Consumptive Use of Water, Yield, and Total Dry Matter of Drip-Irrigated Cabbage Grown Under Different Levels of Applied Water

ABSTRACT

The productivity of cabbage during the dry season in the coastal savannah environment of Ghana is constrained by inadequate availability of water. Two cabbage varieties, K-K Cross and Oxylus were grown in a Coastal Savannah environment using a small-scale drip irrigation system and irrigated at water application levels of 40, 55. 70, 5 and 100% of required water. The experiment was executed using the split-plot design in three replicates with the main plot being the levels of applied water and the two cabbage varieties assigned to the sub-plots. The aims of the study were to estimate consumptive use actual evapotranspiration (AET) for two cabbage cultivars grown at different levels of applied water using the family drip irrigation technology and to determine total fresh, marketable fresh and total dry matter yields of two drip-irrigated cabbage cultivars at different levels of applied water. Generally, the productivity and consumptive use of water of K-K Cross and *Oxylus* decreased in response to decreasing levels of applied water with consumptive use, total fresh yield and total dry matter at 100% level of applied water being highest and significantly ($P \leq 0.01$) different from corresponding values at 40, 55,70 and 85% levels of applied water. Results of the study, therefore, emphasized the need to maintain adequate soil moisture to enhance effective use of water and productivity.

Key words: Consumptive use, Evapotranspiration (ET), Cumulative Actual Evapotranspiration, CAET, Potential Evapotranspiration (PET), Total Dry Matter (TDM), Total Fresh Yield (TFY).

1.0 INTRODUCTION

"Consumptive use or evapotranspiration (ET) is the sum of two terms, transpiration, which is water entering plant roots, used to build plant tissue and being passed through the stomata of leaves into the atmosphere and evaporation, which is water that escapes through the soil surface into the atmosphere. The combination of two different processes whereby water is lost on the one hand from the soil surface by evaporation and on the other hand from plant by transpiration is referred to as evapotranspiration (ET)" [1&2].

The consumptive use of water varies with the type of crop, and the climatic conditions existing at the various stages of plant growth [3&4]. "Crop water use varies substantially during the crop growing period due to variation in crop canopy and climatic conditions" [1]. Though cabbage can be produced throughout the year in Ghana, the supply is seasonal, being abundant during the rainy season (June-November) as the crop requires limited supplementary water application. Depending on climate, cultivars, and growing season, water requirement of cabbage varies from 380 mm to 500 mm per season [3]. Though the seasonal water use of cabbage ranges between 380 and 500 mm of water [3], ET values of 400 mm, 339 mm and 556 mm have been reported by [5] under mulch conditions, [6] under furrow irrigation and [7] in a semi- arid environment, respectively, however, little information exists on the consumptive use of water by the major cabbage varieties in the Coastal Savannah environment, particularly Ghana. Moreover, supply of cabbage in Ghana is limited during the dry season, and early stage of the rainy seasons (December-April) when production is constrained by low availability of water [8]. Consequently, the demand for cabbage during this period is high and cabbage is imported from Burkina Faso to supplement local production [9].

"The production of cabbage in the urban and peri- urban areas of Ghana is an important enterprise and a source of livelihood for small-scale farmers as a result of increased acceptability and demand of cabbage for home consumption and for the food industry, particularly, the fast-food joints. The crop has both health [10][11] and nutritional [5][12][13] benefits". Cabbage production is low during the dry season and early stages of the rainy season in Ghana despite the fact that the produce attracts good price and patronage and hence good returns for farmers. Available water for cabbage production during the dry season is limited and inadequate. Consequently, the productivity of cabbage is low during this period leading to demand outstripping supply. The productivity of cabbage during this period can therefore be enhanced through efficient application of scarce water. Furthermore, the productivity of cabbage at reduced water application levels is a valuable information that could be used to formulate water management strategies that will promote the use of improved irrigation technique; such as the drip irrigation system to ensure efficient application of scarce available water for sustainable and enhanced cabbage production during the dry season. Enhanced production of cabbage during the dry season and efficient application of limited irrigation water to ensure efficient use of applied water and nutrients such as nitrogen, phosphorus, and potassium can be achieved through the use of drip irrigation. Drip systems are justified for high value crops including cabbage [14]. Drip irrigation has also been reported to reduce water use by 30% to 70% and it increases yield by over 50% and save nutrients [15]. [16] [17] and [5] observed that "drip irrigation is the most effective way to convey water and nutrients directly to crop root zone and not only does it save water but also increases yields of vegetable crops".

$H_{O;}$ Consumptive use, yield and dry matter of cabbage are not affected by different levels of applied water.

