Journal of Advanced Zoology

ISSN: 0253-7214

*Volume **44** Issue **S- 07 Year 2023** Page 1563-**1574***

Water Consumption, Yield, and Total Dry Matter of Drip-Irrigated Cabbage Grown at Various Water Application Levels

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Article History

Received:
Revised:
Accepted:

Abstract

In Ghana's coastal savannah climate, the lack of sufficient water during the dry season limits cabbage production. Using a small-scale drip irrigation system, two cabbage varieties—K-K Cross and Oxylus—were grown in a coastal Savannah environment. The irrigation levels were set at40,55,70,85, and 100% of the needed water. The two types of cabbage were assigned to the sub-plots, and the main plot consisted of the applied water levels. The experiment was conducted in three replicates using the split-plot design. The study aims to estimate the actual evapotranspiration (AET) for consumptive use for two cabbage cultivars grown using the family drip irrigation technology at varying applied water levels, as well as to calculate the total fresh matter yield, marketable fresh matter yield, and total dry matter yield of the two drip-irrigated cultivars at varying applied water levels. The overall trend showed that the productivity and water consumption of Oxylus and K-K Cross decreased as applied water levels decreased. The highest values of total dry matter and fresh yield were obtained at 100% of applied water, and these differences were significantly ($P \leq 0.01$) different from corresponding values obtained at 40%, 55%, 70%, and 85% of applied water. Thus, the study's findings highlighted the necessity of preserving sufficient soil moisture to improve productivity and the efficient use of water.

Keywords: *Water Consumption, Yield, Dry Matter, Drip-Irrigated Cabbage, Savannah environment*

1. Introduction

The terms "consumptive use" and "evapotranspiration" (ET) are combined to refer to the process by which water enters plant roots, builds plant tissue, and exits the plant through the stomata of leaves into the atmosphere. On the other hand, evaporation refers to the process by which water escapes through the soil surface into the atmosphere. Evapotranspiration (ET) is the term used to describe the combination of two distinct processes through which water is lost from the soil surface by evaporation and from plants by transpiration. [1, 2].

The kind of crop grown and the climate at different stages of plant growth affect how much water is consumed [3, 4]. "Crop canopy variation and climatic conditions cause substantial variations in crop water use during the crop growing period" [1]. Although cabbage may be grown all year round in Ghana, the crop's availability is seasonal, peaking from June to November during the rainy season. This is because the crop needs little additional water. Cabbage needs between 380 and 500 millimetres of water per season, depending on the climate, cultivars, and growth season [3]. Although cabbage requires between 380 and 500 mm of water per season [3], ET values of 459 mm, 430 mm, and 632 mm have been reported by [5] under mulch conditions, [6] under furrow irrigation, and [7] in a semi-arid environment, respectively. Nevertheless, there is a dearth of information regarding the major cabbage varieties' water consumption in the Coastal Savannah environment, especially in Ghana. Additionally, Ghana has a restricted supply of cabbage throughout the dry season and the first part of the rainy season (December to April), when there is less water available to support production [8]. As a result, Burkina Faso is the source of some of the cabbage imported during this time to help meet the increased demand for the crop [9].

Because cabbage is becoming more and more popular for consumption at home as well as in the food business—particularly in fast-food restaurants—it is becoming a significant industry and a source of income for small-scale farmers in Ghana's urban and periurban areas. The crop has nutritional and health advantages. In Ghana, even though cabbage fetches a decent price and draws in customers, farmers do not receive as much revenue from it during the dry and early rainy seasons. There is not enough water available during the dry season to produce enough cabbage. As a result, during this time, cabbage productivity is poor, which causes demand to exceed supply. Therefore, by effectively using the limited water available, cabbage productivity at this time can be increased. [10] Additionally, the productivity of cabbage at lower water application levels is an important piece of data that can be utilised to develop water management plans that encourage the adoption of better irrigation techniques. One such strategy is the drip irrigation system, which ensures the effective application of limited water resources for improved and sustainable cabbage production during the dry season. Drip irrigation can lead to increased yields of cabbage during the dry season and effective use of the limited irrigation water to guarantee effective utilisation of applied nutrients and water like potassium, phosphate, and nitrogen. High-value crops, such as cabbage, are appropriate candidates for drip irrigation [14]. According to reports, drip irrigation can save nutrients, boost yield by more than 50%, and cut water use by thirty percent to seventy percent [15]. The most efficient technique to deliver nutrients and water straight to the crop root zone is by drip irrigation, which not only conserves water but also boosts vegetable crop yields, according to [5].

