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Evaluation of Reference-Crop Evapotranspiration Models, Crop Evapotranspiration Methods and Water Supply Methods for the Determination of Crop Coefficient of Kenaf

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ABSTRACT

Field and pot experiment were conducted in University of Agriculture, Abeokuta, to develop crop coefficients (Kc) for kenaf. Efficiency of lysimeters and Time Domain Reflectometery (TDR) in the measurement of Crop evapotranspiration (ETc) and the Cropwat and Instat+ models in estimating reference evapotranspiration (ETo) were evaluated. The experiment involved three varieties of Kenaf (Ifeken 100, Cuba 108 and Tainung 2) and two water supply methods (rain-fed and irrigation). Physiological parameters and Kc estimated during the different phenological stages of kenaf grown were analyzed with respect to treatments using inferential statistics. The result showed that Cropwat and Instat+ were related ($P < 0.05$) in their estimation of ETo. A strong positive linear relation ($R2= 0.72$, $p < 0.05$) was recorded between lysimeters and TDR measured crop evapotranspiration both on the field and in the container experiment irrespective of variety and water supply method. The Kc from this study were highest in mid-season (0.9 - 1.2), followed by crop development period (0.5 - 0.8), then late period (0.3 – 0.7) and finally the initial stage (0.2 - 0.4) for all varieties of crop shown irrespective of water supply methods. The Kc for the total growth period is estimated to ranged between 0.6 - 0.7. The Kc determined by lysimeter were about 10% higher than the TDR during the late mid - period and the late period. The field determined Kc were slightly higher than those in the container grown crop due to container surface area lower than the ground area for planting of crop. The study further confirmed that variety selection of kenaf, water supply method and their interaction does not significantly ($p> 0.05$) influenced crop coefficient during the trial. It could be concluded that investigating Kc provides a scientific basis for determining the extent to which the water availability will satisfy water requirement of kenaf during the different phenological stages.

Key words: lysimeter, TDR, kenaf, rain-fed, irrigation, phenologic

INTRODUCTION

The increasing competition among agriculture, industry and municipal water users in tropical wet-and-dry climate regions has brought increased attention to water conservation particularly in agriculture. Precise quantitative characterisation of the plant environment based on moisture requirement (Consumptive water use) of cultivated crops is the first step in reducing water used while maintaining profitable production. This is because water use depends on plant species and size (Niu et.al, 2006). Crop coefficient (Kc) is an important factor to convert reference evapotranspiration (ETo) to Crop evapotranspiration (ETc). There are several models to estimate ETo and methods to measure ETc, but their performances in different environments and conditions are diverse. However, no guideline is given to selection of methods and/or models to be used. Hence, it is desirable to develop an understanding of an accurate method / model. Although, little quantitative information of the actual water needs for kenaf plant exists in the tropical wet-and-dry climate. Kenaf (*Hibiscus cannabinus*) is one of the most important annual herbaceous crops of the world (Liu, 2005), with the leaves rich in protein useful in animal feed and the core used as animal beddings, soil amendments and oil absorbents in chemical industries and in ethanol production (Zhou et. al, 2002; Liu, 2005, Agbaje et al., 2008). Ryma (1999) and Balogun et al., (2005) reported that Kenaf can help to alleviate global warming by absorbing carbon dioxide gases due to its rapid growth rate. The cultivation of kenaf is gradually becoming popular in this agro-ecological zone. Hence the development of Kc for Kenaf is an important tool towards its domestication in this environment. This study was undertaken to evaluate the reference-crop evapotranspiration models, crop evapo-transpiration methods and water supply methods for a reliable determination of crop coefficient of kenaf.

MATERIALS AND METHODS

Description of the Study area

Field and pot experiments were carried out at the Federal University of Agriculture, Abeokuta (7o15′ N, 3o25′ W; 159m asl), south-western Nigeria during 2014 -2015 cropping seasons. The area is characterized by a tropical climate with distinct wet and dry seasons with bimodal rainfall pattern and mean annual air temperature of about 30oC. The actual rainfall totals during the 2014 and 2015 cropping season were 1177.2 and 1201.6mm, respectively. The region is characterized by relatively high temperature with mean annual air temperature being about 30oC. The soil at the experimental site was categorized as a well-drained tropical ferruginous soil. The A horizon of the soil is an OxicPaleudulf of the Iwo series with 83% sand, 5% silt and 12 % clay with a pH of 6 considered tolerable for kenaf cultivation.