H_A; Consumptive use, yield and dry matter of cabbage are affected by different levels of applied water.

The aims of this study were to estimate consumptive use actual evapotranspiration (AET) for two cabbage cultivars grown at different levels of applied water using the family drip irrigation technology and to determine total fresh, marketable fresh and total dry matter yields of two drip-irrigated cabbage cultivars at different levels of applied water.

2.0 MATERIALS AND METHODS

2.1 Experimental site

The research was conducted at the Research farm of the Biotechnology and Nuclear Agriculture Research Institute (BNARI), Ghana Atomic Energy Commission (GAEC). "The site is situated on latitude 05°, 40' N and longitude 0°, 13' W in the coastal Savannah environment of Ghana. The site has an altitude of 76 m above sea level and is 20 km north of Accra with a mean annual rainfall of 850mm. The soil is a well – drained savannah ochrosol (Ferric Acrisol, locally called Haatso series, sandy loam), derived from quartzite schist" [18].

2.2 Experimental design and field layout

A split plot design in three replicates was used. The main plots were the levels of applied water (100, 85, 70, 55 and 40% of required water levels) using the family drip irrigation system and the sub plots were the two cabbage cultivars. The total area of the experimental field was 30 m ×30 m. The sub- plots in each main plot measured 30 m × 0.8 m each with three replicates. Two drip lines made of 74 emitters for each line were placed on each sub –plot. The spacing on the main drip line was 60 cm, upon which the cabbage cultivars were planted at a spacing of 80 cm × 60 cm. Thirty access tubes each sunk to a depth of 120 cm and a micro-plot of 0.8 m × 3.6 m were established in each sub plot to facilitate soil moisture measurement.

2.3 Experimental materials

Cabbage cultivars used were the K-K Cross (a hybrid) and *Oxylus*, the currently available cabbage cultivars on the Ghanaian market. Seeds were nursed on October 21, 2010 on raised beds near the experimental site. They were then covered with plastic wire mesh to protect them against insect pests. Seedlings were transplanted thirty-one days after nursing at a spacing of 60 cm × 60 cm on the experimental site on 22nd November, 2010. A total of two thousand two hundred and fifty seedlings were sown on the field. Water was applied immediately after transplanting through the drip irrigation system.

2.4 Irrigation levels

Five levels of applied water at 100, 85, 70, 55, and 40% of required water, using the family size drip irrigation system were used. The maximum required water (100 %) was computed as:

$$ET_c = K_c \times ET_O \qquad 1$$

where K_c is the crop coefficient and ET_O is the reference evapotranspiration which was computed using a previous day's daily weather variables as inputs based on the Penman-Monteith model (Allen *et al.*, 1998) and ET_c is the maximum required water. The reference evapotranspiration was computed as:

$$ET_o = \frac{0.48\Delta(R_n - G) + \dfrac{890\gamma U_2}{T + 273}(\rho_a - \rho_d)}{\Delta + \gamma(1 + 0.339U_2)} \qquad 2$$

where ET_o is the reference crop evapotranspiration (mm/day), Δ is the slope of the saturated vapour pressure function (kPa/°C), γ is the Psychrometric constant (kPa/°C), R_n is the net solar radiation (MJ/m^2/day), U_2= wind speed (m/s) at 2.0 m height above the ground surface, T = mean daily air temperature (°C), ρ_a is the saturation vapour pressure (kPa) estimated from air temperature measurement as follows [1]:

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

ρ_d is the actual vapour pressure (kPa) also estimated based on the procedure by Hargreaves and Merkley, (2004):

$$\rho_d = 0.611\left(\frac{\mathrm{RH}_{\max}}{100}\right) \exp \left(\frac{17.27T_{\min}}{T_{\min} + 237.3}\right) \quad 4$$

where RH_{max} is the maximum relative humidity (%) and T_{min} is the minimum temperature (ºC). G is the soil heat flux density (MJ m^{-1} day^{-1}) estimated based on the procedure given by [18] as:

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

where T_{day} is the average air temperature on the day of calculations (ºC), T_3 is the average of the average daily air temperatures of the previous three days (ºC). From the time of transplanting till the time of seedlings establishment, all plants received the same amount of irrigation water. Irrigation water was not applied during rainfall. At time of fertilizer application, plants received equal amount of applied water (i.e. 100 % of required water). The total amount of irrigation water applied through the drip irrigation system were 260.85, 222.46, 184.07, 145.68 and 107.29 mm for 100, 85, 70, 55 and 40% water application level respectively.

