepted 3 May 2023; Published 29 May 2023

Academic Editor: Ramadhansyah Putra Jaya

This study aimed to determine the optimum levels of irrigation regime and irrigation schedule based on crop water productivity for the sustainable production of green pepper in a water-limiting tropical savannah agroecological zone. The study was conducted at the Hydro Farm of MotorKing Company Limited in the Tamale Metropolis, Northern Region, Ghana. The experimental design was a 2×3 factorial experiment laid out in a randomized complete block and replicated five times. Irrigation schedule at two levels (one-time daily application and split daily application at 60% morning and 40% evening) and irrigation regime at three levels (100% ET_c, 80% ET_c, and 60% ET_c) were the factors. The "Yolo Wonder" variety of green pepper was the test crop. The crop was planted at a planting distance of 0.3 m within rows and 0.5 m between rows. Treatments were applied using a drip irrigation system. Crop water requirements (ET_c) of green pepper were estimated using the CROPWAT model. Crop yield and water applied under each treatment were determined. Crop yield was measured at harvest as the total weight of fruits per hectare. Crop water productivity was determined under each treatment as crop yield per unit of water consumed. Data analysis was done in Genstat (12^{th} edition). Analysis of variance (ANOVA) and Duncan's multiple range test at 5% level of significance were employed to separate differences in treatment means. The results suggest that both irrigation regime and irrigation schedule have significant influence on the yield and crop water productivity of green pepper. Irrigating at 60% ET_c and split irrigation (60% morning and 40% evening) gave significantly higher yields and crop water productivity compared to the other levels of the factors. This study demonstrated that irrigation schedule and irrigation regime are important factors to consider in the optimization of water management for green pepper; however, further research is needed to identify the optimal levels of these factors and the most effective irrigation strategies for the crop in different environments.

1. Introduction

In many parts of the world, water is increasingly becoming scarce driven largely by competition from industrial, domestic, and agricultural users. Water consumption for crop production constitutes the largest consumption of freshwater supply. According to Kabir et al. [1], about 80% of global water use is for crop production. Out of this, about 70% is used for irrigation [2]. Because water is the most limiting factor in crop production, it has become necessary to explore various strategies and technologies for improving water use efficiency and crop water productivity of crops in both rainfed and irrigated agriculture.

Water use efficiency and crop water productivity used interchangeably hereafter are concerned with the maximization of crop yields per unit of water consumed by crops [3, 4]. Essentially, this involves various strategies and technologies that help to optimize water use by reducing water losses through evaporation and drainage. Some of the strategies and technologies which have been recognized for their capacity to improve crop water productivity of crops include drip and deficit irrigation.

Drip irrigation is noted as the most efficient irrigation system for vegetable production [5]. This system delivers water to crops in low amounts and at high frequency which helps to reduce water loss through evaporation and drainage, thus improving the water use efficiency of the crops. According to Badr et al. [6], drip irrigation is increasingly being adopted in arid and semi-arid regions with the aim to improve water use efficiency (WUE) of plants.

Deficit irrigation has emerged over the past decade as an important technique for enhancing water productivity [7]. As explained by Rathore et al. [7], it involves an application of the amount of irrigation water lesser than the full crop water requirement or crop evapotranspiration (ET) of a particular crop. By reducing the amount of water needed to meet the crop water requirement or the field capacity water content of the soil, DI aims to maximize water productivity and to stabilize—rather than maximize—yields [8]. In the arid and semi-arid regions, DI is increasingly being reported to increase water productivity and water savings in the production of many crops.

Over the past three decades, studies into deficit irrigation have investigated the effects of different irrigation water application regimes (100% of crop water requirement (ET_c) or field capacity water content (FC), 80% ET_c or FC, and 60% ET_c or FC) and irrigation frequencies (daily, 2 days, and up to 5 days irrigation interval) on the growth and yield of various crops including green pepper [9–13]. While some studies have shown that reducing water supply to crops during the growing period led to adverse effects on yield and growth of crops [13], others have reported that deficit irrigation can potentially lead to significant savings of water, improved water productivity, and increased crop yields [7].

