

FIELD-BASED CROP COEFFICIENTS (K_c) FOR A MAIZE CROP UNDER DEFICIT IRRIGATION SCHEDULING

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ABSTRACT

This study presents crop coefficient (K_c) values of TMV1-ST maize variety cultivated under deficit irrigation scheduling in Mkoji sub-catchment, Tanzania. Field experiments consisting of eight (8) treatments were conducted in 2004 and 2005 irrigation seasons. The treatments variation was irrigation intervals. The control treatment was irrigated on weekly basis while the other treatments were irrigated every other week at one or more growth stages of the maize crop. Surface irrigation method was used and soil moisture contents were monitored weekly throughout the crop growing season from which weekly crop actual evapotranspiration was computed. Weather data of the study location were used to compute weekly reference evapotranspiration based on the FAO-Penman-Monetieth model. Crop coefficients were computed as the ratio of crop actual evapotranspiration of the different treatments to reference evapotranspiration on weekly basis. Water stress coefficients were also computed. The crop coefficients had similar trend in the two seasons which make them reliable. The average crop coefficient (K_c) of the fully irrigated treatment for the two seasons for the establishment, vegetative, flowering and grain filling stages were 0.53, 0.82, 1.10, and 1.06, respectively, while the average crop coefficients of the deficit irrigated treatments (K_c') for the two seasons for the establishment, vegetative, flowering and grain filling stages were 0.53, 0.75, 0.94, and 0.78, respectively. Withholding regular irrigation at any crop growth stage reduced crop coefficient by between 17 to 30 %, while withholding regular irrigation at two or more successive growth stages of the maize crop reduced crop coefficient by about 40 %. The water stress coefficient (K_s) resulting from deficit irrigation at any one growth stage only of the maize crop were found to range from 0.74 to 0.83, while deficit irrigation at two or more successive growth stages ranged from 0.68 to 0.77. The crop and water stress coefficients developed from this study could be used in irrigation systems planning and design for the study area in Tanzania.

Keywords: Irrigation scheduling, deficit irrigation, crop coefficient, water stress, maize, Tanzania

1.0 INTRODUCTION

Sustainability of irrigated agriculture depends largely on the efficient management of irrigation water. To be able to efficiently manage water such that crop productivity is enhanced, information on crop water requirement is very vital. That is why the water requirements of crops have and will continue to remain a subject of interest to stakeholders in irrigation and water resources management. Crop water requirement is defined as the quantity of water needed by a crop at any given time from planting to the time it is harvested. The seasonal crop water requirement is the total amount of water required to grow the crop. Water requirement varies widely from crop to crop and during the period of growth of individual crops. In order to adequately apportion the water required at any given time, crop water requirement has to be measured or estimated, and one important parameter which is commonly required for estimation of crop water requirement is the crop coefficient also referred to as crop factor (K_c).

The crop coefficient (K_c) is basically expressed as the ratio of crop evapotranspiration (E_{Tc}) to atmospheric evaporative demand expressed as reference evapotranspiration (E_{To}). It integrates the crop and soil factors that make the crop water use differ from the evaporative atmospheric demand. Information on crop coefficient (K_c) is very important in agro-hydrological studies. It is required in irrigation planning and design, irrigation management, basic irrigation schedule, real time irrigation scheduling for high frequent and non-frequent water application, supplemental irrigation and in detailed soil and hydrological water balance studies. K_c has also been understood to vary predominantly with the specific crop characteristics, and to a limited extent, with climate; hence the adoption of K_c values across locations and climates. This believe also has been the primary reason for the global acceptance of the K_c values developed in past studies and usefulness of the crop coefficient approach in estimating crop evapotranspiration. Table values of K_c for different crops are available in literature (Doorenbos and Pruitt, 1977; Pruitt, 1986; Wright, 1982; Snyder *et al.*, 1989; Allen *et al.*, 1998) and are being used in many irrigation researches and planning.

