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Full Length Research Paper

Determination of evapotranspiration and crop coefficients for bush okra (*Corchorus olitorius*) in a sub-humid area of Nigeria

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A two-year field experiment was carried out to determine crop evapotranspiration (ETc) and crop coefficients (Kc) for irrigated bush okra (*Corchorus olitorius*) at Minna in a tropical sub-humid area of Nigeria between February and April of 2008 and 2009. Eight 4 x 1 m check basins were laid out in a randomized complete block design with two treatments and four replications. The two common local varieties of *C. olitorius* (*Amugbadu and Oniyaya*) constituted the treatments. The soil moisture depletion method was used to determine ETc while potential evapotranspiration (ETp) was calculated on a daily basis using Blaney-Morin-Nigeria (BMN) evapotranspiration model developed for Nigerian environmental conditions. Kc values were derived as dimensionless ratios of ETc to ETp on a weekly basis. Across varieties and cropping periods, average weekly ETc ranged from 2.0 to 6.8 mm day^{-1} while seasonal ETc ranged from 326 to 374 mm, with *Amugbadu* having significantly higher seasonal ETc ($P \leq 0.01$) in each cropping period, presumably because of its spreading growth habit. Weekly Kc values rose from a minimum of 0.38 at the initial stage of crop growth to a peak value of 1.05 at the mid-season stage and dropped to 0.40 at the end of the late season stage. Closer spacing of *Oniyaya*, which has an erect growth habit, is recommended in order to increase its ground coverage, ETc and fresh leaf yield, under sole cropping system.

Key words: *Corchorus olitorius*, Amugbadu, Oniyaya, evapotranspiration, crop coefficients.

INTRODUCTION

Bush okra, Jew's mallow, jute mallow or tossa jute (*Corchorus olitorius* L.) belongs to the Tiliaceae family and is primarily known as a fibre crop. However, special types with shorter and more branched stems are frequently cultivated for consumption as a leafy vegetable. Bush okra is one of the popular tropical leafy vegetables in Africa, Asia, and some parts of the Middle East and Latin America. In Nigeria, the mucilaginous (somewhat slimy) nature of the young green leaves and shoots of this vegetable makes it a good alternative for okra and one of the leading leafy vegetables. The vegetable can also be harvested and dried for off-season consumption. In Nigerian local languages, bush okra is referred to as *Ayoyo* in the North and *Oyoyo* or *Ewedu* in the South West. Two main cultivars of bush okra are commonly grown in Nigeria, namely *Amugbadu* and *Oniyaya* (Akoroda, 1985). The nutritional value of bush okra compares very well with other common tropical leafy vegetables. It is high in fibre, calcium, iron, and carotene, and contains appreciable amount of protein (Schippers, 2000).

In view of the popularity which this vegetable enjoys in Nigerian cooking traditions and its increasing demand by consumers all over the country, more research and development work needs to be done to improve its culture and production, especially under irrigation. The vegetable thrives in the wild or as volunteer plants in

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Abbreviations: ETc, Crop evapotranspiration; **Kc,** coefficients; **ETp,** potential evapotranspiration; **BMN,** Blaney-Morin-Nigeria; **WAT,** weeks after transplanting; **CEC,** cation exchange capacity.

cultivated fields and this suggests efficient use of soil nutrients. Crop production, however, demands not only efficient use of nutrients but also efficient and economic utilization of water, especially when it is applied artificially. Crop evapotranspiration (ETc) is a principal factor of crop productivity in humid and sub-humid tropics. In these regions, when soil water is available, ETc can reach or even exceed 10 mm day^{-1} under low atmospheric humidity and high wind velocity conditions (Fasinmirin and Olufayo, 2009). Information on ETc and crop coefficients (Kc) is useful for normal irrigation planning and management purposes, for the development of basic irrigation schedules, and for most hydrologic water balance studies (Tyagi et al., 2000; Suleiman et al*.,* 2007). The objective of this study, therefore, is to derive Kc for different growth stages of irrigated bush okra from measurements of ETc and potential evapotranspiration (ETp), using the two common local varieties (*Amugbadu* and *Oniyaya*).