HO; Various applied water levels had little effect on the dry matter, yield, or consumptive use of cabbage.

H_A; Various applied water levels have an impact on the dry matter, yield, and consumptive usage of cabbage.

2. Materials and Methods

Experimental Site

The study was carried out at the Ghana Atomic Energy Commission's (GAEC) Research Farm, which is home to the Biotechnology and Nuclear Agriculture Research Institute (BNARI). "The site is located in Ghana's coastal Savannah environment at latitude 05°, 40' N and longitude 0°, 13' W. The location is 20 kilometres north of Accra, at an elevation of 76 metres above sea level, and receives 850 mm of rain on average per year. The soil is an ochrosol from quartzite schist that drains nicely in a savannah.

Experimental Design and Field Layout

Three replicates of a split plot design were employed. The two cabbage cultivars were subplots, while the main plots represented the water application levels utilising the household drip irrigation system. The experimental field measured 30 m by 30 m in total area. Each main plot has three replicates and a subplot measuring 30 m × 0.8 m. On each sub-plot, there were two drip lines, each with 74 emitters. The main drip line was spaced 60 centimetres apart, and the cultivars of cabbage were planted 80 centimetres apart by 60 centimetres.

Experimental Materials

The cabbage cultivars that were utilised were Oxylus, which is already accessible on the Ghanaian market, and the hybrid K-K Cross. On October 21, 2010, raised beds close to the experimental site were used for seedlings. After that, a plastic wire mesh was placed over them to keep insects and other pests out. On November 22, 2010, thirty-one days after they had been nursed, seedlings were moved to the experimental site, with a 60 cm × 60 cm space between them. 2200 and 50 seedlings in all were planted on the field. Immediately following transplantation, the drip irrigation system was used to apply water.

A total of 2,500 seedlings were planted on the field. Immediately following transplantation, the drip irrigation system was used to apply water.

Irrigation Levels

Using a family-sized drip irrigation system, five application levels— 85,100,, 55,40, and 70% of the needed water—were employed. The water needed at 100% of the maximum was calculated as follows:

$$ET_c = K_c \times ET_o \qquad (1)$$

where ETc is the maximum necessary water, K c is the crop coefficient, and E TO is the reference evapotranspiration, which was calculated using the daily meteorological variables from the day before as inputs based on the Penman-Monteith model. It was calculated that the reference evapotranspiration was:

$$\mathrm{E}T_a = \frac{0.48\Delta(R_a - G) + \frac{890\gamma U_2}{T+273}(\rho_a - \rho_d)}{\Delta + \gamma(1 + 0.339U_2)} \qquad (2)$$

$$\rho_a = 0.611\exp\left(\frac{17.27T}{T+237.3}\right) \qquad (3)$$

The actual vapour pressure (kPa), denoted as d, is also determined using the method described by Hargreaves and Merkley [19]:

$$\rho_d = 0.611\left(\frac{\mathrm{RH_{aux}}}{100}\right)\exp\left(\frac{17.27T_{\mathrm{aia}}}{T_{\mathrm{ais}} + 237.3}\right) \qquad (4)$$

where Tmin is the lowest temperature (ºC) and RHmax is the maximum relative humidity (%). According to the method described by [18], G is the estimated soil heat flow density (MJ m-1 day-1) as follows:

3 $$G = 0.38(T_{day} - T_3) \quad (5)$$

where T3 represents the average of the daily mean air temperatures over the preceding three days (ºC), and Tday represents the mean temperature of the air on the day of computations (ºC). Every plant got the same quantity of irrigation water from the moment of transplanting to the growth of the seedlings. Rainfall did not trigger the application of irrigation water. Plants received the same amount of water applied at the time of fertiliser application—100% of the water needed.