Pot experiment study

The pot experiment involved 9 pots of 10 kg each of sterilized soil samples collected from the field experimental site location. The soil was sterilized using soil sterilizer at 650C for 1.5hrs. The treatments consisted of 3 varieties of kenaf (Ifeken 100, Cuba 108 and Tainung 2), planted in 2 seasons (wet and dry) using two water supply methods. The kenaf varieties were planted at 2.5 cm depth with two seedlings per stand in a Randomized Complete Block Design (RCBD) in three replicates. Irrigation water was supplied using watering can to soil saturation per day. The plants growth was monitored and growth parameters measured at the different phonological stages. Weighing lysimeter and Time Domain Reflectometery (TDR) were used in the pot experiment to measure the crop evapotranspriation at the different phonological stages. At maturity stage (three months), the seed and fibre of the plants in each pot were harvested. The kenaf yield was estimated by summing up the total weight of kenaf harvested per pot multiplied by the area of the circular pot (Πd2/4) and converting the same to t ha-1. The fibre weight was measured using manual weighing scale. The area of pot (Πr^2) was used for estimation of crop evapotranspiration.

Field experiment

The experimental site, comprised of a piece of land (20 x 20m2) was previously cultivated with cassava but had been fallowed for over 3 years. The site was cleared in June 2014, in preparation for cropping following the popular practice by the farmers in the study area. This period marks the preparatory period for the cultivation of wet season planting in the study area for kenaf. The land was ploughed twice to a 20 cm depth using a tractor and subsequently, clearing was done manually using cutlass and hoe. The clearing was repeated for the dry season planting in November 2015. The experiment involved two treatments (3 varieties and 2 water supplymethods) laid out arrangement in randomized complete block design (RCBD) and the resulting 6 treatments were replicated three times with 3 drainage lysimeters on plot of 15 x 5m^2 piece. The total of 9 of 5 x 5 m^2 plots with a walk way of 1m between adjacent plots covering the total land area of 20 x 20m. Two kenaf seedlings each per cultivar were planted into each plot at 2.5cm depth with 5 x 5 cm spacing and watered immediately after planting. Water supply is basically rainfed on the field during the wet season and by jet irrigation during the dry season. The irrigation water was sourced from the university reservoir adjacent to the experimental site. The plant's growth was monitored and growth parameters measured at the different phonological stages. Drainage lysimeter and Time Domain Reflectometer were used in the field experiment to determine the crop evapotranspriation (ETcrop) at the different phonological stages. A cyclinder-shaped (drum) drainage lysimeter was buried on each plot on the field. At maturity stage (three months), the seed and fiber of the plants in each plot were harvested. The kenaf yield was estimated by summing up the total weight of kenaf harvested per plot and converting the same to t ha^{-1}. The fibre weight was measured using manual weighing scale. The area of drum (Πd2/4) was used to estimate the crop evapotranspiration.

Estimation of water use

The water use of pot-grown plant under rain-fed and irrigation was weighed after every 24 hours. The plants were then reweighed after 24 hr. The difference between the beginning and ending weights over the 24 hr period was the water used (cm^3).The estimate for evapotranspiration (ET) was calculated by the following equation: ETc (mm) = volume of water use (cm3) / container surface area (Πr2) as described by Niu *et al.* (2006). Consumptive water use (CU) from a drainage lysimeter was calculated by a water balance equation. The amount of water entering the lysimeter through precipitation was determined from manual rain gauge in adjacent meteorological station. As described by Perkins (2001), this is determined by dividing the surface area of lysimeter (cm^2) ⁄ surface area of rain gauge (cm) to get a conversion factor for accurate estimation. The estimate for crop evapotranspiration (ETc) using the lysimeter was calculated by the following equation: ETc (mm) = volume of water use cm3 / lysimeter surface area (Πd2/4) cm2.

The unit in centimeter (cm) is then converted to millimeter(mm). Water use (ET) of the plants in both the drainage and weighing lysimeters were also estimated by monitoring the soil moisture depletion using the Time Domain Reflectometery (TDR). The TDR contains two long probes which are buried into the soil to determine water content immediately after irrigation and 24 hours before the next irrigation to obtain the crop water consumptive use. Crop evapotranspiration which is the same as consumptive water use determined by TDR method was calculated using this formula described by Michael, (1978).

