Hindawi
International Journal of Agronomy
Volume 2021, Article ID 9978974, 7 pages
https://doi.org/10.1155/2021/9978974

Research Article

Productivity of Selected Cabbage Varieties under Varying Drip Irrigation Schedules in Humic Nitisols of Embu County, Kenya

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Received 1 April 2021; Accepted 17 May 2021; Published 22 May 2021

Academic Editor: Maria Serrano

Use of controlled irrigation in vegetable production is considered a viable option for optimizing input use and productivity. This study aimed at assessing the effects of different drip irrigation schedules on productivity and profitability of three cabbage varieties grown in *humic nitisols* of Embu County. The study was laid out in a split plot design arranged in Randomized Complete Block Design (RCBD). The drip irrigation schedules were allocated the main plots and crop varieties allocated the subplot treatments. Cabbage test varieties investigated were Riana F1 (V1), Gloria F1 (V2), and Triperio F1 (V3). Irrigation schedule one (S1) involved application of irrigation water twice a week, S2 once a week, and S3 once every two weeks. Soil water content was determined before irrigation and then replenished to field capacity using a known volume of water. The data were subjected to Analysis of Variance using SAS version 9.4. Mean separation was done using Fisher's least significant difference at 95% level of confidence. The findings revealed that the yields and net revenue obtained from different cabbage varieties were not significantly different. However, the cabbage yields and subsequent revenue increased as irrigation frequency increased. The study recommends adoption of irrigation schedule S1 whose productivity remained high despite the high cost of production.

1. Introduction

In the recent past, climate change phenomenon has brought about sporadic weather patterns that have resulted in poor rainfall distribution [1]. These erratic conditions have made it hard to predict the onset and expected amount of rainfall especially in rain-fed agriculture. The decline of agricultural water poses a potential drop in agricultural production and a spike in food prices, thus contributing significantly to perpetual food insecurity and malnutrition [2, 3]. Water scarcity poses a major challenge to the wellbeing of approximately 70% of Embu County residents who are mainly small-scale farmers that depend on rain-fed agriculture as their main economic activity [4].

In Kenya, demand for vegetables has been increasing as their production decreases. The low production is attributed to several challenges including water scarcity, competing farm enterprises, and decline in soil fertility among other challenges [5]. Most small-scale farmers have adopted irrigated agriculture as an alternative farming strategy to cushion against sporadic rainfall distribution [6]. This has been shown to be effective in achieving optimum production of annual crops such as kales and cabbages [7]. However, limited information on efficient irrigation approaches and access to sufficient agricultural water for irrigation have continued to increase the production cost and reduce the net profit margins [8]. Consequently, production trends are on the decline, while the demand is escalating amid the growing population, thus overwhelming the potential of agricultural fields to meet the food demands [7]. In this predicament, food hunger index and malnutrition are expected to increase if agricultural productivity is not revitalized through sound management of declining water resources.

Vegetables are among the most suitable crops to grow in marginal areas characterized with erratic and insufficient rainfall. This is because such conditions are less conducive for the major pests and diseases as the short growing period of vegetables can be sustainably managed through supplemental irrigation. In addition, the high temperatures in these semiarid areas significantly shorten the growing period of vegetables if adequate water is provided through appropriate method of irrigation [9]. Therefore, provision of adequate information and irrigation infrastructure and their management are the key to improving the farmers' potential output and productivity [10].

Cabbage (*Brassica oleracea* var. *capitata*) is a leafy short season crop that is abundant in bioactive antioxidant components such as polyphenols that are key in inhibiting too much accumulation of free radicals in the body [11]. The crop is also rich in vitamin C (ascorbic acid) that boosts the body's immunity against scurvy and cardiovascular related ailments [12–14]. It is also rich in roughage, glutamine, and flavonoids which are essential in controlling constipation and excellent anti-inflammation [15, 16]. The crop enjoys a ready market in Kenya, especially in the Central and Eastern parts of the country, and its short growing period makes it profitable even with limited land and water through incorporation of supplemental irrigation.

Drip irrigation method is recommended over many other irrigation methods due to its ability to apply water continuously under low pressure, thus saving more water and minimizing nutrient leaching as experienced when using other methods of irrigation [17]. Its mode of water delivery directly to the root zone not only supplies water sparingly but also helps reduce build-up of weeds [18]. This helps reduce competition for nutrients and water as well as eliminating certain weeds species that serve as hosts for pests [17]. Drip irrigation is therefore deemed the most efficient, economical, and suitable method for ensuring continuous production in response to climate change effects, especially on water resources. However, there is limited information on the appropriate drip irrigation frequency for different crops in different climatic and edaphic conditions. It is therefore important to understand the appropriate scheduling of drip irrigation for target crops to ensure their optimum productivity at minimum production cost [18].