Soil Moisture Measurement

Throughout the cabbage season of growth, the neutron probe was used to measure moisture once a week in a 120 cm soil profile. The real the transpiration of water ETa, based on the use of the water balance technique, was estimated using soil moisture data:

$$ET_a = P + I \pm \Delta S \pm D - R \quad (6)$$

where D is deep drainage or capillary rise below the 100 cm soil profile (mm), R is runoff (mm), I is irrigation (mm), ∆S is change in moisture stored in the soil profile (mm), and P is precipitation (mm). Since the experiment was conducted in a dry environment and water application was regulated using family-sized irrigation equipment, runoff, deep drainage, and capillary rise were all believed to be zero. The Penman-Monteith model's reference evapotranspiration was used to estimate irrigation (I). The daily meteorological parameters were obtained at an Imetos weather station, which was roughly 50 metres from the experimental site. Using the following equation, the change in moisture stored in the profile (∆S) was calculated:

Fertilizer Application

Four days after transplanting, an NPK starting solution weighing 10 grammes was applied, diluted in 4 litres of water. This was done in order to establish the seedlings quickly. Split applications of 50 kg ha-1 of triple super phosphate as P, 130 kg ha-1 of muriate of potash as K, and 120 kg ha-1 of urea as N were made. Two weeks after transplanting, one-third was administered, and three weeks later, the remaining portion. Fertiliser was applied at the same time as full irrigation, or 100% applied water. This was done to ensure that the nutrients in the fertiliser would dissolve quickly and avoid scorching the leaves and roots.

Plant Harvesting and Sampling

Seventy-six days following the transplanting of seedling emergence, harvesting was completed. For every cultivar on each sub-plot, ten plants total were gathered and weighed from a sampling area of 4.80 m2. Separate measurements were taken of the biomass above ground (head and leaves) and below ground (stem and roots). A 2.88 m2 area of plants was also collected in order to calculate the marketable yield. After harvesting, samples were transferred to the lab to be subsampled. Knives were used to chop fresh plant material into small bits. While the stem and roots were chopped together, the head and leaves were chopped separately. Following a thorough mixing of the chopped components, subsamples were weighed until a consistent weight was reached and then sealed in an envelope. They were used to calculate total dry matter (TDM) after being dried in an oven until the constant weight reached a temperature of 70 °C. The estimated amount of dry matter overall was:

$$TDM(\text{ kgha}^{*}) - \frac{TFW(\text{ kg})}{AH(m^2)\times SFW(\text{ kg})} \times SDW(\text{ kg}) \qquad (7)$$

where AH is the harvested area, SFW is the sub sample fresh weight, SDW is the sub sample dry weight, and TDM is the total dry matter.

Computations and Statistical Analysis of Data

Analysis of variance (ANOVA) centred on the split-plot design was performed on consumptive usage, marketable fresh yield,total dry matter, and total fresh yield. When significant differences were identified at ($P \leq 0.05$), the least significance difference (LSD) was utilised to separate means. The data was analysed using the statistical programme GENSTATS.

3. Results and Discussion

Results

Weather conditions at the experimental site

Throughout the trial period, the highest and lowest air temperatures were 31.2 and 35.1ºC and 18.3 and 25.7ºC, respectively. Additionally, the sun radiation varied from 155.0 to 259 Ws-1. Additionally, eight rainfall episodes yielded a total of 49.2 mm of rain.

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Cumulative actual evapotranspiration

At the water application levels, there were significant differences in the water consumed by the several cultivars of cabbage ($P < 0.001$). The crop of cabbage that was watered at 100% water application level utilised 432.4 mm of water, which is a large amount.Furthermore, the cabbage crop utilised 200.34 mm and 342.4 mm of water at the 60% and 50% water irrigation levels, respectively, as indicated by Fig. 1a. These values were statistically similar ($P > 0.05$). At the cultivar level, K-K Cross and Oxylus utilised 345.2 mm and 398.4 mm of water, respectively, suggesting that there was not a significant distinction ($P > 0.05$) between the two cabbage cultivars Fig. 1b..

Total fresh yield (TFY)

This is just the head of the cabbage, or the portion that is marketed for human use. At the cultivar and water application levels ($P < 0.001$) as well as the interaction level ($P < 0.06$), a significant difference was found. The maximum mean marketable fresh yield, 43211 kg ha-1, (Fig. 2a). was achieved at 100% water level. Subsequently, the 85% water level yielded a mean marketable yield of 32346 kg ha-1. The 80% and 78% water application levels yielded, respectively, 20345 kg ha-1 and 21345 kg ha-1. Under the 56%, the lowest commercial yield of 7689 kg ha-1 was achieved (Fig. 2b).