In most previous studies, deficit irrigation has often been given as one-time application either in the morning or evening. This strategy could not only be resulting in high water loss through evaporation but low irrigation water use efficiency. Split deficit irrigation could be an efficient and effective strategy for minimizing water loss through evaporation and deep percolation and for ensuring efficient use of water by crops [14]. Indeed, some studies have shown that split application of nitrogen fertilizers resulted in improved yields and nitrogen use efficiency in many crops [15–18]. However, information on how split deficit irrigation could be used to optimize water management in the production of vegetables is currently limited.

Green pepper also known as sweet or bell pepper (*Capsicum annuum* L.), is an important economic crop belonging to *Solanaceae* family. In Ghana, it is one of the most common and highly valued vegetable crops [19]. In the Tamale Metropolis, green pepper is an important vegetable crop largely grown under irrigated dry-season agriculture. Most vegetable farmers in this area are currently using traditional irrigation practices which often result in under-application and excessive application of water. Since it has been noted that green pepper is sensitive to both water deficit and excessive soil water conditions, it is critical to understand how much water stress can be imposed on the crop and the best strategy for imposing the water stress. Optimizing water management for the production of green pepper in the Tamale Metropolis is essential for the sustainability of the crop and for meeting the increasing demand for the crop.

The focus of the present study was to investigate the effects of different irrigation regimes (100% ET_c, 80% ET_c, and 60% ET_c) and different irrigation schedules (one-time daily application and split application of daily irrigation; 60% morning and 40% evening) on the yield and crop water productivity, of green pepper in the Tamale Metropolis, Northern Region, Ghana.

2. Materials and Methods

2.1. Description of the Experimental Site. The study was conducted at the experimental farm (Hydro Farm) of MotorKing Company in Nyohini, one of the suburbs of the Tamale Metropolis. The area is located within latitudes 9°16′N and 9°34′N and longitudes 0°34′W and 0°57′W (Figure 1). The topography is generally flat, and the elevation is about 166 m above sea level. The geology of the area is defined by the Paleozoic consolidated sedimentary rocks developed mainly from sandstone, shale, and mudstone [20]. The major soil groups in this area are Stagnic Plinthosols and Planosols [21]. The soils in this area are predominantly sandy loams with a bulk density of 1.29 g/cm^3, pH of 6.5, organic carbon of 0.66%, nitrogen of 0.06%, phosphorus of 9.54 mg/kg, potassium of 82.7 mg/kg, and cation exchange capacity of 4.18 cmol+/kg.

2.2. Planting Material. Seeds of the "Yolo Wonder" variety of green pepper (*Capsicum annuum* L.), with a germination percentage of 95%, was procured from a renowned licensed agrochemical company called Wumpini Agrochemicals located in Tamale, Northern Region, Ghana. No treatment was applied to the seeds before planting. Seeds were planted on a raised nursery bed under a shed, and after germination, the seedlings were watered and the manure was applied for six weeks after transplanting.

2.3. Experimental Design. The study adopted a 2 × 3 factorial experiment in a randomized complete block design. The factors were irrigation schedule at two levels (one-time daily application and split daily application at 60% morning and 40% evening) and irrigation regime at three levels (100% ET_c, 80% ET_c, and 60% ET_c). This design was adopted because of the fewer treatment combinations and its capacity to evaluate the main effects of each treatment as well as any interaction effects between the two treatments. The experiment consisted of six treatment combinations (Table 1) which were replicated five times. The treatments were randomly assigned separately and independently in each block using the table of random numbers.