With advances in knowledge, it is now understood that K_c varies to a greater extent with climate, and specifically with wind speed and humidity, beside crop and soil characteristics. This is strongly supported by the report of Kang *et al.* (2003). According to Allen *et al.* (1998), the K_c values reported in many of the literatures commonly consulted and used in irrigation planning (e.g. Doorenbos and Pruitt, 1977; Pruitt, 1986; Wright, 1982) represent those of sub-humid climate with an average daytime minimum relative humidity (RH_{min}) of about 45% and with a calm to moderate wind speed averaging 2 m s^{-1} . For more humid and arid conditions, or for more or less windy conditions, Allen *et al.* (1998) suggested that the K_c for the mid and end seasons should be modified. They emphasized the strong need for local calibration of crop coefficients under given climatic conditions. Beside the effect of climatic variables on K_c , Allen *et al.* (1998) has also emphasized a difference in K_c values under fully irrigated condition and moisture stress condition. The foregoing suggests the strong need for development of K_c for different locations, and soil moisture regimes.

Crop coefficients (K_c) values are usually developed from experiments in which ET_a and ET_o are either measured or estimated. The ET_o is usually estimated from climatic data using any of the combination models; and the one widely recommended is the FAO-Penman-Monteith model (Allen, et al., 1998). The crop evapotranspiration (ET_c) is usually the water use of cropped field or crop planted in lysimeters (micro or macro, weighing and non-weighing types) which are placed in the midst of similar crop cultivated in the field. K_c values developed using ET_c measured directly from cropped field is referred to as field-based, while those from lysimeters are referred to as lysimeter-based. Amayreh and Al-Abed (2005) developed crop coefficients for field-grown tomato under drip irrigation and the crop evapotranspiration were measured directly from the field without lysimeter. Mofoke (2000) developed field-based crop coefficient for selected vegetables which include tomato, onion and potato cultivated in the flood plains of Zango-Shanu, Zaria, Nigeria. Kashyap and Panda (2001) also developed crop coefficients for potato crop in a sub-humid region of Kharagpur, India. Similarly, Kuo et al (2006) used non-weighing lysimeters to develop crop coefficients for selected upland (corn, sorghum and soybean) and paddy crops in ChiaNan Irrigation Association, Taiwan. Ko et al. (2009) developed evapotranspiration crop coefficients for cotton and wheat based on data from weighing lysimeters in Texas Agric-life Research fields, Uvalde, Texas, USA.

Maize (*Zea mays*) is one of the crops largely cultivated under irrigation in Mkoji sub-catchment of the Great Ruaha River Basin in Tanzania. However, a crop coefficient (K_c) studies have not been carried out for the crop in that location. In order to develop an effective irrigation schedule and plan an efficient water management system for the area, the crop coefficient of the maize crop cultivated under irrigation will be useful information. The objective of this study was to develop field-based basal crop coefficients for maize in the study area.

2.0 MATERIALS AND METHODS

2.1 The study Area

This study was carried out in the Mkoji sub-catchment (latitudes $7^{\circ}48'$ and $9^{\circ}25'$ South, and longitudes $33^{\circ}40'$ and $34^{\circ}09'$ East (SWMRG-FAO, 2003)) of the Great Ruaha River Basin, which is one of the four sub-basins of the Rufiji River Basin in Tanzania. The location of the experimental field was the Igurusi ya Zamani Traditional Irrigation Scheme (IZTIS), Igurusi, Mbeya Region. The study area has a unimodal type of rainfall. The rainy season is between November and April, and the mean annual rainfall is about 800 mm. The mean daily maximum temperatures range from 28°C to 32°C , while the mean daily minimum temperatures range from 9.5° to 19.5°C , respectively. Table 1 shows the weather data obtained from the Igurusi weather station situated about 4 km from the field experimental site for the seasons the experiments were conducted. The soil of the experimental field is that of alluvial clay and clay loam soils (SWMRG-FAO, 2003). Table 2 shows some physical properties of the soil. The water holding capacity of the 1 m profile depth was about 0.10 m, and the average soil bulk density was 1420 kg/m^3 .