Marketable fresh yield (MFY)

This is just the head of the cabbage, or the portion that is marketed for human use. At the cultivar and water application levels ($P < 0.001$) as well as the interaction level ($P < 0.06$), a significant difference was found. The maximum mean marketable fresh yield, 43211 kg ha-1, (Fig. 3a). was achieved at 100% water level. Subsequently, the 85% water level yielded a mean marketable yield of 32346 kg ha-1. The 80% and 78% water application levels yielded, respectively, 20345 kg ha-1 and 21345 kg ha-1. Under the 56%, the lowest commercial yield of 7689 kg ha-1 was achieved (Fig. 3b).

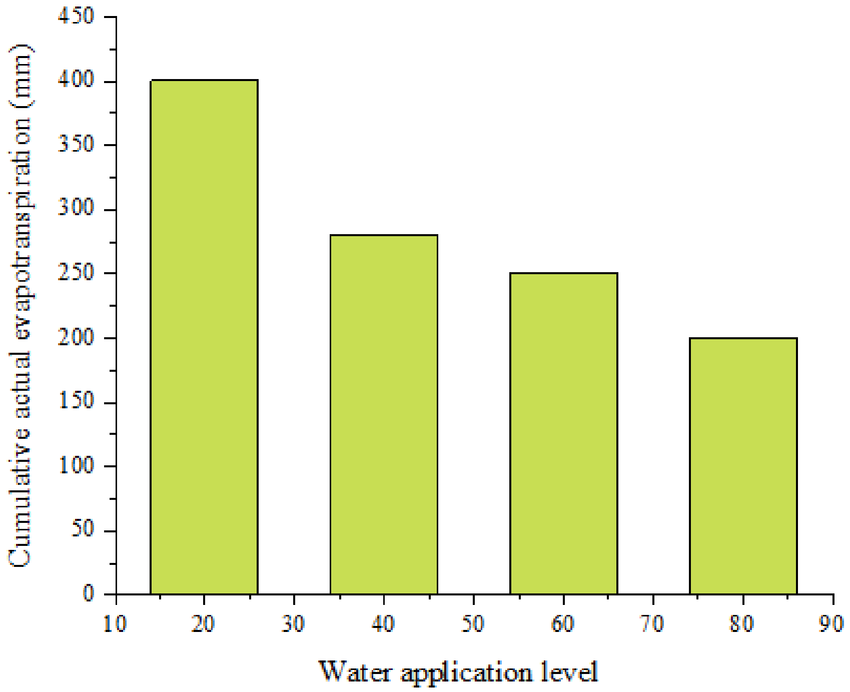

Fig. 1a. Actual cumulative evapotranspiration of Oxylus and K-K Cross at varying drip irrigation water application levels. Letter-free bars did not differ substantially at (P≥0.05).