Majority of irrigation programs and studies in Kenya have focused on production of cereal crops such as maize and rice while overlooking the production of the high value vegetables which are potentially more profitable [19]. Information on performance of most vegetable crops under irrigation among smallholder farmers is therefore scanty, despite vegetables constituting the major portion of the daily human diet, whose demand often surpasses the production capacity [20, 21]. Adoption of efficient irrigation schedules can therefore ensure continuous production and commercialization of vegetables such as cabbage, thus improving the livelihoods of the smallholder farmers living in marginal areas with insufficient or poorly distributed rainfall [22]. This study evaluated the suitability of different drip irrigation schedules on productivity of three cabbage varieties grown in *humic nitisols* of Embu County. The test cabbage cultivars were selected based on their known proximity in agronomic performance, resilience to water stress, water use efficiency, and profitability.

2. Materials and Methods

2.1. Study Site Description. The study was carried out in the University of Embu Agricultural Demonstration Farm. The site is located in Embu County, Kenya, on latitude 0° 30′ S and longitude 37° 27′E at an elevation of 1480 m above sea level. The area receives annual mean low and high temperatures of 9°C and 28°C, respectively, and an average annual rainfall of 1120 mm [23]. The region receives bimodal rainfall and has two major growing seasons, whereby the long-rain season is experienced between the months of March and August, while the short-rain season comes between October and December. The soils are mainly *humic nitisols* which are derived from basic volcanic rocks which are deep and highly weathered with friable clay texture and moderate-to-high inherent fertility [24].

2.2. Experimental Layout. The experiment was laid out in a split plot arranged in Randomized Complete Block Design (RCBD) in which drip irrigation schedules were allocated to the main plot, while the test cabbage varieties were allocated the subplots. The experiment was replicated three times with each block having twelve treatments, that is, four irrigation schedules and three cabbage varieties (Riana F1, Gloria F1, and Triperio F1). Each subplot was measured 3 m by 2 m with a crop spacing of 60 cm by 50 cm and a path of 75 cm separating each plot. The irrigation schedules were arranged as follows: S1 where supplemental irrigation was done twice a week in order to replenish soil water content (SWC) to field capacity (FC); S2 involving application of supplemental irrigation once a week to replenish SWC to FC; S3 involving supplemental irrigation done after every 2 weeks to replenish SWC to FC; and S4 acting as the negative control where supplemental irrigation was not done to simulate farmer practices where production relies on precipitation as the only source of water for the crop. The study was conducted in an uncontrolled environment to have conditions similar to which most small-scale farmers produce their crops. Rainfall effects were accounted for using the daily rainfall data recorded. Moreover, soil moisture content was determined before irrigation was done for every schedule subtracted from the field capacity to determine the amount of supplemental irrigation to supply.

Well-decomposed farmyard manure (FYM) and Triple Super Phosphate (TSP) fertilizer were incorporated into the planting holes before planting at the local recommended rates of 10 $t{\cdot}ha^{-1}$ and 200 $kg{\cdot}ha^{-1}$, respectively. The seedlings were frequently and uniformly irrigated for a period of two weeks to ensure uniform establishment after transplanting and then subjected to the various growing treatments in the open field. Other crop management practices like weeding and spraying against pests and diseases were carried out uniformly and as recommended.

2.3. Data Collection. Field capacity was determined following a gravimetric procedure for soil moisture at the beginning of the experiment for the soils at the study site. The soil moisture determination was done at a two weeks' interval at three depths for each treatment using the gravimetric procedure. Soil samples were collected, weighed, and oven-dried for 24 hours before measuring their dry weight. Feld capacity was established by wetting sections of the experimental land with water to saturation point and then covered with light shed for 48 hours after which samples were collected and subjected to gravimetric procedure of soil moisture determination. Maturation time was determined when 50% of the cabbage heads had become compact and solid according to Rizzolo and Zerbini [25]. Harvesting for first season was done in March 2020 and second season in August 2020.