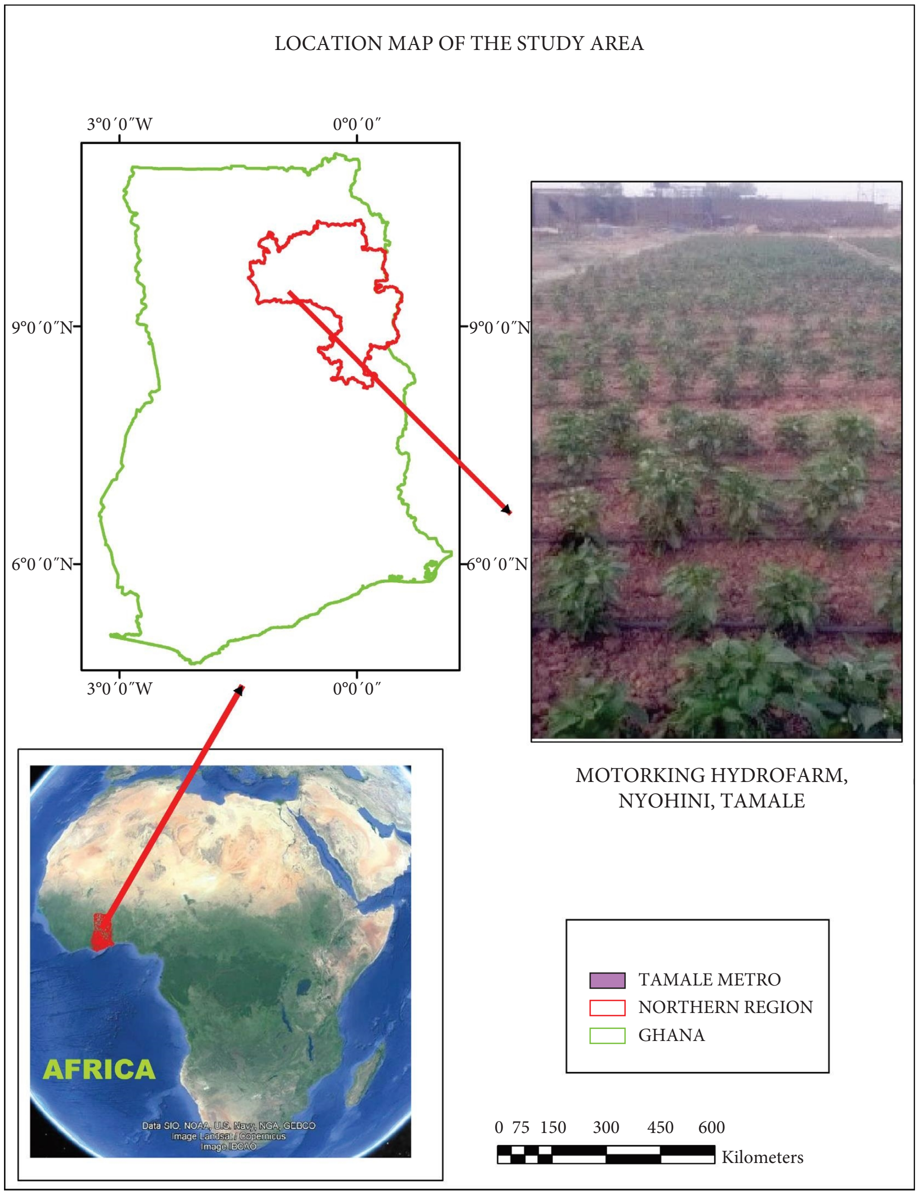

Figure 1: Location of study area.

Table 1: Treatment combinations used for the experiment.