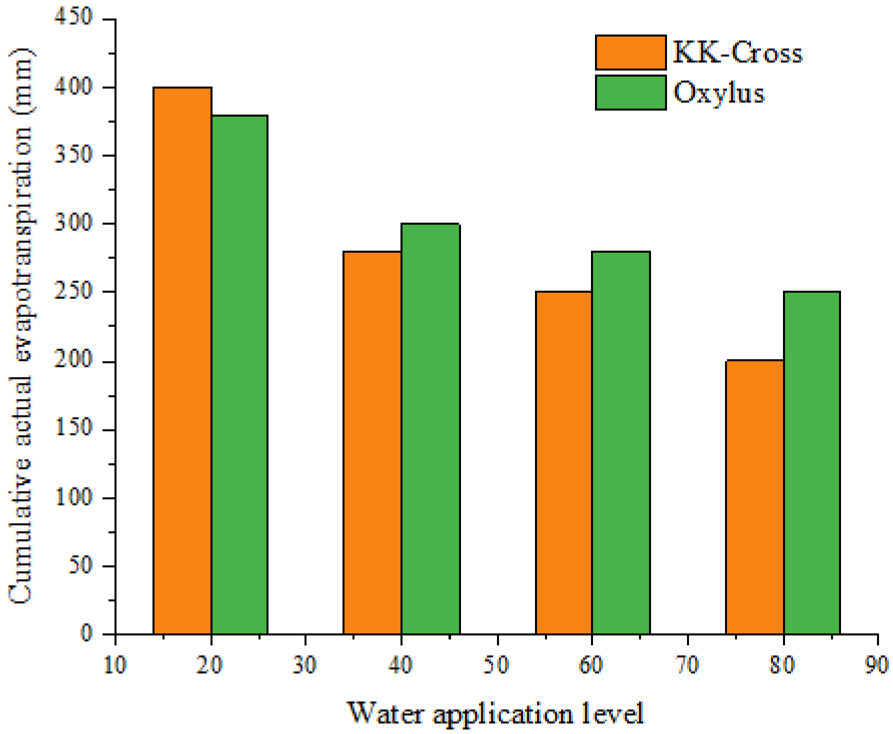

Fig. 1b. Actual cumulative evapotranspiration of Oxylus and K-K Cross at varying drip irrigation water application levels. Letter-free bars did not differ substantially at (P≥0.05).

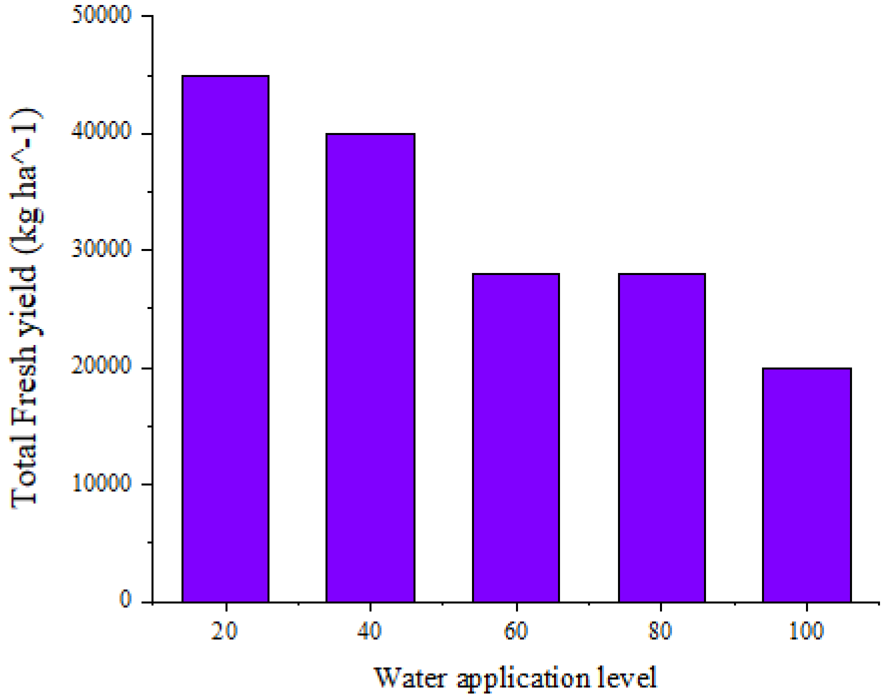

Fig. 2a. Two varieties of cabbage with varying water application levels and their total fresh yield. The same-letter bars did not differ substantially at (P > 0.05).