MATERIALS AND METHODS

Site location and characteristics

The 2-year (2008 to 2009) study was conducted at Minna on a site that is approximately 2 km away from the Bosso campus of the Federal University of Technology, Minna in the Northeast direction (9°41′ N, 6°31′ E). Minna falls within the southern Guinea savanna vegetation zone with a sub-humid tropical climate.

Soil properties

The soil of the experimental site is an Alfisol characterized by Odofin (2005) as Typic Plinthustalf (USDA) or Plinthic Lixisol (FAO/UNESCO). The profile horizons have very low to low cation exchange capacity (CEC), organic matter content, N, P, K, Ca and Mg; moderate base saturation and moderately acid to slightly alkaline soil reaction. The texture of the soil varies from sandy loam in upper horizons to sandy clay in deeper horizons. The surface horizon (0 to 20 cm) contains 76% sand, 14% silt and 10% clay while the sub-soil horizon (20 to 40 cm) contains 70% sand, 14% silt and 16% clay and is hence argillic. The soil exhibits plinthic and mottled subsoil characteristics.

Treatments and experimental design

Eight check basins were laid out in a randomized complete block design with two treatments and four replications. The two common local varieties of *C. olitorius* (*Amugbadu* and *Oniyaya*) constituted the treatments. Individual basins had dimensions of 4 x 1 m and were separated by intervals with a width of 1 m. Each basin was completely surrounded by an earth dike to facilitate the retention of applied water and prevent runoff. Seedlings of the two varieties were transplanted to pre-wetted basins at 21 days after sowing. The basins were irrigated again on the day after transplanting and thereafter on every fourth day, at 3-day interval between successive irrigation events. During the first 4 weeks after transplanting, an amount of water corresponding to half of the available water capacity for 25 cm soil depth was applied per irrigation event. The quantity of water was subsequently doubled during the remaining weeks of the cropping period in order to increase the soil depth being wetted to 50 cm. Water was applied using a 10-L capacity galvanized watering can.

Cultural practices

Prior to sowing, seeds of the two varieties were steeped in hot water at a temperature of about 97°C for 10 s to break their dormancy and then air-dried before sowing in daily wetted trays. Transplanting of seedlings was done at a spacing of 40 x 30 cm, giving a population of 26 plants per basin or 65,000 plants ha^{-1}. The basins received a uniform application of 60-30-30 kg ha^{-1} N, P_2O_5 and K_2O. The N was split-applied in two equal doses at 2 and 5 weeks after transplanting while P and K were applied once at 2 weeks after transplanting. The fertilizers were applied by side placement in two small holes near the base of each stand and covered up. Weeds were controlled by hoeing and hand pulling.

Measurement of crop evapotranspiration (ETc)

The soil moisture depletion method, otherwise known as field capacity method, described by Michael (2006), which holds that downward flow or drainage virtually ceases after 1 to 3 days (for sands and clays respectively) was used to determine ETc for irrigated bush okra. Thermo-gravimetric (oven-drying) measurement of soil wetness was done twice within each 4-day irrigation cycle, using triplicate soil samples from depths of 0 to 20 cm, 20 to 40 cm and 40 to 60 cm in each check basin. The first soil sampling was done a day after each irrigation event, in order to allow soil moisture content of the coarse-textured soil to drop to field capacity and drainage to become negligible, so that subsequent water loss could be attributed essentially to evapotranspiration. The second soil sampling was done on the 4th day after the previous irrigation event, just prior to the next irrigation event, at 3-days sampling interval. The measurements were repeated until the cropping period ended. ETc was calculated from the change in soil moisture content in successive samples from the following relationship:

$$ET_C = \sum_{i=1}^{n} \frac{M_{1i} - M_{2i}}{\mathbf{100}} \,.\, Ai \,.\, Di$$

where, Etc = evapotranspiration from the root zone for one 3-day sampling interval (mm); n = number of soil layers sampled in the root zone depth, D; M_{1i} = gravimetric water content (%) at the time of the first sampling in the ith layer; M_{2i}, gravimetric water content (%) at the time of the second sampling in the ith layer; A = soil bulk density of the ith layer (g.cm^{-3}); D = depth of the ith layer of the soil (mm).