Treatment	Description
S_1R_1	100% ET_c (one-time application in the morning)
S_2R_1	80% ET_c (one-time application in the morning)
S_3R_1	60% ET_c (one-time application in the morning)
S_1R_2	100% ET_c (split application, 60% in the morning and 40% in the evening)
S_2R_2	80% ET_c (split application, 60% in the morning and 40% in the evening)
S_3R_2	60% ET_c (split application, 60% in the morning and 40% in the evening)

The linear model for the experiment was given by

$$Y_{\text{ijklm}} = \mu + B_i + \delta_{(i)j} + R_k + BR_{ik} + S_l + BS_{il} + RS_{kl} + BRS_{ikl} + \varepsilon_{(ijkl)m}, \quad (1)$$

where $i = 1, 2, 3, 4, 5$; $j = 1$; $k = 1, 2, 3$; $l = 1, 2$; $m = 1$; Y_{ijklm} = the yield of the only (mth) replicate of the lth level of irrigation schedule and the kth level of irrigation regime in the ith block; μ = the overall mean; B_i = the ith effect of blocks; $\delta_{(i)j}$ = the jth restriction effect on the randomization of treatments on

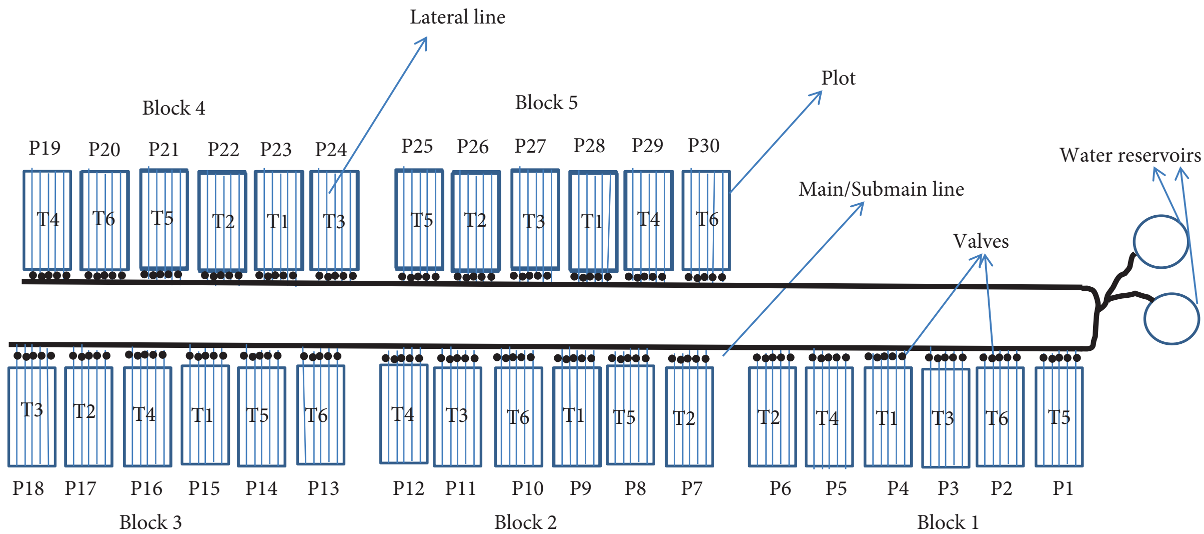

Figure 2: A schematic layout of the field and the drip irrigation network.

Table 2: Estimated monthly ET_o for the study area.

Month	ET_o
January	8.37
February	8.85
March	8.60
April	7.47
May	6.34
June	5.03
July	4.39
August	4.18
September	4.27
October	5.48
November	6.30
December	7.41
Average	6.39

blocks; R_k = the kth effect of irrigation regime (fixed); BR_{ik} = the interaction effect of the ith block with the kth level of irrigation regime; S_l = the lth level of irrigation schedule; BS_{il} = the interaction effect of the lth level of irrigation schedule with the ith block effect; RS_{kl} = the fixed interaction effect of the lth level of irrigation schedule with the kth level of irrigation regime; BRS_{ikl} = the interaction effect of the lth level of irrigation schedule and the kth level of irrigation regime in the ith block; and $\delta_{(ijkl)m}$ = the random error effect associated with the lth irrigation schedule effect and the kth irrigation regime effect in the ith block assuming IID ~ $N(0, \sigma^2)$.