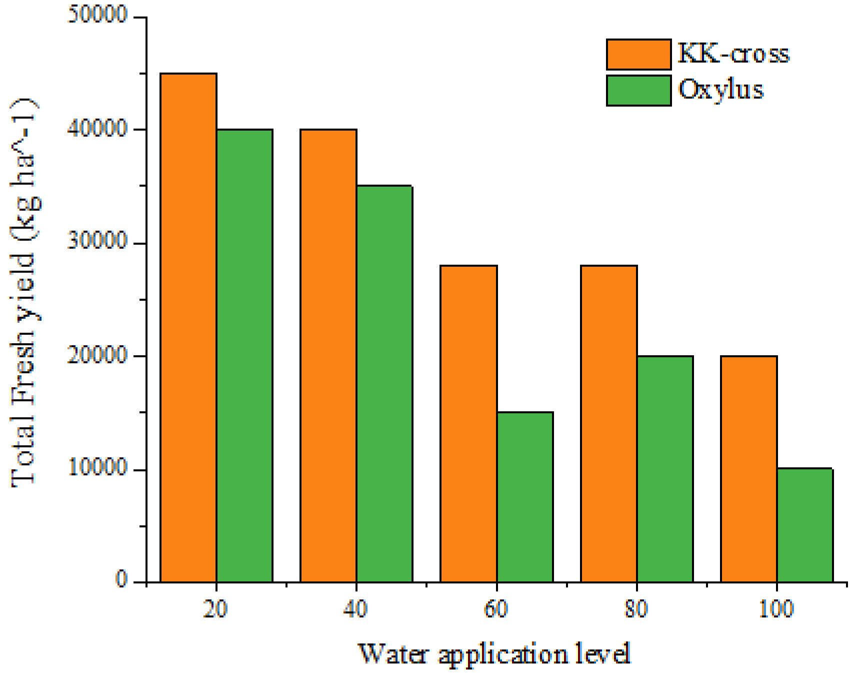

Fig. 2b. Total fresh yields of Oxylus and K-K Cross at varying applied water levels. The same-letter bars did not differ substantially at (P > 0.05).

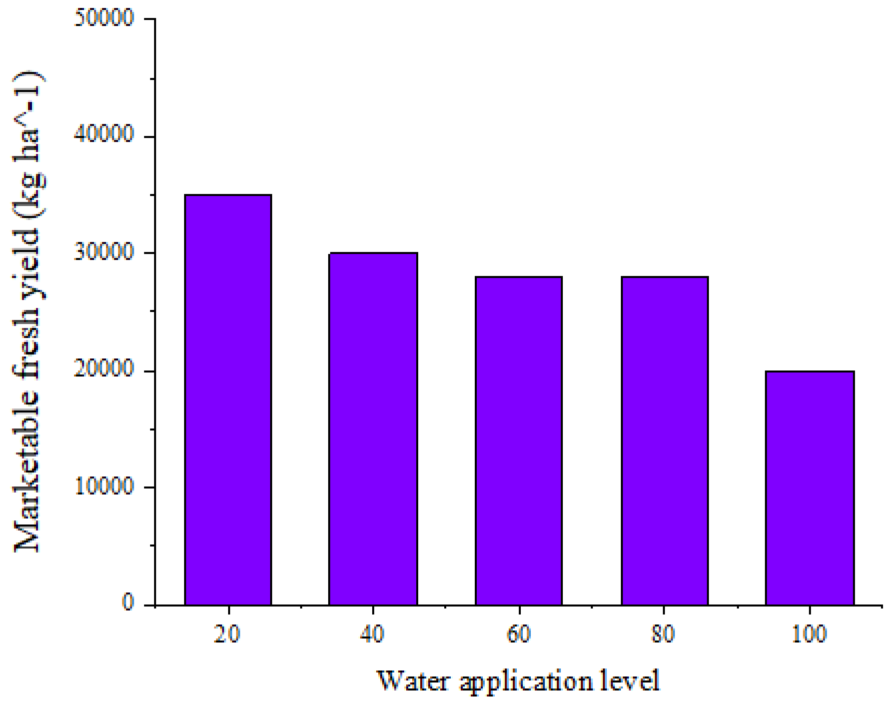

Fig. 3a. Marketable fresh yield of two varieties of cabbage with varying water applications. The same-letter bars did not differ substantially at (P > 0.05).