Seasonal ETc was calculated by summing the ETc values of each sampling interval. For each 4-day irrigation cycle, a correction was made by adding potential ETp value for accelerated water loss during the 1-day interval between each irrigation event and the first soil sampling.

Determination of potential evapotranspiration (ETp) and crop coefficients

ETp was calculated on a daily basis using BMN evapotranspiration model developed for Nigerian environmental conditions (Duru, 1984; Abu and Edoga, 2008). The ETp model is given as:

$$ETp = r_f\,(0.45T + 8)\,(520 - R^{1.31})/100$$

where, ETp is in mm day^{-1}; r_f is radiation ratio which is calculated

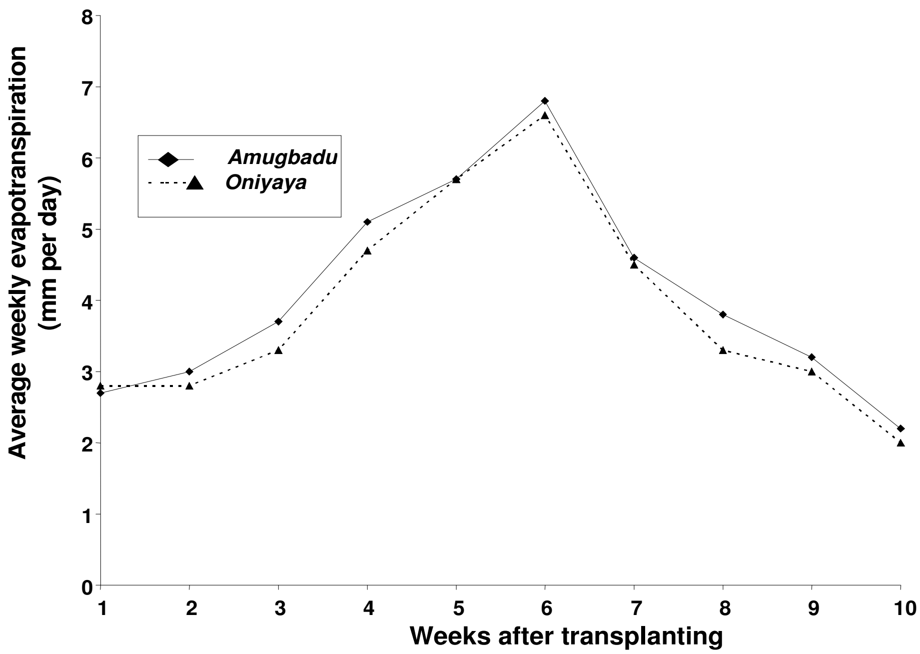

Figure 1. Weekly variation of crop evapotranspiration (ETc) from plots of *Amugbadu* and *Oniyaya* in 2008 cropping period.

as the ratio of maximum possible radiation to the annual maximum; T, mean daily temperature in (°C) obtained by averaging the daily maximum and minimum temperatures; R, mean daily relative humidity in (%) obtained by summing the daily means of relative humidity at 09 h 00 m and 15 h 00 m GMT.

Kc was computed on a weekly basis from transplanting to final harvest as a dimensionless ratio of ETc to ETp according to the equation:

$$Kc = ETc/ETp$$

RESULTS AND DISCUSSION

Weekly and seasonal crop evapotranspiration

In 2008, the average weekly ETc for *Amugbadu* rose from an initial value of 2.7 to 6.8 mm day^{-1} at 6 WAT and dropped to 2.2 mm day^{-1} at the end of the late season stage at 10 WAT (Figure 1). The corresponding values for *Oniyaya* in the same year were 2.8, 6.6 and 2.0 mm day^{-1}. In 2009, the average weekly ETc for *Amugbadu* was 2.7 mm day^{-1} at 1 WAT, 6.5 mm day^{-1} at 6 WAT and 2.8 mm day^{-1} at 10 WAT, while the values for *Oniyaya* were 2.6, 6.5 and 2.7 mm day^{-1}, respectively (Figure 2). In both years, *Amugbadu* recorded higher average weekly ETc than *Oniyaya* during the greater part of the cropping period and this translated to higher cumulative or seasonal ETc values for *Amugbadu* (Table 1). For the entire cropping period in 2008, seasonal ETc amounted to 374 mm for *Amugbadu* and 334 mm for *Oniyaya*, against a seasonal ETp value of 551 mm. The values of seasonal ETc were 368 mm for *Amugbadu* and 326 mm for *Oniyaya*, while the seasonal ETp was 535 mm during the 2009 cropping period. Notably, the differences between the seasonal ETc values of the two varieties were highly significant ($P \leq 0.01$) in both years, with *Amugbadu* losing more water by evapotranspiration.

The two varieties have different growth habits and this might be accountable for the significant differences between their seasonal ETc values. *Amugbadu* plants produced wide open branches while *Oniyaya* plants produced branches that were nearly erect. Consequently, *Amugbadu* had a wider canopy, and by extension, a higher percentage ground cover than *Oniyaya* during the different stages of growth, especially during the crop development and mid-season stages. The percentage ground cover determines the rate of ETc. Generally, ETc increases as percentage ground cover increases and maximum ETc is attained during the mid-season stage when ground cover is about 70 to 80% for field and row crops (Van der Gulik and Nyvall, 2001). The major factors governing ETc levels are resistance to transpiration, crop height, crop roughness, reflection, leaf area, ground coverage and crop rooting characteristics (Allen and Pereira, 1998). Differences in these factors result in different ETc levels for dissimilar crop types and varieties and for different crop growth stages under identical environmental conditions.

Crop coefficients

Table 2 shows that in 2008, Kc values for *Amugbadu* rose from 0.39 at 1 WAT to 1.05 at 6 WAT and dropped to 0.44 at 10 WAT, while the corresponding values for

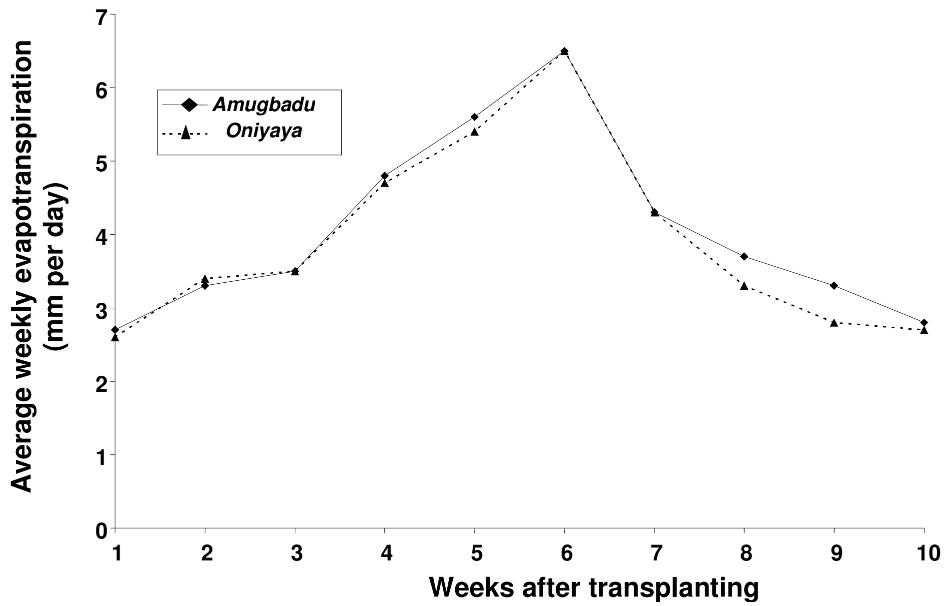

Figure 2. Weekly variation of crop evapotranspiration (ETc) from plots of *Amugbadu* and *Oniyaya* in 2009 cropping period.