2.2 Field Experimentation

The field experiments from which this study is reported were among series of experiments carried out during the 2004 and 2005 dry season irrigation period (June-October) in which TMV1-ST maize variety was planted under deficit irrigation scheduling. Details of these experiments have

Table 1: Weatherdata for the 2004 and 2005 irrigation cropping seasons

Month	Maximum air temperature (°C)		Minimum air temperature (°C)		Wind speed (m/sec)	
	2004	2005	2004	2005	2004	2005
June	26.9	26.3	12.6	14.3	0.8	1.0
July	28.2	26.3	10.7	14.0	1.0	1.1
August	29.5	27.6	11.5	14.1	1.1	1.2
September	30.7	29.3	13.2	15.7	1.3	1.3
October	32.6	30.7	13.4	17.1	1.4	1.7

Table 2: Some soil physical properties of the experimental site

Soil profile depth (mm)	Moisture content at field capacity (m ³ /m ³)	Moisture content at wilting point (m ³ /m ³)	Soil bulk density (dry) (g/cm ³)	Clay %	Silt %	Sand %	Soil Textural Class ^a
0-150	0.283	0.122	1.38	33	15	52	Sandy clay
150-400	0.301	0.164	1.40	35	15	50	Sandy clay
400-700	0.312	0.215	1.41	35	13	52	Sandy clay
700-1000	0.311	0.211	1.35	35	19	46	Sand clay loam

^a USDA classification

been reported by Igbadun (2006), Igbadun et al. (2006 and 2008). In the study reported herein, field data from one of the field experiments during the 2004 and one in 2005 were used. The field trials were conducted at the Ministry of Agriculture and Food Security (MAFS) Training Institute Igurusi farms located in Igurusi ya Zamani Traditional Irrigation Scheme (IZTIS), Tanzania. In 2004, the maize crop was planted on 24th June, while in 2005 season, planting was done on 6th July. The TMV1ST maize variety (*Zea mays* L.) was planted in the two seasons. TMV1-ST is one of the maize varieties commonly grown under irrigation in the study area. The characteristics of the maize variety which make it preferable under irrigation in the study area is that it is tolerant to moisture stress and maize streak disease (ARI-Uyole, 2002). It attains physiological maturity at 115-130 days after planting.

The experiments for both seasons consisted of eight treatments each. The 2004 experiment was replicated three times, while the 2005 experiment was replicated four times. In both seasons the experiments were laid in a randomized complete block design. The treatment designs were similar for both seasons. The treatment variation was based on frequency of irrigation. The description of the experimental treatments is shown in Table 3. A weekly irrigation interval was maintained in Treatment 1 (labelled TR₁₁₁₁). In the other treatments, the weekly irrigation was maintained only at some growth stages, while at the other growth stages, the weekly irrigation was skipped after every other irrigation until the targeted growth stage duration elapsed. This method of varying irrigation regimes by withholding irrigation at some growth stages of the crop was similar to that used by Pandey *et al.* (2000).

The crop growth duration was divided into four stages similar to those of Doorenbos and Kassam (1979). The crop growth stages include: Establishment stage, which was from planting to 6-8 leaves formation (0-23 days after planting (DAP)); Vegetative stage, from crop establishment to tassel formation (24-65 DAP); Flowering stage, from tassel formation to silking (66-93 DAP), and grain filling stage which included milk, dough and dent stages of grain filling to physiological maturity (94-125 DAP). The lengths of growth stages were based on field observations of the crop development. However, the observed length of the growth stages compared closely with Doorenbos and Kassam (1979). The experimental treatment variation started at the vegetative growth stage. Irrigation was not skipped in any treatment during the establishment growth stage so as to allow the crop to establish before being subjected to moisture stress.