Hypothesis test was done using the conservative test where the block, irrigation regime, and irrigation schedule interaction effects were used as the denominator degrees of freedom to test for the main effects of the factors on the yield of green pepper.

2.4. The Drip Irrigation Network. Drip irrigation was used for the application of various treatments to crops in the field. This system was used because of its high-water application efficiency and precision. The system consisted of 1500 litre and 1000 litre "polytanks" as water reservoirs, main/sub-main lines, laterals, online drippers, valves, and water meters. The main/sub-main lines and the laterals were made up of 32 mm diameter pipes with a total length of 120 m and 16 mm diameter pipes with a total length of 1260 m, respectively. There were five blocks each measuring 143.5 m^2 and 30 plots each measuring 21 m^2 (Figure 2). Each block contained 6 plots with 0.5 m spacing between them. In each plot, there were six laterals each with 23 drip holes or emitters which had a manufacturer's design discharge rate of 2.7 litres per hour. The 1500 litre and 1000 litre polytanks were mounted at 1.2 m and 3.6 m elevations, respectively, to provide required pressure needed to allow the emitter discharge of 2.7 l/h per emitter. This was monitored using a pressure gauge. Water flow through each lateral was controlled using a valve, whereas pressure and water consumption were monitored using a pressure gauge and a water meter, respectively.

Table 3: Crop coefficient of pepper at different growth stages.

Growth stage	Crop coefficient (K_c)
Initial stage	0.6
Crop development	0.81
Mid-season stage	1.00
Late season stage	0.86

2.5. Irrigation Scheduling. The growth cycle of the test crop was determined using the CROPWAT model. The number of days in each growth stage was 15 days for the initial stage, 25 days for the crop development stage, 30 days for the mid-season stage, and 21 days for the late season stage.

Irrigation scheduling was based on the reference crop evapotranspiration (ET_o) and crop factor as described by Allen et al. [22]. Monthly reference crop evapotranspiration (ET_o) values were estimated from thirty-one years of climatic data (1987–2018) using Penman–Monteith method in the

CROPWAT model (8.0). The climate data consisting of temperature, rainfall, relative humidity, wind speed, and sunshine hours were obtained from the Northern Regional Meteorological Services Department, Tamale. The crop coefficients (K_c) of green pepper (Table 2) as reported by Paku [23] were adopted for the study. Using the $\mathrm{ET_o}$ and K_c values of Tables 2 and 3, the crop water requirements of green pepper at various growth stages were calculated using the following equation [24]:

$$\mathrm{ET_c} = \mathrm{ET_o} \times K_c, \tag{2}$$

where $\mathrm{ET_c}$ is the crop water requirement, $\mathrm{ET_o}$ = reference crop evapotranspiration, and K_c is the crop coefficient at each crop growth stage.

Daily gross irrigation (Table 4) was estimated using the following equation [24]:

$$\mathrm{GIR} = \frac{\mathrm{ET_c}}{\mathrm{AE}}, \tag{3}$$

where GIR is the daily volume of water to be applied per plant (litres/day/plant), $\mathrm{ET_c}$ is the crop evapotranspiration (mm)/net irrigation water requirement, and AE is the application efficiency.

The amount of time allowed for applying the daily gross irrigation per plant (Table 5) was calculated using the following equation:

$$\mathrm{T} = \frac{\mathrm{GIR}}{q}, \tag{4}$$

where T is the time (in hours/minutes) to supply the required volume of water, GIR is the volume of water/crop water requirement (litres/day/plant) to be supplied, and q is the average emitter flow/discharge rate (litres/hour).