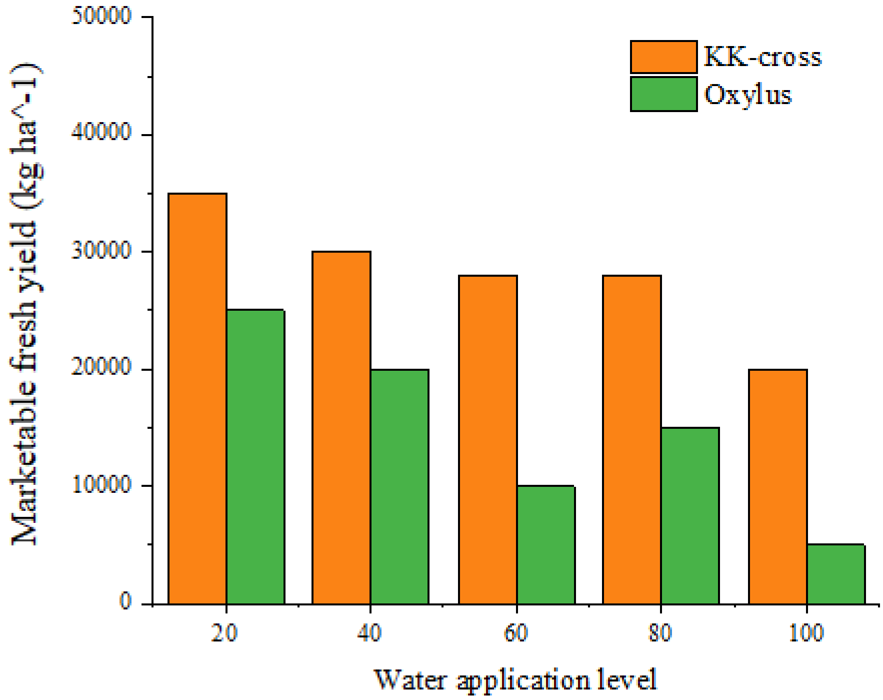

Fig. 3b. Evaluation of two cabbage cultivars' commercial fresh yields at varying water application amounts using Oxylus and K-K Cross. The same-letter bars did not differ substantially at (P > 0.05).

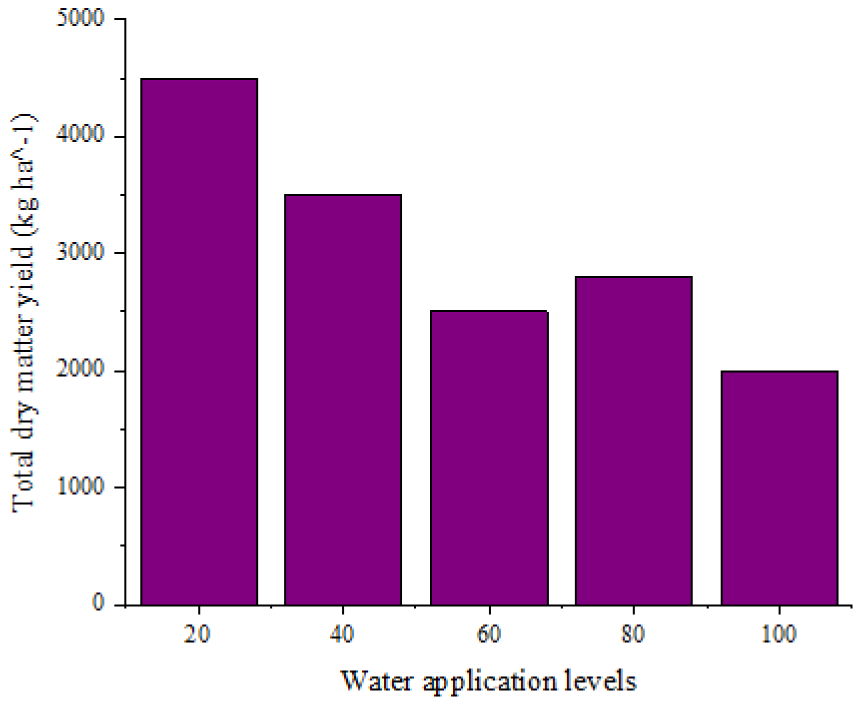

Fig. 4a. Total dry matter yields of Oxylus and K-K Cross at varying applied water levels. The bars that shared the same letters did not differ substantially at (P>0.05).