2.5 Soil moisture measurement

Moisture was monitored weekly in a 120 cm soil profile throughout the cabbage growing season using the neutron probe (CPN 503 DR model). Soil moisture data was used to estimate the actual evapotranspiration ET_a based on the water balance approach:

$$ET_a = P + I \pm \Delta S \pm D - R \quad [6]$$

Where P is precipitation (mm), I is irrigation (mm), ΔS is change in moisture stored in the soil profile (mm), D is deep drainage or capillary rise below the 100 cm soil profile (mm) and R is run- off (mm). Run-off and deep drainage or capillary rise were assumed to be zero since the experiment was undertaken in dry conditions and water application was controlled using the family size irrigation technology. Irrigation (I) was estimated using the reference evapotranspiration based on the Penman-Monteith model.

An **Imetos** weather station located about 50 m away from the experimental site recorded the daily weather variables. Change in moisture stored in the profile **(ΔS)**, was determined using the equation:

$$S_L = \int_0^L \theta \times \Delta Z \qquad [7]$$

where:

S_L is the depth of water stored in the soil profile (mm)

θ is the volumetric water content ($cm^3 \, cm^{-3}$)

Δz is the thickness of each soil layer (cm)

Hence, the difference between the previous S_L and the current or present S_L gives the ΔS in (mm). Seasonal actual evapotranspiration (AET) was estimated by summing up ET_a for the various time steps within the cropping system.

2.6 Fertilizer application

NPK starter solution weighing 10 grams dissolved in 4 litres of water was applied four days after transplanting. This was done for quick seedlings establishment. A total of 120 kg ha^{-1} of urea as N, 130 kg ha^{-1} of muriate of potash as K and 50 kg ha^{-1} of triple super phosphate as P was split applied. One –third was applied two weeks after transplanting and the rest applied 3 weeks later. Full irrigation (100% applied water) was applied at time of fertilizer application. This was done for quick dissolution of applied fertilizer nutrients so as to prevent leaves and root scorching.

2.7 Plant Harvesting and Sampling

Harvesting was done seventy–six days after transplanting seedling emergence. A total of ten plants from a sampling area of 4.80 m^2 for each cultivar on each sub- plot were harvested and weighed. The above ground biomass (head and leaves) were separated from the below ground biomass (stem and roots) and weighed separately. In addition, plants from an area of 2.88 m^2 were harvested for the determination of marketable yield.

Harvested samples were sent to the laboratory for sub-sampling to be done. Fresh plant materials were chopped into pieces using knives. The head and leaves were chopped together but separated from the stem and roots. The chopped materials were then mixed thoroughly and sub- samples weighed until a constant weight was obtained and placed in an envelope. They were dried in an oven till the constant weight reached a temperature of 70 ^oC and used to determine total dry matter (TDM). The total dry matter was estimated as:

$$TDM\left(kg\ \mathrm{ha}^{-1}\right) = \frac{TFW(kg)}{AH\left(m^2\right) \times SFW\ (\mathrm{kg})} \times SDW(kg) \qquad [8]$$

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

2.8 Computations and statistical analysis of data

Consumptive use, total fresh yield, marketable fresh yield and total dry matter, were subjected to analysis of variance (ANOVA) based on the split-plot design used and the least significance difference (LSD) used to separate means when significance differences were observed at ($P \leq 0.05$). The GENSTATS statistical package was employed in the analysis of the data.

3.0 RESULTS AND DISCUSSION

3.1 RESULTS

3.1.1 Weather conditions at the experimental site

The maximum and minimum air temperatures during the experimental period ranged between 31.2 and 35.1 ºC and 18.3 and 25.7 ºC respectively. The solar radiation also ranged between 155.0 and 259 Ws^{-1}. Additionally, a total of 49.2 mm of rains was obtained in eight rainfall events.

3.1.2 Cumulative Actual Evapotranspiration.

Water used by the cabbage cultivars was significantly different at the water application levels ($P < 0.001$). Cabbage crop irrigated at 100% water application level used significantly the highest amount of water 374.7 mm.

Additionally, the cabbage crop used 202.9 mm and 184.0 mm of water at the 55 and 40% water application levels, respectively, which were statistically similar ($P > 0.05$) as shown in Figure 1a.

At the cultivar level, no significant difference ($P > 0.05$) was observed between the two cabbage cultivars, as K-K Cross and *Oxylus* used 252.4 mm 247.2 mm of water, respectively. Though no significant difference was observed at the interaction level, K-K Cross at the 100% water application level used the highest amount of water (370.7 mm) followed by 257.3, 238.4, 206.7 and 189.20 mm of water used at 85, 70, 55 and 40% water applications respectively

(Figure 1b). Water used by *Oxylus* at the different water application levels followed the trend observed for K-K Cross, being 244.8, 234.6, 199.2 and 178.9 mm for 100, 85, 70, 55 and 40% water application level respectively.