ETc = M1i-M2i / 100 x Di

Where:
ETc = evapotranspiration from the root zone for each sampling interval (mm)
M1i = volumetric water content (%) at the time of first sampling
M2i = volumetric water content (%) at the time of 2nd sampling
Di = depth of soil which was the length of the TRD prong (3).

Estimation of of potential evapotanspiration (ETo)

CROPWAT 8.0 software designed by the Food and Agricultural Organisation (FAO, 2009) of the United Nations and INSTAT + software designed by the University of Reading, England for both statistical purposes as well as computation of climatic parameters were applied in this study to determine the potential or reference evapotranspiration. The software were designed based on the Penman monteith empirical formula for estimating potential evapotranspiration by computing and manipulating four climatic parameters (Relative Humidity, Temperature, Wind Speed and Sunshine) for estimation of potential evapotranspiration.

Estimation of crop coefficient(Kc)

The crop coefficient (Kc) was calculated as follows Kc = ETc ÷ ETo

Where Kc = crop coefficient; ETcrop= Crop evapotranspiration (mm); ETo= Reference evapotraspiration (mm)

The Kc curves were plotted following the Food and Agriculture Organization of the United Nations (FAO, 1977) proposed defining four phenological stages (initial, development, mid-season and late or final stages), computed as a function of days after sowing (Kang et al., 2003; Sepaskhah and Andam 2001) and also estimating three Kc values (at the initial, Kcini, mid-season, Kcmid, and late-season, Kcend), and connecting straight line segments through each of the four growth stages (Allen et al. 1998); horizontal lines are drawn through Kc in the initial and mid-season stages, while diagonal lines are drawn from Kcini to Kcmid within the course of the development stage and from Kcmid to Kcend within the course of the late-season stage.

Data analysis

Data collected were subjected to analysis of variance (ANOVA) using statistical software to evaluate the effects of varieties, water supply methods and their interactions on the response variables. Correlation, T-test and regression analysis were the statistical tools employed in analyzing the data. The strength of relationship between ETo models (Cropwat and Instat+) and ETcrop measurement methods were determined using correlation. The significant difference of treatment means were determined using least significance difference (LSD) 5% level of probability. The significance of the main and interaction effects were determined and significant means were separated using DUNCAN multiple range test at 5 % level of probability.

RESULTS AND DISCUSSION

The analysis of the relationship between Cropwat and Instat+ models of estimating reference evapotranspiration using meteorological variable in the determination of crop coefficient of kenaf during rain-fed and irrigated cultivation period as shown in Table 1. The linear regression shows that Cropwat model has a very strong positive correlation (r = 0.99) as well as the highest coefficient of determination (R2 = 99%) with the Instat+ models in the estimation of reference evapotranspiration for the determination of crop coefficient of kenaf during rain-fed and irrigated cultivation period. This can be interpreted to mean that irrespective of water supply method, the Cropwat model and Instat+ models has the capability of reliably predicting the ETo.This was not surprising because both models are developed from the original formula of Penman and the meteorological variables applied in their application were similarly selected from the same locality. This agreed with Eruola *et al.* (2010). Also Bello (1997) has indicated that Penman approach is suitable for the determination of ETo in area characterized by an irregular sequence of wet and dry spells as in the study area.

Table 1: Simple linear regression of reference evapotanspiration (ETo) models and crop evapotanspiration (ETc) in field and pot experiments during rainfed and irrigated cultivation of kenaf

Water Supply Method	Regression equation	Model types	Correlation Coefficient (r)	Coefficient of determination R^2 (%)
		ETo		
Rain-fed Cultivation	Y=0.9516X - 0.0795	Y= Cropwat X = Instat+	0.99	99
Irrigated Cultivation	Y=0.9094X - 0.2235	Y= Cropwat X = Instat+	0.99	98
		Field determination of Etc		
Rain-fed Cultivation	Y=0.7333X - 0.3018	Y= Lysimeter X = TDR	0.85	72
Irrigated Cultivation	Y=1.1918X - 0.8283	Y= Lysimeter X = TDR	0.95	91
		Pot determination of Etc		
Rain-fed Cultivation	Y=0.679X - 1.2512	Y= Lysimeter X = TDR	0.91	82
Irrigated Cultivation	Y=0.9637X - 0.4914	Y= Lysimeter X = TDR	0.95	90

A linear regression model of Y = 0.9516X + 0.0795 and Y = 0.9094X + 0.2235 for rain-fed and irrigated water supply respectively was developed to relate Cropwat to Instat+ for the estimation of reference evapo-transpiration using meteorological variable.
The crop evapotranspiration measured using lysimeter and TDR at different phenophases of selected kenaf variety during the field and pot trials indicated strong correlation of between 85 - 95% in their estimation of crop evapotranspiration irrespective of water supply method and type of trial (field or pot). A linear regression model of Y = 0.7333X + 0.3018 and Y = 1.1918X - 0.8283 for rain-fed and irrigated water supply respectively was developed to relate lysimeter and TDR for the measurement of crop evapo-transpiration in the field experiment and linear regression model of Y = 0.679X + 1.2512 and Y = 0.9637X + 0.4914 for rain-fed and irrigated water supply respectively for pot trial.