2.5.1. Determination of Crop Water Productivity. Crop water productivity was estimated using the following equation [24]:

$$\mathrm{CWP} = \frac{Y}{\mathrm{ET_c}}, \tag{5}$$

where CWP is crop water productivity, Y is the fruit yield, and $\mathrm{ET_c}$ is the crop water requirement

2.6. Data Collection and Analysis. Data were collected on crop water consumption under each treatment based on the computed net irrigation at various growth stages of green pepper. Fresh fruit weight was determined at harvest by weighing the mature green fruits using an electronic scale. The data collected was analysed in Genstat (12^{th} edition). Descriptive statistics such as means and standard deviations were calculated for each treatment. The data were also subjected to analysis of variance (ANOVA) to determine whether there were significant influences of the factors and their interaction on the CWP of green pepper. Where there were significant differences in treatment means ($p \leq 0.05$), the means were further separated using Duncan's multiple range test also at 0.05 level of significance.

3. Results and Discussion

3.1. Effect of Irrigation Regime and Irrigation Schedule on the Yield and Crop Water Productivity of Green Pepper. The results obtained from this study showed that crop water productivity (CWP) of green pepper ranged from 1.29 kg/m^3 under S_1R_1 (one-time application of 100% $\mathrm{ET_c}$) to 3.30 kg/m^3 under S_3R_2 (split application of 60% $\mathrm{ET_c}$) (Table 5). The results of an analysis of variance (ANOVA) (Table 6) indicated that the irrigation schedule (F (2, 20) = 9.36, p = 0.001) and irrigation regime (F (1, 20) = 12.25, p = 0.002) had a significant effect on the yield of green pepper. The interaction between irrigation schedule and irrigation regime was however not significant (F (2, 20) = 2.00, p = 0.161). The ANOVA also yielded a significant residual mean square (s.s = 7.2488, m.s = 0.3624, and d.*f.* = 20), indicating that there was variability in the yield of green pepper that was not accounted for by irrigation regime and irrigation schedule.

In order to separate the means of the different levels of irrigation schedule and irrigation regime, Duncan's multiple range test was performed. The results of the test showed that with and LSD of 0.562 at $p < 0.05$, irrigation schedule at 60% $\mathrm{ET_c}$ gave a significant CWP (mean = 2.61 kg/m^3) of green pepper compared to 100% $\mathrm{ET_c}$ (mean = 1.59 kg/m^3) and 80% $\mathrm{ET_c}$ (mean = 1.62 kg/m^3) which produced similar CWPs. Also, with an LSD of 0.459 at $p < 0.05$, split irrigation regime resulted in a significant CWP (mean = 2.32 kg/m^3) compared to one-time irrigation regime (mean = 1.55 kg/m^3) (Table 7). Further, based on Duncan's multiple range test, the study showed that treatment S_3R_2 had significantly higher CWP than all other treatments.

The higher CWP of green pepper recorded under 60% $\mathrm{ET_c}$ compared to that of 100% $\mathrm{ET_c}$ and 80% $\mathrm{ET_c}$ could be attributed to better and efficient use of water and the maximization of biomass production per unit of water consumed by the plants irrigated at 60% $\mathrm{ET_c}$ [25]. Although it is generally believed that water stress in plants leads to a reduction in plant growth and yield, studies have shown that many plants can maintain relatively high photosynthetic rates even under water-limited conditions by efficiently utilizing available water to produce more biomass per unit of water used. Also, Dai et al. [5] have explained that the application of some degree of water stress could help to prevent the redundant growth of various plant parts and ensure redistribution of photosynthetic products to essential tissues and organs to increase yield, improve water use efficiency, and save water.

This assertion is supported by several authors. For instance, Khalkho et al. [26] observed that water stress at 60% available soil moisture gave the highest yield and water use efficiency of green pepper. Xiang et al. [27] compared the effect of applying irrigation water at 105% $\mathrm{ET_c}$, 90% $\mathrm{ET_c}$, 75% $\mathrm{ET_c}$, and 60% $\mathrm{ET_c}$ on the water use efficiency of pepper and found that deficit irrigation at 90% $\mathrm{ET_c}$, 75% $\mathrm{ET_c}$, and 60% $\mathrm{ET_c}$ led to an increase in the water use efficiency of pepper by 23.04%, 33.44%, and 5.28%, respectively, compared to 105% $\mathrm{ET_c}$. Kabir et al. [1] also found that deficit irrigation at 67% $\mathrm{ET_c}$ improved the water use efficiency and gave similar

Table 4: Estimated daily net and gross irrigation and duration of irrigation at different growth stages (application efficiency at 90%).