Table 3: Description of the experimental treatments for the 2004 and 2005 seasons

Treatment No	Description
1 (TR ₁₁₁₁)	Irrigated weekly without skipping irrigation at any crop growth stage. (Reference treatment).
2 (TR ₁₀₁₁)	Irrigation was skipped every other week at vegetative stage only. Weekly irrigation was observed at flowering and grain filling growth stages.
3 (TR ₁₁₀₁)	Irrigation was skipped every other week at flowering stage only. Weekly irrigation was observed at vegetative and grain filling growth stage.
4 (TR ₁₁₁₀)	Irrigation was skipped every other week at grain filling stage only. Weekly irrigation was observed at vegetative and flowering growth stages.
5 (TR ₁₀₀₁)	Irrigation was skipped every other week at vegetative and flowering stages. Weekly irrigation was observed only at grain filling growth stage.
6 (TR ₁₀₁₀)	Irrigation was skipped every other week at vegetative and grain filling stages. Weekly irrigation was observed only at flowering growth stage.
7 (TR ₁₁₀₀)	Irrigation was skipped every other week at flowering and grain filling stages. Weekly irrigation was observed only at vegetative growth stage.
8 (TR ₁₀₀₀)	Irrigation was skipped every other week at vegetative, flowering and grain filling stages.

* The subscripts represent the growth stages: 1= weekly irrigation at the growth stage and 0 = irrigation was skipped every other week at the stage.

The details of the agronomic practices and the method used in measuring irrigation water application depths for the two experiments has been reported in Igbadun (2006), Igbadun et al. (2006 and 2008). Surface irrigation method was used to deliver water to the crops in both seasons. An average discharge of 4 l/s was allowed to flow into a basin at a time. Water application depths per irrigation were based on the average weekly reference evapotranspiration amount for each month of the crop-growing season (rounded to tens). Thus, water applied per irrigation was 30, 30, 40, 50, 50 mm for the months of June, July, August, September and October, respectively. The seasonal water applied in treatments 1, 2, 3, 4, 5, 6, 7 and 8 were 700, 590, 600, 610, 490, 500, 510, and 400 mm, respectively in the 2004 season experiments, and 750, 620, 650, 670, 520, 540, 570, and 440mm for treatments 1, 2, 3, 4, 5, 6, 7, and 8, respectively in the 2005 experiments. These depths included a pre-planting irrigation of 30mm carried out 3 days before planting. A total of 17 and 18 irrigations were carried out during the 2004 and 2005 season's experiments, respectively for the reference treatment. In the other treatments, the number of irrigations ranged between 10 and 16, depending on the number of times irrigation was skipped per treatment. The differences between the seasonal water applied in the 2004 and 2005 experiments were simply due to the number of irrigation events in each season. The crop attained physiological maturity in late October each year at about 126 days after planting during the 2004 season, and 122 days in the 2005 season. Harvesting was carried out four weeks after physiological maturity was attained. Grain moisture content at harvesting was obtained in the laboratory as 13.4 %.

2.3 Soil Moisture Measurements

Soil moisture content was monitored throughout the crop-growing seasons. In 2004 season, a ML1 Theta Probe (Delta-T Devices, Cambridge) was used. The Theta Probe measures moisture content in-situ and expresses the volumetric soil moisture content in m^3/m^3 . In 2005 season, a Neutron Probe was used to monitor the soil moisture regime. Soil moisture content measurements were carried out twice a week. Moisture measurement was done at 2 days after an irrigation event and on the day of the next irrigation (7th day after irrigation). When irrigation was skipped in any treatment, soil moisture content was measured 2, 7 and 9 days after irrigation, and just before the next irrigation event (that is, the 14th day). It was assumed that soil moisture content of the field would be at field capacity and deep percolation will be negligible 2 days after irrigation since the soil is sandy clay to sandy clay loam (James, 1988; Michael, 1999). Soil moisture contents measured at 2 days after irrigation were fairly close (about $\pm 5\%$) to laboratory determined soil moisture content at field capacity.