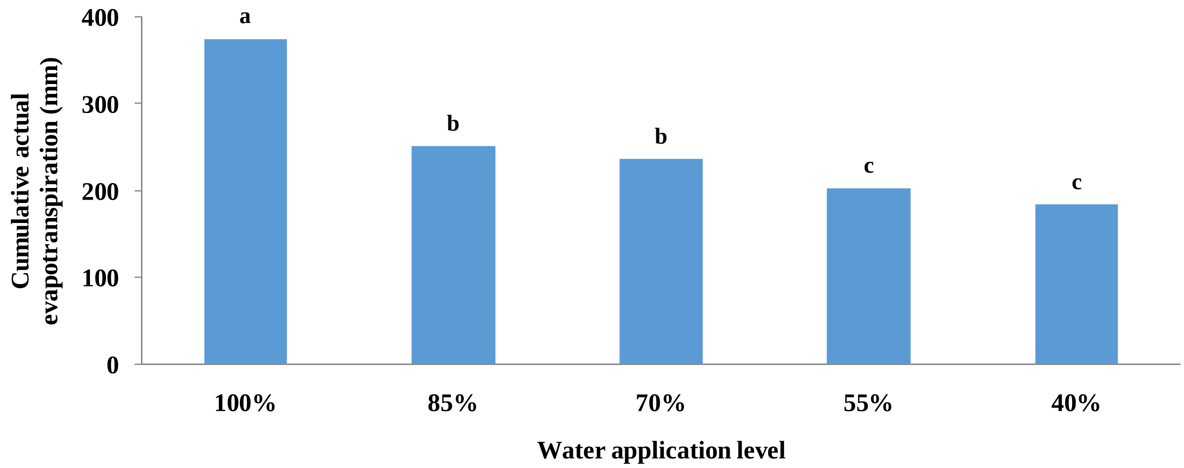

Figure 1a. Cumulative actual evapotranspiration (CAET) of two cabbage cultivars at different water application levels. Bars with the same letters were not significantly different at (*P* > 0.05).

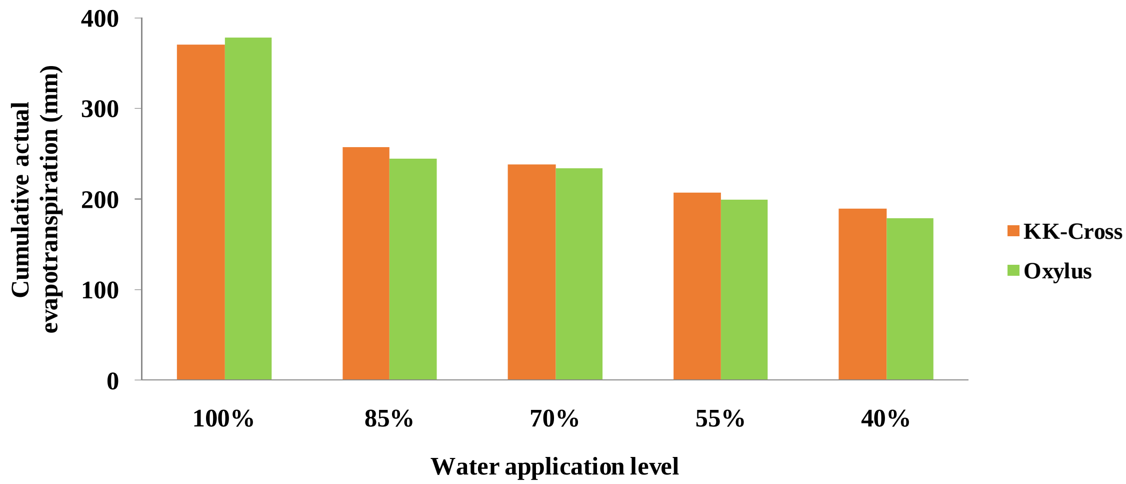

Figure 1b. Cumulative actual evapotranspiration of K-K Cross and *Oxylus* at different levels of applied drip irrigation water. Bars without letters were not significantly different at (*P*≥0.05).