Treatment		Initial			Development			Mid-season			Late season		
		ET_c	GIR	IRR time	ET_c	GIR	IRR time	ET_c	GIR	IRR time	ET_c	GIR	IRR time
1		5.02	5.58	18 mins, 36 sec	5.78	6.42	21 mins, 24 sec	8.77	9.7	32 mins, 30 sec	5.14	5.71	19 mins
2		4.02	4.47	14 mins, 54 sec	4.62	5.13	17 mins, 6 sec	7.02	7.8	26 mins	4.11	4.57	15 mins, 12 sec
3		3.01	3.34	11 mins, 6 sec	3.47	3.86	12 mins, 54 sec	5.26	5.8	19 mins, 30 sec	3.08	3.42	11 mins, 24 sec
4	Morn	3.01	3.34	11 mins, 6 sec	3.47	3.86	12 mins, 54 sec	5.26	5.8	19 mins, 30 sec	3.08	3.42	11 mins, 24 sec
	Eve	2.01	2.23	7 mins, 24 sec	2.31	2.57	8 mins, 36 sec	3.51	3.9	13 mins	2.06	2.29	7 mins, 36 sec
5	Morn	2.41	2.68	8 mins, 54 sec	2.77	3.08	10 mins, 18 sec	4.21	4.7	15 mins, 36 sec	2.47	2.74	9 mins, 6 sec
	Eve	1.61	1.79	6 mins	1.85	2.06	6 mins, 54 sec	2.63	2.9	9 mins, 42 sec	1.64	1.82	6 mins, 6 sec
6	Morn	1.81	2.01	6 mins, 42 sec	2.08	2.31	7 mins, 42 sec	3.16	3.5	11 mins, 42 sec	1.85	2.06	6 mins, 54 sec
	Eve	1.2	1.33	4 mins, 24 sec	1.39	1.54	5 mins, 6 sec	2.1	2.3	7 mins, 48 sec	1.23	1.37	4 mins, 36 sec

Morn, morning; Eve, evening; ET_c, crop water requirement; GIR, gross irrigation requirement; IRR, irrigation.

Table 5: Crop water productivity of green pepper under different levels of irrigation regime and irrigation schedule.

Treatment	Number of fruits	Average weight of fruits/plant (g)	Yield (kg/ha)	ET_c (m^3/ha)	GIR (m^3/ha)	CWP (kg/m^3)
S_1R_1	2.84	39.892	7635.7ab	5908.4	6077.7	1.292a
S_2R_1	2.58	38.882	6827.3a	4727.1	4862.3	1.444a
S_3R_1	2.72	37.134	6811.8a	3543.8	3645.3	1.922a
S_1R_2	3.96	40.122	11099.1ab	5908.4	6077.7	1.879a
S_2R_2	3.1	40.756	8458.3ab	4723.8	4862.3	1.790a
S_3R_2	4.18	42.19	11687.0b	3543.8	3645.3	3.298b

ET_c, crop water requirement; GIR, gross irrigation requirement; CWP, crop water productivity. Treatment means with the same or similar letters are not significantly different at 0.05 level of significance.

Table 6: ANOVA table for the main and interaction effects of the factors on CWP.

Source of variation	d.*f.*	s.s.	m.s.	*F*	Prob. (<0.05)
Replication	4	0.6442	0.1611	0.44	
Irrigation schedule	2	6.7867	3.3934	9.36	0.001*
Irrigation regime	1	4.4396	4.4396	12.25	0.002*
Interaction	2	1.4504	0.7252	2.00	0.161^{ns}
Residual	20	7.2488	0.3624		
Total	29	20.5697			

*Significant at $p < 0.05$; ns = not significant at $p < 0.05$.