In the 2004 experiment, soil moisture measurements were carried out at soil profile depths of 0-15, 15-40, 40-70, and 70-100 cm, respectively. Three pieces of 7.6cm diameter PVC pipes were installed to the depths of 25, 55 and 80 cm, respectively, in each plot to provide access for inserting the theta probe into the soil. Soil moisture content measurements were made by inserting the sensing head of the Theta probe into the soil, through the access pipes to depths of 25, 55, and 80 cm below the soil surface.

The measurements made at these depths were taken to represent soil profile depths of 15-40, 40-70, and 70-100 cm, respectively. The theta probe was inserted from the soil surface to measure the moisture content of the 0-15 cm depth. In 2005 season where the Neutron probe was used to measure soil moisture content, measurements were made at 0-15, 15-30, 30-45, 45-60, 60-75, and 75-100 cm profile depths through access tubes installed in each experimental plot. Due to the presence of mudstones and gravels at about one metre below the soil surface it was difficult to go below 100 cm depth with the access tubes. Both the Theta probe used in 2004 and the Neutron probe used in 2005 were calibrated for the experimental site at the beginning of each season. The Neutron probe was calibrated for the 0-15 cm depth and for the 15-100 cm depths as recommended by the manufacturers.

2.4 Computation of Actual Crop Evapotranspiration

The actual crop evapotranspiration from the fully irrigated treatment (ET_a) and the deficit irrigated treatments ($ET_{a,deficit}$) were calculated from measured soil moisture content data using the soil moisture depletion method as outlined by Michael (1999). The average daily actual evapotranspiration (AET) was expressed as:

$$AET = \frac{\sum_{i=1}^n (VMC_{1i} - VMC_{2i}) D_i}{t} \quad (1)$$

where, AET is average daily actual evapotranspiration between successive soil moisture content sampling periods (mm/day); VMC_{1i} is volumetric soil moisture content (m^3/m^3) at the time of first sampling in the i th soil layer; VMC_{2i} is volumetric soil moisture content (m^3/m^3) at the time of second sampling in the i th layer; D_i is depth of i th layer (mm); n is number of soil layers sampled in the root zone depth D , and ' t ' is number of days between successive soil moisture content sampling.

The actual crop evapotranspiration for a week was therefore the product of the daily crop evapotranspiration between successive soil moisture content sampling and the number of days in the week.

2.5 Computation of Reference Evapotranspiration (ET_o)

Reference evapotranspiration (ET_o) was computed using the FAO-Penman-Monteith method as given in Allen et al. (1998). The weather data available at the Igarusi Meteorological station situated about 4 km away from the experimental site during the 2004 and 2005 seasons when this study was carried out were daily maximum and minimum temperatures, and wind speed only. Solar radiation and vapour pressure data were estimated from the available data using the method given in Allen et al. (1998).

2.6 Computation of Crop Coefficients

The crop coefficient (K_c) for the fully irrigated treatment (TR_{full}) was computed as the ratio of the average daily ETa of the fully irrigated treatment (ETa) to the average daily ETo for each week (Eq. 2). The crop coefficient of the deficit irrigated treatments (referred to as K_c') was computed as the ratio of the average daily ETa of the deficit irrigated treatments ($ETa_{deficit}$) to the average daily ETo for each week (Eq. 3).

$$K_c = \frac{ETa}{ETo} \quad (2)$$

$$K_c' = \frac{ETa_{deficit}}{ETo} \quad (3)$$

2.7 Computation of Water Stress Coefficient (K_s)

The water stress coefficient (K_s) integrates the crop and soil factors that make the actual crop water use under moisture stress condition differ from crop water use under fully irrigated condition. The relationship is expressed as:

$$ETa_{deficit} = K_s * ETa \quad (4)$$

where, K_s is water stress coefficient

Other parameters are as previously defined.