2.4. Economic Analysis. A partial budgeting approach was used to assess the profitability of each cabbage variety and irrigation schedule due to its ease of projecting incomes and expenses based on the produce. Net revenue was determined by subtracting the total production cost from the gross revenue. Gross revenue was determined by multiplying the marketable cabbage heads with the prevailing farm gate price at that time in season. Total cost of production comprised the operational costs and fixed costs incurred during the experiment where operational costs included the cost of labour and inputs, while the fixed cost only accounted for the cost of acquiring the drip kit. Other fixed costs such as the cost of land and other farm implements were excluded with an assumption that farmers already have them. The study sought to determine the cost that these farmers would incur by switching from rain-fed to irrigated cabbage farming.

Using a Cost Recovery Factor procedure, fixed costs were computed to reflect the value of the asset for that respective year of production. Straight line depreciation method was used to capture the value depreciation of the assets used in the production. The method allocates even rates of depreciation of the equipment over its useful life period. The price of the drip kit was USD 352.92 with an economic life of 8 years. An interest rate of 6.86% was used, which was the annual average deposit interest rate for commercial banks in Kenya for the period of 2019-2020 [26]. The gross returns from the different irrigation levels and varieties were calculated using the marketable yield and the prevailing farm gate price during the season of harvest.

2.5. Statistical Analysis. Data collected was analysed using Statistical Analysis Software (SAS) version 9.4. A two-way ANOVA was used to assess whether there were significant variations and interactions between different varieties and irrigation schedules on growth and yield of cabbages. Treatment means were separated using Fisher's LSD test at 95% level of confidence.

3. Results

3.1. Weather Data. Weather conditions during the study period were erratic, whereby the amount of precipitation experienced was mostly ineffective, below 5 mm [27] (Table 1). During the first two months of the first season (December 2019 and January 2020), high levels of precipitation were experienced, after which a drought spell ensued to the end of the season. In the second season (May to July 2020), light rainfall was experienced in the month of May after which drought again ensued, a phenomenon that was unusual considering that June and July fall within the long rain season usually characterized with rainfall. The changes in the amount and distribution of rainfall within the region were attributed to the effects of climate change. Daily and monthly mean temperatures were fairly similar across the two seasons, although higher mean temperatures were recorded in the first season as compared to the second season (Table 1).

3.2. Irrigation Water Supplied. The amount of irrigation water applied in every irrigation schedule in season one was not significantly ($p > 0.05$) different from the amount supplied in the second season. Rainfall received during the first growing season was higher and well distributed within the first two months of growing, unlike season two that hardly received any significant amount of rainfall, thus demanding more supply of irrigation water. There were significant differences ($p < 0.05$) in the amount of irrigation water added in different irrigation schedules (Figure 1) to replenish the soil moisture to field capacity. In the first season, S1 received the highest addition of water of 1,283.57 m^3/ha, while S4 received the lowest amount (553 m^3/ha) which was purely from rainfall. There was no significant ($p > 0.05$) difference in the amount of irrigation water that was added in S2 and S3 irrigation schedules which amounted to 965 m^3/ha and 905 m^3/ha, respectively. In the second season, S1 received the highest amount of water totalling 1,443 m^3/ha, while S4 received the lowest amount of 198 $m^3 \cdot ha^{-1}$, respectively. Similar to season 1, there was no significant ($p > 0.05$) difference in the amount of irrigation water that was added in S2 and S3 irrigation schedules in season 2, which amounted to 907 $m^3 \cdot ha^{-1}$ and 808 $m^3 \cdot ha^{-1}$, respectively.

3.3. Cabbage Growth and Yield. Growth parameters assessed included time to maturity, cabbage stand count (number of heads per ha), and yields per ha in tons (Table 2). The time to maturity was scored by recording the number of weeks taken by 50% of the cabbage to mature. In the first season, the cabbages grown under S1 took the shortest period of 9 weeks to attain maturity which was significantly ($p < 0.05$) different from the 11 weeks taken under S2 and 15 weeks taken under S3 and S4. A similar trend was observed in the second season, although growth was slightly enhanced under S3 and S4 in the second season, where the cabbages took 13 and 14 weeks, respectively, to attain maturity. The cabbage varieties did not differ significantly ($p > 0.05$) in maturity period. Consequently, there was no interaction between supplemental irrigation and cabbage variety on maturity period.

In both seasons, irrigation schedules S1, S2, and S3 were not significantly ($p > 0.05$) different in the number of heads per hectare. However, S1 and S2 were significantly ($p > 0.05$)

Table 1: Weather data recorded during the growing periods of 2019 and 2020.