Table 1. Seasonal crop evapotranspiration (ETc) from plots of *Amugbadu* and *Oniyaya* and corresponding seasonal potential evapotranspiration (ETp) in parentheses in 2006 and 2007 cropping periods.

Year	*Amugbadu*	*Oniyaya*	Difference
2008	374 (551)	334 (551)	40**
2009	368 (535)	326 (535)	42**

**, Significant at 1% level.

Table 2. Weekly variation of single (time-averaged) crop coefficients for *Amugbadu* and *Oniyaya*.

WAT	2008		2009	
	Amugbadu	*Oniyaya*	*Amugbadu*	*Oniyaya*
1	0.39	0.40	0.38	0.38
2	0.44	0.44	0.46	0.45
3	0.55	0.53	0.60	0.56
4	0.70	0.67	0.69	0.66
5	0.91	0.85	0.93	0.88
6	1.05	0.96	1.00	0.98
7	0.95	0.90	0.97	0.90
8	0.77	0.72	0.79	0.75
9	0.62	0.60	0.66	0.65
10	0.44	0.40	0.45	0.45

WAT, Weeks after transplanting.

Oniyaya were 0.40, 0.96 and 0.40. In 2009, Kc values for *Amugbadu* were 0.38 at 1 WAT, 1.00 at 6 WAT and 0.45 at 10 WAT, compared with 0.38, 0.98 and 0.45, respectively for *Oniyaya*. The values of Kc were consistently higher for *Amugbadu* compared with *Oniyaya* from 3 to 9 WAT. This was as a result of higher evapotranspiration losses from *Amugbadu*, particularly during the crop development and mid-season stages, when it developed more foliage and ground coverage and transpired more water than *Oniyaya*. Crop coefficients and crop evapotranspiration are governed by the same factors and the former increases as the latter increases.

Comparability with ETc and Kc values generated using a different irrigation interval

The values of ETc and Kc generated in this experiment should only be compared with other sets of values generated using a 3-day irrigation interval. Adjustments have to be made for shorter or longer intervals because the values of ETc and Kc are influenced by the time interval between wetting events, particularly during the initial stage of annual crops (Villagra et al., 1994; Allen and Pereira, 1998). At this stage of crop growth, the soil surface is almost completely bare and ETc is predominantly in the form of soil evaporation. Where the soil is frequently irrigated, soil evaporation can be considerable and Kc will be large. Soil evaporation can account for as much as 50% of the total evapotranspiration when the soil surface is frequently wetted. On the other hand, where the soil surface is dry due to infrequent irrigation, soil evaporation is restricted and the Kc will be small. As the crop develops, the leaf area and ground cover increase and soil evaporation decreases while crop transpiration increases. Consequently, the influence of wetting interval on ETc and Kc diminishes and becomes minimal during the mid-season stage.

Conclusion

The information generated in this study on the ETc of *Amugbadu* and *Oniyaya* is useful for the determination of the crop water requirement and irrigation water requirement of *C. olitorius* in the southern Guinea savanna of Nigeria. ETc refers to the amount of water that is lost through evapotranspiration, while crop water requirement refers to the amount of water that needs to be supplied which includes ETc plus the losses during the application of irrigation water (unavoidable losses) and the quantity of water required for special operations such as land preparation, transplanting, leaching, etc. The irrigation water requirement refers to crop water requirement, exclusive of effective rainfall and contribution from soil profile (Michael, 2006).

The study generated Kc values on a weekly basis for each variety from the beginning to the end of each cropping period. However, three Kc values are the irreducible minimum for describing and constructing the Kc curve, namely Kc values at the initial stage (Kc_{ini}), at the mid-season stage (Kc_{mid}) and at the end of the late season stage (Kc_{end}). With the three-point Kc curve, there are no set Kc values for the crop development stage. If irrigating during this period, a Kc value that is between Kc_{ini} and Kc_{mid} should be chosen. A similar approach should be adopted for the time period between Kc_{mid} and Kc_{end}, if the time period is too long to permit a jump directly from Kc_{mid} to Kc_{end} (Van der Gulik and Nyvall, 2001).

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