3.1.3 Total Fresh Yield (TFY)

This consisted of both the cabbage head and roots. A significant difference ($P \leq 0.001$) was observed among total fresh yields of the cabbage cultivars at the water application levels (Figure 2 a), with the 100% water application level producing the highest mean total fresh yield of 43920 kg ha^{-1} (44.0 t ha^{-1}), followed by 32952 kg ha^{-1} (33.0 t ha^{-1}) at the 85% water application level. The 70% and 55% water levels produced statistically similar TFY of 20399 kg ha^{-1} (20.4 tons ha^{-1}) and 19306 kg ha^{-1} (19.3 t ha^{-1}) respectively. The 40% water application level however, produced the lowest TFY of 11396 kg ha^{-1} (11.4 t ha^{-1}). At the cultivar level, K-K Cross produced TFY of 26920 kg ha^{-1} (27.0 t ha^{-1}) which was significantly different ($P \leq 0.018$) from the 24263 kg ha^{-1} (24.3 t ha^{-1}) produced by *Oxylus*. However, there was a significant interaction ($P \leq 0.01$) in TFY between water application levels and cabbage cultivars. Specifically, TFY of *Oxylus* was higher at 55% water application level (19.6 tons ha^{-1}) than 15.8 t ha^{-1} at 70% water application level, the trend which was opposite observed for the K-K Cross at the 55% and 70% water application levels (Figure 2 b).

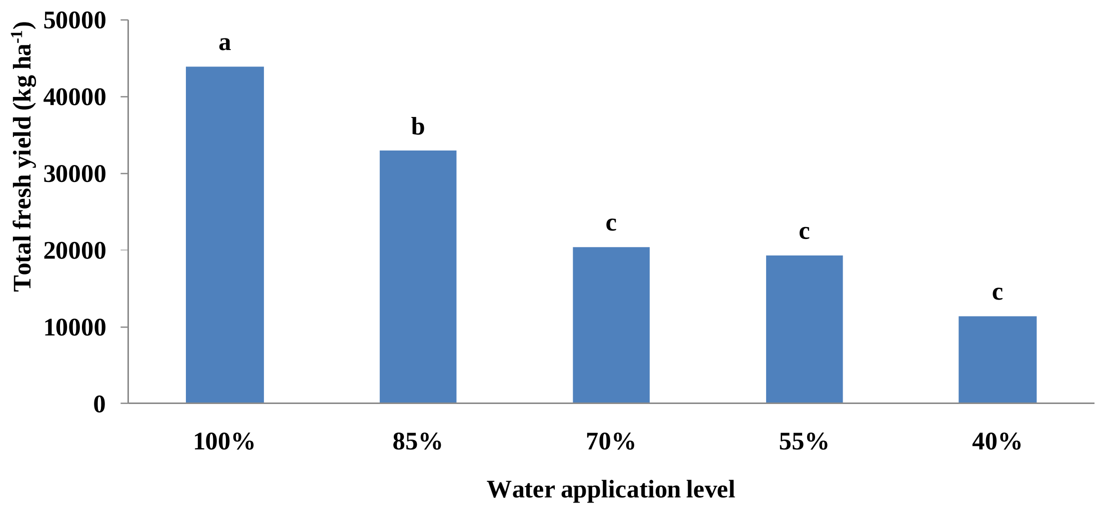

Figure 2a. Total Fresh Yield of two cabbage cultivars at different water application levels. Bars with the same letters were not significantly different at ($P > 0.05$).

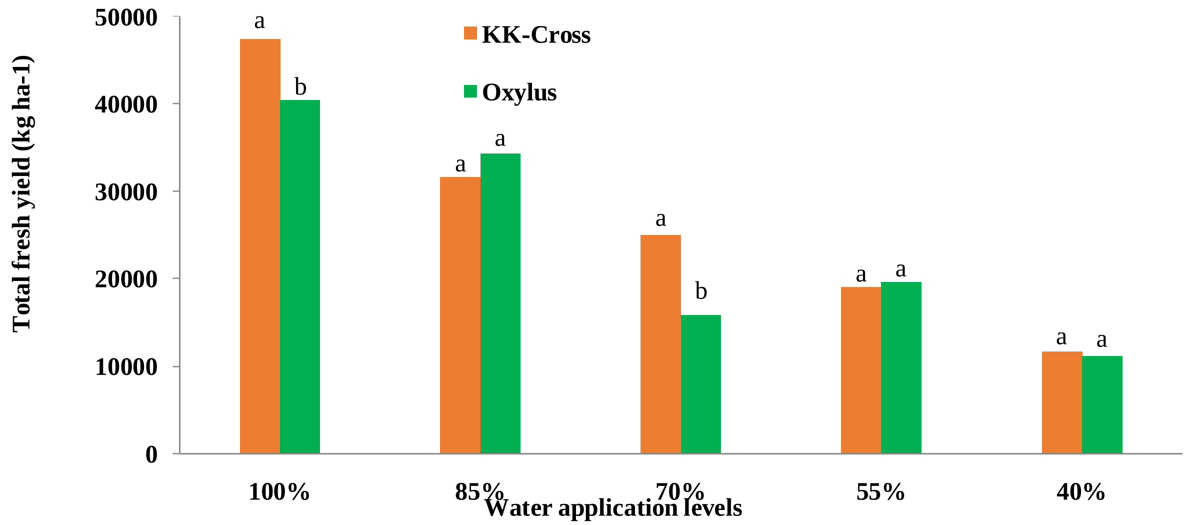

Figure 2b. Total fresh yields of K-K Cross and Oxylus at different levels of applied water. Bars with the same letters were not significantly different at (*P* > 0.05).