Season	Month	Rainfall (mm)	Mean temperature (°C)	Mean relative humidity (%)
	Dec, 2019	23.57	20.45	0.85
1	Jan, 2020	32.87	20.94	0.83
	Feb, 2020	0.56	21.56	0.79
	May, 2020	2.06	20.34	0.87
2	Jun, 2020	0	18.94	0.85
	Jul, 2020	0	18.17	0.84

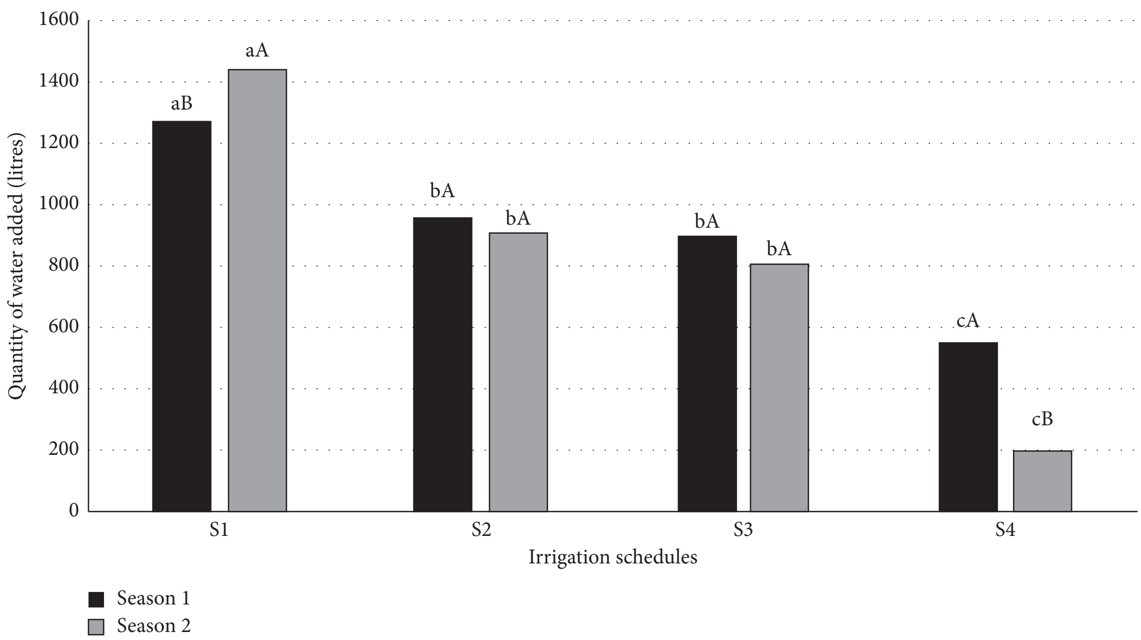

Figure 1: Cumulative quantity of irrigation water added in the four irrigation schedules (S1, S2, S3, and S4) during the study period. The small letters represent treatment variations, while the capital letters represent seasonal variations per treatment.

Table 2: Growth and yield response of different cabbage varieties to different drip irrigation schedules.

Treatment	Factor	Season 1			Season 2		
		Weeks to maturity	Heads/Ha	Yield (t ha^{-1})	Weeks to maturity	Heads/Ha	Yield (t ha^{-1})
Irrigation schedule	S1	9^c	29,815^a	67.58^a	9^c	31,296^a	64.99^a
	S2	11^b	27,778^a	53.05^b	11^b	29,444^{ab}	53.09^b
	S3	15^a	26,481^{ab}	43.75^c	13^a	29,259^{ab}	22.75^c
	S4	15^a	23,519^b	33.69^d	14^a	27,037^b	16.45^d
	LSD	1	3547	6.25	1	2817	5.95
Cabbage variety	Gloria	11^a	27,778^a	49.04^a	12^a	30,000^a	40.60^a
	Riana	12^a	27,083^a	51.49^a	12^a	29,167^a	41.01^a
	Triperio	12^a	25,833^a	48.02^a	12^a	28,611^a	36.35^a
	LSD	1	3072	5.41	1	2440	5.15
	R^2	0.81	0.51	0.89	0.79	0.46	0.94
	CoV	12.12	13.49	12.91	8.73	9.85	15.66
	Mean	12	26,898	49.52	12	29,259	39.32
	Interactions	NS	NS	NS	NS	NS	NS

Means followed by the same letter within a column are not significantly different. R^2: coefficient of determination; CoV: coefficient of variation; NS: not significant.

different in head count from S4 in season 1, while S1 was significantly ($p < 0.05$) different in head count from S4 in season 2 (Table 2). The cabbage varieties had no significant ($p > 0.05$) differences on the stand, implying that they have similar establishment characteristics under similar conditions. There was no interaction between supplemental irrigation and cabbage variety on the stand count in both seasons.