The crop coefficient (Kc) estimated using Cropwat and Instat+ models against lysimeter and TDR methods during rain-fed and irrigated cultivation for the selected kenaf varieties following the Food and Agriculture Organization of the United Nations (FAO) proposed four phenological stages during the field and pot trials presented in Table 2. There is no significant variation in the Kc pattern at all the pheno-phases of all varieties sown irrespective of models use in reference evapotranspiration estimation and method used in determination of crop evapotranspiration both on the field and in container-grown crop. The highest Kc was recorded during the mid –season ranging between 0.85 – 1.2, followed by the crop development period ranging between 0.45 -0.69, then the late period ranging between 0.2 – 0.6 and finally the initial stage ranging between 0.2-0.4 for all varieties of crop shown during the experimental year as shown in Table 2. The high Kc at crop development to mid-season can be attributed to the high moisture condition during the periods. The wetness encountered during these periods resulted in high evaporation from soil thus increasing total Etc (Kang et al., 2003 , Allen et al., 1998 and Simon et al., 1998). However, the Kc as determined using TDR was lower than that ofLysimeter during the late mid- period and the late period. The Kc determined by Lysimeter were about 10% higher than the TDR during the late mid- period and the late period. Furthermore, the weekly variation in the Kc pattern of kenaf varieties is not as wide as the pheno-phases variation. It is noteworthy that Kc determination on the field was slightly higher than those in the container grown crop. This can be as a result of the container surface area lower than the ground area for planting of crop (Niu et al., 2006)

The effect of variety selection, water supply method and their interaction on crop coefficient of kenaf is shown in Table 3. Generally, variety selection of kenaf does not significantly (P> 0.05) influenced crop coefficient during the trial. There was also no significant difference in Kc of kenaf irrespective of water supply method used. Furthermore, there exists no significant interaction (P> 0.05) between variety selection and water supply method in the crop coefficient of kenaf in the trial. The average Kc of kenaf irrespective of variety, water supply method and their interaction is 0.65 in the trial.

Table 2: Crop coefficient (Kc) as determined using different reference Evapo- transpiration (ETo) models and crop evapotanspiration (ETc) ratio at various phenological phases of growth in field and pot experiments during rainfed and irrigated cultivation for the selected varieties

	Field Experiment								Pot Experiment							
Kc using different ETo/ ETc	Rain-fed Cultivation				Irrigated Cultivation				Rain-fed Cultivation				Irrigated Cultivation			
	Initial stage	Crop dev. stage	Mid-season stage	Late-season stage	Initial stage	Crop dev. stage	Mid-season stage	Late-season stage	Initial stage	Crop dev. stage	Mid-season stage	Late-season stage	Initial stage	Crop dev. stage	Mid-season stage	Late-season stage
Cuba 108																
Kc = Lys/Copwat	0.26	0.60	1.10	0.29	0.31	0.60	0.93	0.50	0.21	0.52	1.07	0.52	0.25	0.44	0.92	0.67
Kc = Lys/Instat+	0.27	0.62	1.15	0.35	0.33	0.64	0.98	0.52	0.22	0.54	1.1	0.54	0.26	0.47	0.96	0.70
Kc = TDR/Copwat	0.37	0.66	0.85	0.15	0.30	0.56	0.93	0.93	0.34	0.59	0.86	0.36	0.27	0.48	0.94	0.76
Kc = TDR/Instat+	0.38	0.67	0.89	0.16	0.31	0.60	0.99	0.99	0.35	0.60	0.89	0.37	0.28	0.51	0.98	0.79
Ifeken 100																
Kc = Lys/Copwat	0.26	0.58	1.1	0.30	0.32	0.62	0.94	0.52	0.22	0.50	1.07	0.59	0.24	0.42	0.90	0.66
Kc = Lys/Instat+	0.26	0.60	1.20	0.37	0.33	0.66	0.98	0.54	0.22	0.51	1.1	0.61	0.25	0.44	0.95	0.68
Kc = TDR/Copwat	0.37	0.65	0.85	0.16	0.33	0.58	0.96	0.32	0.31	0.56	0.87	0.36	0.27	0.47	0.94	0.75
Kc = TDR/Instat+	0.38	0.67	0.89	0.16	0.32	0.62	1.00	0.33	0.31	0.57	0.89	0.37	0.28	0.50	0.99	0.77
Tainung 2																
Kc = Lys/Copwat	0.28	0.64	1.32	0.32	0.36	0.65	0.99	0.55	0.25	0.60	1.17	0.73	0.30	0.52	0.98	0.74
Kc = Lys/Instat+	0.29	0.66	1.22	0.40	0.37	0.69	1.00	0.57	0.25	0.61	1.20	0.76	0.31	0.55	1.03	0.77
Kc = TDR/Copwat	0.40	0.68	0.92	0.18	0.32	0.62	1.09	0.41	0.35	0.65	0.99	0.42	0.31	0.56	1.03	0.86
Kc = TDR/Instat+	0.41	0.70	0.94	0.16	0.33	0.65	1.15	0.42	0.35	0.67	0.99	0.43	0.32	0.59	1.09	0.89