3.1.4 Marketable Fresh Yield (MFY)

This consists of the cabbage head only, i.e. the pat sold for consumption. A significant

difference was observed at both the water application and cultivar levels ($P < 0.001$) and at the interaction level ($P < 0.06$). The 100% water level produced the highest mean marketable fresh yield of 30220 kg ha^{-1} (30.0 t ha^{-1}). This was followed by the 85% water level recording a mean marketable yield of 21499 kg ha^{-1} (22.0 t ha^{-1}) followed by 12558 kg ha^{-1} (13.0 t ha^{-1}) and 11777 kg ha^{-1} (12.0 t ha^{-1}) for the 70% and 55% water application level, respectively. The lowest marketable yield of 6626 kg ha^{-1} (7.0 t ha^{-1}) was obtained under the 40% (Figure 3 a).

At the cultivar level, K-K Cross produced the higher MFY of 18831 kg ha^{-1} (19.0 t ha^{-1}**)** which was significantly different ($P < 0.06$) from 14241 kg ha^{-1} (14.0 t ha^{-1}) produced by *Oxylus*.

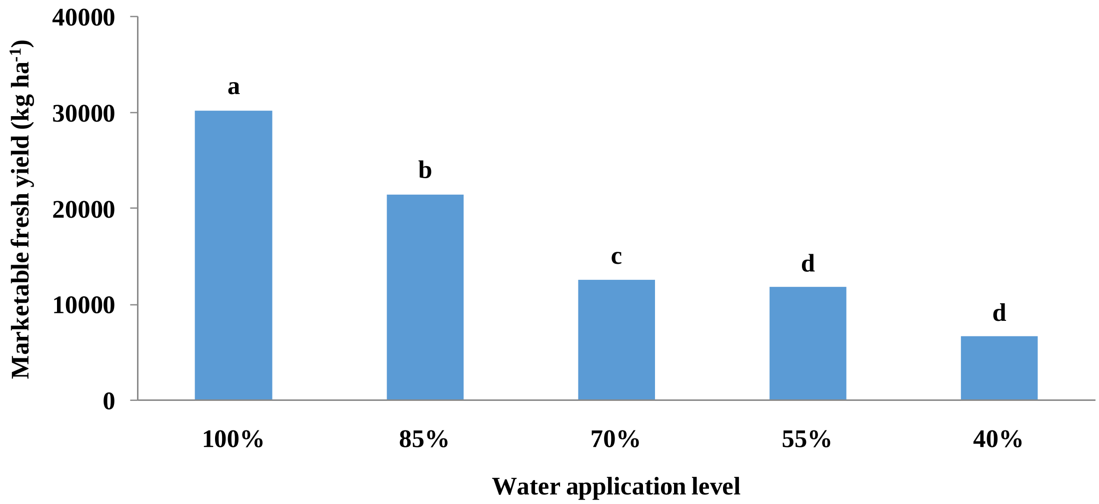

Figure 3a. Marketable fresh yield of two cabbage cultivars at different levels of applied water. Bars with the same letters were not significantly different at (*P* > 0.05).