The marketable cabbage yield was obtained by measuring the cumulative fresh weight in kilogram of each cabbage variety per experimental plot and then converting the data to yields in tons per hectare. There were significant ($p < 0.05$) differences in the marketable yield of harvested cabbages across all the irrigation schedules (Table 2). In the first season, S1 gave the highest yield (67.58 $t\cdot ha^{-1}$) followed by S2 (53.05 $t\cdot ha^{-1}$), S3 (43.75 $t\cdot ha^{-1}$), and S4 (control) that produced the lowest yields (33.69 $t\cdot ha^{-1}$). Similarly, in the second season, S1 gave the highest yield of 64.99 $t\cdot ha^{-1}$ followed by S2 (53.09 $t\cdot ha^{-1}$), S3 (22.75 $t\cdot ha^{-1}$), and S4 (16.45 $t\cdot ha^{-1}$). The cabbage varieties did not differ significantly ($p > 0.05$) in yield, and there was no interaction between supplemental irrigation and cabbage variety in terms of yield (Table 2).

3.4. Economic Returns. The production cost incurred in both seasons was similar for specific cabbage varieties and specific irrigation schedules, but application of different irrigation schedules resulted in significantly ($p < 0.05$) different production costs (Table 3). Irrigation schedule 1 (S1) resulted in the highest production cost of $2,103 per hectare per season followed by S2, S3, and S4 with production costs of $1,992, $1966, and $1,854 per hectare per season. The potential net revenue realizable from the sale of cabbage obtained from the different irrigation levels was significantly ($p < 0.05$) different with S1 producing the highest revenue and S4 giving the lowest revenue in both seasons (Table 3). There were significant ($p < 0.05$) differences in net revenue from the different cabbage varieties in season 1, but no significant ($p > 0.05$) differences were observed among different cabbages in season 2 (Table 3) and in combined season analysis.

4. Discussion

Production and achievement of optimum marketable yield of cabbages are greatly anchored on the amount of water available to the crop, owing to its intensive water requirement among other resources. Establishing the best level of irrigation that can be adopted and used to optimize on the yield and economic returns while keeping the production cost at bay is key [28]. This study sought to determine the best irrigation schedule among the selected levels that can ensure optimization in use of water as a productive resource. Different irrigation schedules were found to have a significant influence on growth and yield of cabbage head count and head weight. Time to maturity, cabbage heads per hectare, yields per hectare, and net revenue obtained per hectare were used as parameters for estimating the response of cabbage to varying irrigation schedules.

Time to maturity was observed to increase as the available soil moisture reduced. Therefore, cabbages grown under S1 took the shortest time to mature (9 weeks), followed by those in S2 (11 weeks), while those under S3 and S4 took the longest time to mature (13 to 15 weeks). This finding corroborates the findings of Averbeke & Netshithuthuni [29] which postulate that performing irrigation twice a week would optimize early leaf development, maturation, and the overall yield. A study by Nyatuame et al. [30] ascribed the delayed maturity under water stress to the tendency of crops to redirect the available water and energy towards survival rather than to production.

There were no significant variations in cabbage stand counts (number of marketable cabbage heads per treatment) between irrigated treatments S1, S2, and S3. However, the rain-fed treatment produced significantly lower number of marketable cabbage heads per unit area compared to the three irrigated treatments. A relative declining trend of the cabbage stand count was observed as the irrigation frequency decreased from twice per week to once per week and then to once per fortnight to rain-fed treatment. The declining trend in marketable heads was attributed to the water stress induced by reduced irrigation frequency. These findings are in coherence with those of Xu & Leskovar [31] who revealed that yield components diminished as the amount of irrigation water supplied reduced. These findings indicate that the number of cabbage heads per unit area can be significantly improved through supplemental irrigation where rainfall is not adequate.