Table 7: Table of means for the levels of the two factors.

Factor level	Means (kg/m^3)
100% ET_c	1.59
80% ET_c	1.62
60% ET_c	2.61
LSD	0.562
Split irrigation	2.32
One-time irrigation	1.55
LSD	0.459
Grand mean	1.94

marketable fruit yield of green pepper compared to 100% ET_c and 133% ET_c. Further, in a study aimed at optimizing water and nitrogen management for green pepper production under drip irrigation, Dai et al. [5] found that the highest water use efficiency and fruit yields were recorded when green pepper crops were irrigated at 65% to 80% of field capacity compared to 100% of field capacity.

Another reason which could be attributed to the higher CWP recorded under 60% ET_c compared to 80% ET_c and 100% ET_c is the fact that, at 60% ET_c, the amount of water applied to the plants was close to the water holding capacity of the soil which prevented water lost through deep percolation, resulting in higher crop water productivity. This fact is supported by Dai et al. [5] who opined that delivering low amounts of water at high frequency limits the amount of evaporation and drainage leading to high water use efficiency. Further, according to Liu et al. [28], under deficit irrigation, soil water content could still reach higher than 70% of field capacity which is sufficient for promoting the growth and yield of pepper.

Further, by reducing the amount of water applied to the green pepper plants, the concentration of nutrients in the soil solution increased, thereby improving nutrient uptake by the plants and improving crop water productivity. This assertion is backed by the findings of several studies. For instance, Jehan et al. [29] in a study to assess the effect of deficit irrigation practice on nitrogen mineralization and nitrate-nitrogen leaching under semi-arid conditions found that deficit irrigation level at 60% ET_c restricted nitrate-nitrogen movement up to 60 cm soil depth with high concentration at 30 cm soil depth. The high concentration of nitrogen in the upper soil layer made it more available to the plants. Also, Rathore et al. [7] in a study aimed at optimizing deficit irrigation and nitrogen fertilizer management for peanut production in an arid region found that slight deficit irrigation resulted in higher crop water productivity compared to full irrigation. Several other studies as cited by Rathore et al. [7] have reported that deficit irrigation led to increased crop water productivity of different crops in arid and semi-arid regions.

The fact that split application of irrigation resulted in higher CWP compared to one-time application of irrigation could be attributed to a number of factors. One is the fact that under split irrigation, there was minimal water loss through evaporation and deep percolation, leading to improved water use efficiency of the crops. That is, when the water was split and applied in the morning and evening, it allowed the soil to absorb and retain more of the water resulting in reduced water lost through evaporation and runoff. This is supported by Barrett et al. [14] who indicated that split irrigation reduces both risks of water loss through deep percolation and nutrient leaching.

Another explanation for the higher CWP under split irrigation is the fact that under split irrigation, nutrient uptake was enhanced because water was applied at the time when the plant needed them the most. By applying water and nutrients at different times of the day, the crop can absorb them more efficiently, which can lead to better growth, development, and yield. Further, split irrigation helped to reduce water stress in the crop by ensuring that the soil moisture remains at an optimal level throughout the day. This helped to reduce the impact of water stress on the crop and promoted better growth and yield.

4. Conclusions and Recommendation

This study showed that both irrigation regime and irrigation schedule have significant influence on the yield and crop water productivity of green pepper in the study area. Irrigating at 60% ET_c and split irrigation (60% morning and 40% evening) might be beneficial to farmers as it gave significantly higher yields and crop water productivity compared to the other levels of the factors. This study demonstrated that irrigation schedule and irrigation regime are important factors to consider in the optimization of water management for green pepper. However, further research is needed to identify the optimal levels of these factors and the most effective irrigation strategies for the crop in different environments.

Data Availability

The data underlying this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This study was supported by MotorKing Company Limited, Tamale.

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