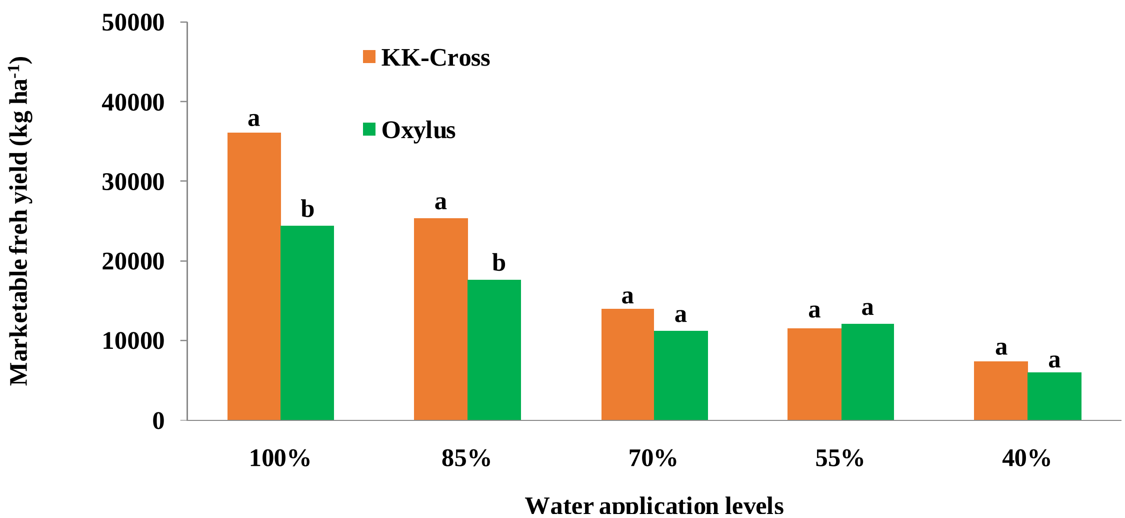

Figure 3b. Comparison of K-K Cross and *Oxylus* for marketable fresh yield of two cabbage cultivars at different levels of applied water. Bars with the same letters were not significantly different at (*P* > 0.05).

3.1.5 Total Dry Matter (TDM)

A significant difference ($P < 0.001$) was observed at the water application levels. The 100% water application level produced the highest mean TDM of 4225 kg ha^{-1} (4.2 t ha^{-1}), followed by 3267 kg ha^{-1} (3.3 t ha^{-1}), 2051 kg ha^{-1} (2.1 t ha^{-1}), 2066 kg ha^{-1} (2.1 t ha^{-1}) and 1371 kg ha^{-1} (1.4 t ha^{-1}) produced by the 85, 70, 55 and 40% water application level, respectively (Figure 4 a). Though, the two cabbage cultivars produced statistically similar TDM under each of the water application levels, the mean TDM produced by K-K Cross was lower (2573 kg ha^{-1}) than that produced by *Oxylus* (2619 kg ha^{-1}). A significant difference (P < 0.001) was observed at the interaction level as TDM for K-K Cross at 85% water application level was lower than that of *Oxylus* while TDM for *Oxylus* at 55% and 40% water application levels were significantly higher (P< 0.001) than corresponding values for K-K Cross (Figure4 b).

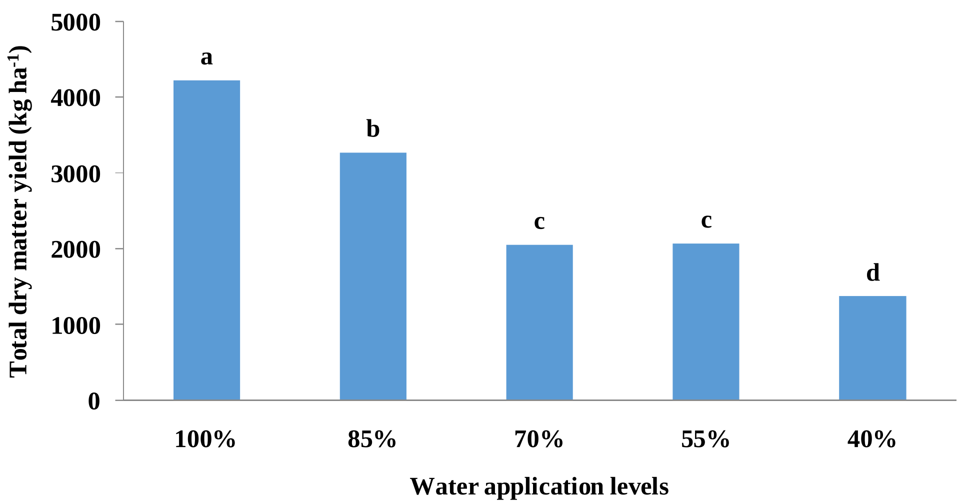

Figure 4a. Total dry matter yield of two cabbage cultivars at different water application levels. Bars with the same letters were not significantly different at (*P* > 0.05).