The yields were found to increase as irrigation frequency increased, where S1 (irrigated twice per week) recorded the highest yield and S4 (rain-fed) recorded the lowest yields. These findings were similar to those reported by Kadyampakeni [32] who investigated the response of cabbages to irrigation and observed the highest yield, where supplemental irrigation was done twice a week, whereas the lowest yields were obtained where supplemental irrigation was done after every fortnight. Similar findings were also reported by Himanshu et al. [33], Kumar & Sahu [34], Mzini [35], and Xu & Leskovar [31]. Despite the locational and varietal differences, all the cited studies reported a decrease in cabbage head weight and ultimately reduced yields with reduced frequency of irrigation water, implying that adequate soil moisture is key in achieving optimum yields in cabbage. In all the studies, increasing the frequency of irrigation increased the yield of cabbage. Therefore, supplemental irrigation is vital for cabbage productivity where rainfall is suboptimal.

The production costs were similar for Gloria and Riana cabbage cultivars over the seasons but it was significantly high for Triperio cultivar due to relatively higher cost of seed. The production cost also varied significantly across the four irrigations schedules depicting a diminishing trend from S1 down to S4. The similar productions costs for the three cabbage cultivars were enabled by their similar agronomic performance, resilience to water stress, water use efficiency, and profitability as reported by small-scale farmers. In addition, all the other agronomic practices except irrigation were carried out uniformly in all the experimental plots. The difference in production cost among the different irrigation schedules arose from different labour demand and varying amount of irrigation water supplied. S1 had the highest production cost due to its higher water input and more man hours used to apply the irrigation as compared to the other schedules. These finding are similar to those of Himanshu et al. [33] who reported that production cost of irrigated cabbage increased with the increase in irrigation frequency.

Table 3: Economic analysis for drip irrigated cabbage varieties over different irrigation schedules.

Factor		Season 1		Season 2	
		Production cost (USD)	Net revenue (USD)	Production cost (USD)	Net revenue (USD)
Irrigation schedule	S1	2,103[a]	5,947[a]	2,103[a]	4,460[a]
	S2	1,992[b]	3,443[b]	1,992[b]	2,872[b]
	S3	1,966[c]	2,903[b]	1,966[c]	2,753[b]
	S4	1,854[d]	1,575[c]	1,854[d]	2,011[c]
	LSD	25.98	819.82	25.98	692
Cabbage variety	Gloria	1,959[a]	3,853[a]	1,959[a]	3,033[a]
	Riana	1,959[a]	3,519[ab]	1,959[a]	3,302[a]
	Triperio	2,019[b]	3,028[b]	2,019[a]	2,737[a]
	LSD	59.56	709.9	59.65	599.4
	R^2	1	0.86	1	0.69
	CoV	0	24.19	0	23.70
	Mean	1,979	3,467	1,979	3,024
	Interactions	NS	NS	NS	NS

Means followed by the same letter within a column are not significantly different. R^2: coefficient of determination; CoV: coefficient of variation; NS: not significant.

The net revenue accruing after the sale of cabbages varied significantly between the irrigation schedules, although there were no significant differences between the net revenues obtained from S2 and S3. The difference between these two treatments may have been neutralized by the relatively huge revenue differences between treatments S1 and S4. However, the net revenue was found to decrease as irrigation frequency decreased. This was attributed to reduced yields of cabbages as water stress increased. These findings are in line with those by Kondo et al. [36] who investigated the economic returns of two different cabbage cultivars produced under different levels of irrigation and observed an increase in net income as the amount of supplemental irrigation water was increased. This shows that use of supplemental irrigation improved the total revenue from cabbage production in both seasons. The net revenue from the three cabbage cultivars did not vary significantly over the seasons, since the three cultivars had similar agronomic potentials and were subjected to similar agronomic practices.

5. Conclusion

The time to maturity, head count, head weight, ultimate yield, and net revenue were found to increase as irrigation frequency increased. Despite the higher investment cost and relatively higher cost of production involved in S1 irrigation schedule, where supplemental irrigation was applied twice a week, its productivity and profitability were higher compared with other irrigation schedules. This irrigation schedule is therefore recommended for adoption by cabbage farmers under *humic nitisols* in Embu County and other areas with similar conditions. This will ensure well-distributed amount of water the crop for optimum production. The varietal effects were insignificant on both productivity and profitability in response to the drip irrigation schedules that were investigated. Cabbage farmers may therefore select any of the three or any other preferred variety based on other considerations including the cost of seed, other agronomic variations, customer preference, and marketability.

Data Availability

Most of the data gathered throughout this study have been presented herein to support the findings in this article. Additional data are also available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

The authors acknowledge the University of Embu for providing the experimental site. The authors also thank Trans-African Hydro-Meteorological Observatory (TAHMO) for the provision of meteorological data.

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