Table 3: Effect of variety, water supply methods and their interaction on crop coefficient (kc) of kenaf

Treatments Variety (V)	Field trial Kc	Pot trial Kc
Tainung 2 (Vt)	0.71[a]	0.71[a]
Ifeken 100 (Vi)	0.64[a]	0.63[a]
Cuba 108 (Vc)	0.63[a]	0.62[a]
Water Supply Method (Ws)		
Rain-fed (R)	0.66[a]	0.68[a]
Irrigation (I)	0.65[a]	0.63[a]
Interaction (V x Ws)		
Vt x R	0.72[a]	0.75[a]
Vt x I	0.69[a]	0.68[a]
Vi x R	0.65[a]	0.65[a]
Vi x I	0.63[a]	0.60[a]
Vc x R	0.63[a]	0.64[a]
Vc x I	0.63[a]	0.61[a]

Mean with the same letter are not significantly different ($P \leq 0.05$) using Duncan multiple range test

Table 4: Summary of crop coefficient (Kc) for kenaf at different phenological stages

Kc using different ETo/ Etc	Initial stage	Crop development Stage	Phenological stages Mid-season stage	Late-season stage	Total Growth Period
Field	0.2 -0.4	0.5 -0.9	1.0 -1.2	0.2 -0.6	0.6 -0.7
Pot	0.2 -0.4	0.4 -0.7	0.8 -1.2	0.3 -0.7	0.6 -0.7
Average	0.2 -0.4	0.5 -0.8	0.9 -1.2	0.3 -0.7	0.6 -0.7

However, there is a little deviation from the mean with respect to variety and water supply method. Allen et al., 1998 and Kang et al., 2003 reported that Kc for crops may vary from one place to the other, depending on factors such as soil, soil type, crop type, crop variety and water supply methods.The summary of crop coefficient obtained in the study is presented in Table 4. It was obvious that Kc varied along the crop phonological development following the Food and Agriculture Organization of the United Nations (FAO) proposed definition of four phenological stages. From the estimates of the average Kc values of kenaf varieties obtained in field and pot experiments as in the Table, it was observed that the initial (Kcini) ranged between 0.2- 0.4, crop development (Kccrop dev) ranged between 0.5- 0.8, mid-season (Kcmid) ranged between 0.9- 1.2, and late-season (Kcend) ranged between 0.3 - 0.7. The Kc (Kctotal) for the total growth period is estimated to ranged between 0.6 - 0.7.

CONCLUSION

From this study, it is obvious that knowledge of crop coefficient can allow us to develop a seasonal crop water management strategy for kenaf production in Southwest Nigeria. The study revealed that partitioning of the growing season into different phenological stages for investigating Kc determined from ETo and Etc ratio estimated from Cropwat and Instat+ models along with Lysimter and TDR measurement will allow the determination of the extent to which the water availability will satisfy water requirement of crops during the different phenological stages. Such information helps in the design of appropriate technological/ agronomical devices that will maximize beneficial effects. For instance, the derived models can be use to relate ETo models and Etc methods to achieve accurate Kc for efficient irrigation practice.

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