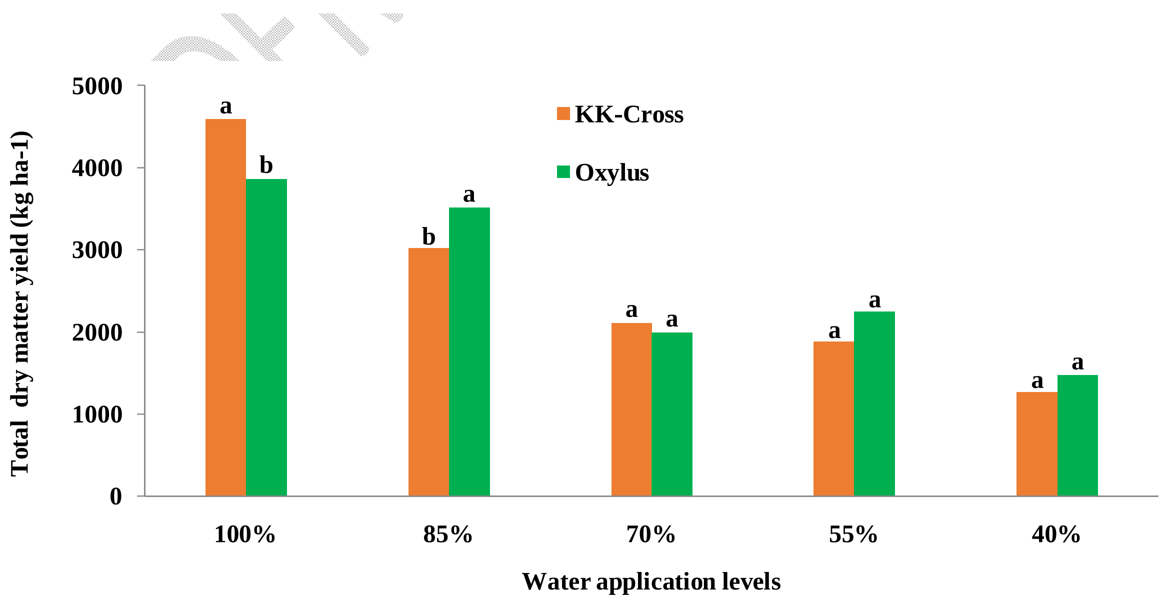

Figure 4 b. Total dry matter yields of K-K Cross and *Oxylus* at different levels

of applied water. Bars with the same letters were not significantly different at (P> 0.05).

3.2 DISCUSSION

3.2.1 Consumptive use cumulative actual evapotranspiration (CAET)

The high cumulative actual evapotranspiration (CAET) for 100% water application level is due to high seasonal water application. The mean CAET of 374.7 mm at the 100% water application level, for the cabbage cultivars is within the range of CAET values of 380-500 mm reported by [3]. Additionally, this observed mean CAET value of 374.7 mm is in agreement with the water use value of 339.0 mm reported by [6] for furrow-irrigated cabbage. This mean CAET is also close to the seasonal water use of 400.0 mm estimated by [5] for drip-irrigated cabbage under mulch and non-mulch conditions. However, the mean CAET observed was lower than the 710.44 mm for cabbage reported by [20]. Though mean CAET values for 85, 70, 55 and 40% water application levels are less than the reported seasonal water use for cabbage production, the corresponding yield cabbage levels are in agreement with the world's production level [21]. Therefore, improved management of water application, as done through drip irrigation, could improve water use by crops [22] which could subsequently enhance crop production. This suggests that efficient application of limited water, as done through drip irrigation, could potentially enhance crop production.

3.2.2 Fresh Yields

Fresh yield of the two drip-irrigated cabbage cultivars, grown under different levels of applied water ranges between 11.0 t ha^{-1} and 45.0 t ha^{-1} across the 40-100% water application levels, yield levels that are in agreement with the world's cabbage yield of 10.0-40.0 t ha^{-1} [21] but lower than 69.0 t ha^{-1} reported by [23] and also lower than 106 t ha^{-1} reported by [5] grown under plastic mulches with drip irrigation. Furthermore, the observed cabbage fresh yields are close to 30.0 t ha^{-1} under drip irrigation with poultry manure [24], 32.0-37.0 t ha^{-1} under drip irrigation [25] and 15.0-46.0 t ha^{-1} under sprinkler irrigation [25]. However, the observed fresh yields of cabbage were higher than 5.5 t ha^{-1} reported by [27] for cabbage grown under rainfall conditions and also higher than 18.0-28.0 t ha^{-1} reported by [28].

Conclusions

Generally, consumptive use, productivity (total fresh weight and marketable fresh weight) and total dry matter (TDM) for the two cabbage cultivars, K-K Cross and *Oxylus*, were affected by different levels of applied water. Consumptive use, yield and total dry matter increased with an increasing water application and vice versa. The use of 85% of the required level of water resulted in yield reduction of 33.5% and 15.0% for K-K Cross and *Oxylus* respectively compared to the yield at 100% required level of water. This shows that 85% water application level could be used when water is limiting. Thus, the productivity of K-K Cross drops sharply as the level of applied water drops slightly. This has to be taken into consideration when growing K-K Cross under reduced applied water levels.

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