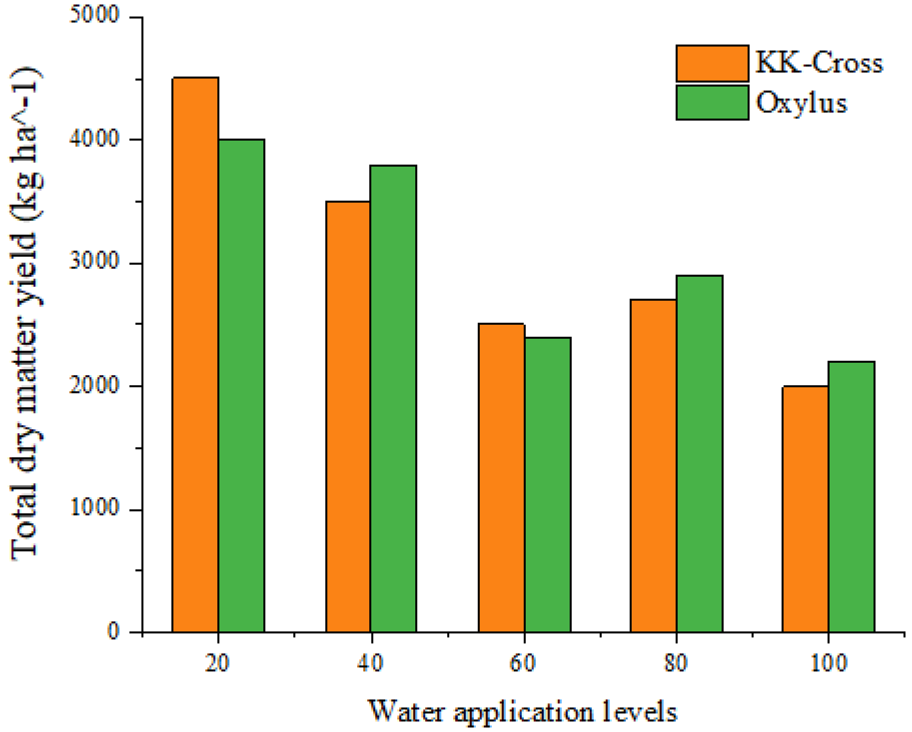

Fig. 4b. Total dry matter yields of Oxylus and K-K Cross at varying applied water levels. The bars that shared the same letters did not differ substantially at (P>0.05).

Discussion

Consumptive use cumulative actual evapotranspiration (CAET)

Due to high seasonal water application, the cumulative actual evapotranspiration (CAET) for 100% water usage level is high. With 100% water application, the cabbage cultivars' mean CAET of 432.5 mm falls between the 420 and 600 mm range. (Fig. 4a). Furthermore, the observed mean CAET value of 435.8 mm and the water use value of 402.5 mm for cabbage grown in furrows are in agreement. This average CAET is also quite similar to the predicted seasonal water consumption of 399.8 mm for drip-irrigated cabbage in both mulched and non-mulched circumstances. On the other hand, the observed mean CAET was less than the 432.67 mm value for cabbage. The related yield levels of cabbage are in line with global output levels, even though the mean CAET readings for 90, 69, 63, and 54% water usage amounts are lower than the seasonal consumption of water for cabbage growth that has been reported. (Fig. 4b). Therefore, better water application management—achieved through drip irrigation—may increase crop water use, which in turn could boost crop yield. This implies that drip irrigation, which is an effective way to apply limited water, may improve crop productivity.

4. Conclusions

Diverse applied water levels had varying effects on consumptive usage, productivity and total dry matter (TDM) for the 2 cabbage species, Oxylus, and K-K Cross. As the amount of water applied grew, so did the consumption, yield, and total dry matter, and vice versa.When comparing the yield at 100% needed level of water to that of K-K Cross and Oxylus, respectively, the yield reduction was 40.5% and 22.8% when 79% of the required level of water was used.This demonstrates that when water is limited, an application level of 85% of water could be employed.As a result, when the amount of water applied decreases marginally, K-K Cross production falls dramatically. This is something that needs to be considered when growing K-K Cross with less water provided.

Competing interests

The authors declare that they have no competing interests.

Consent for publication

Not applicable

Ethics approval and consent to participate

Not applicable

Funding

This research study is sponsored by the **institution name**. Thank you to this college for supporting this article!

Availability of data and materials

Not applicable

Authors' contribution

Author A supports to find materials and results part in this manuscript. Author B helps to develop literature part.

Acknowledgement
I offer up our fervent prayers to the omnipotent God. I want to express my sincere gratitude to my co-workers for supporting me through all of our challenges and victories to get this task done. I want to express my gratitude for our family's love and support, as well as for their encouragement. Finally, I would like to extend our sincere gratitude to everyone who has assisted us in writing this article.

Abbreviation

AET - actual evapotranspiration
ET – Evapotranspiration
GAEC - Ghana Atomic Energy Commission's
BNARI - Biotechnology and Nuclear Agriculture Research Institute
TDM - total dry matter
ANOVA - Analysis of variance
CAET - Cumulative Actual Evapotranspiration

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