Substituting Eq. 2 in 4,

$$ETa_{deficit} = K_s * K_c * ETo \quad (\text{Allen et al., 1998}) \quad (5)$$

and from Eqs.3 and 5:

$$K_s = \frac{K_c'}{K_c} \quad (6)$$

The values of K_c , K_c' and K_s for the four growth stages of the crop were computed by finding the averages of the weekly coefficients values for the growth stages.

3.0 RESULTS AND DISCUSSION

3.1 Introduction

The grain and biomass yields from these experiments have been reported in Igbadun et al. (2006 and 2008), and will therefore not be repeated here. This report will concentrate on the crop coefficients derived from the experiments.

3.2 Reference Evapotranspiration (ETo)

Figure 1 shows the trend of the reference ETo for the 2004 and 2005 irrigation season for the study location. The ETo values ranged from 3.08 to 7.57 mm/day in the 2004 season, and 3.43 to 6.63 mm/day in the 2005 season. The average daily ETo for the months of June, July, August, September, October, and November were 3.48, 3.81, 4.15, 4.89, 5.40 and 5.62 mm/day, respectively.

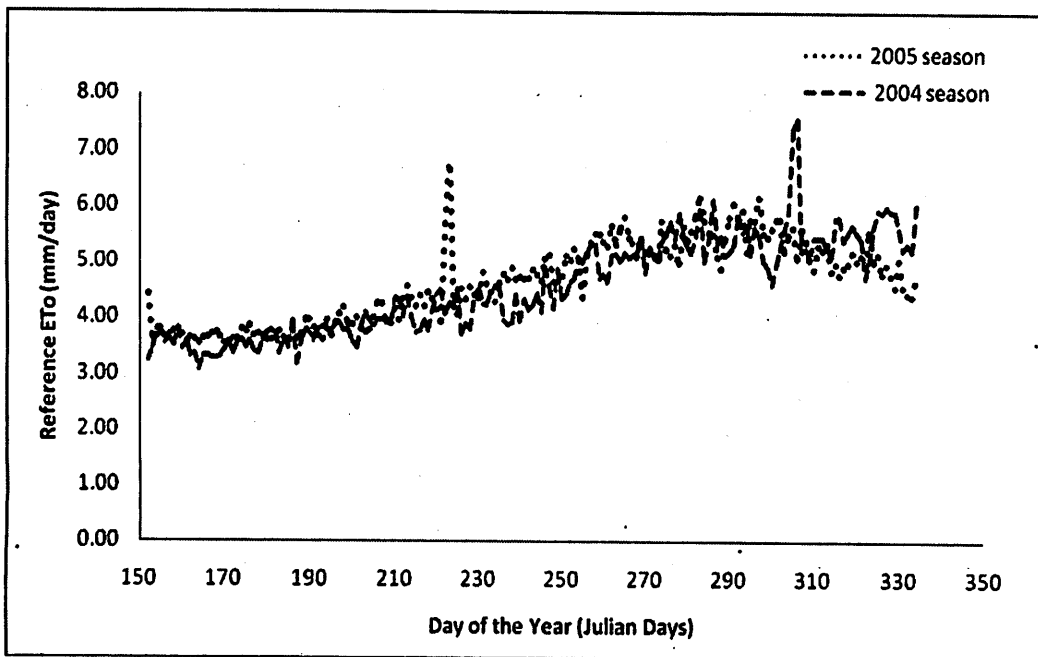


Figure 1: Daily reference evapotranspiration (June 1st to November 30th, 152 to 334 Julian days) for 2004 and 2005 cropping seasons

3.3 Average Daily Actual Evapotranspiration

The average daily actual evapotranspiration (ET_a) of the experiments for 2004 and 2005 seasons are shown in Tables 4 and 5, respectively. The values of the ET_a ranged from 1.6 to 6.2 mm/day for the weekly irrigated treatment (TR₁₁₁₁), and from 1.1 to 5.2 mm/day for the treatment irrigated every other week (TR₁₀₀₀) in 2004 season. Similar trend was noticed in 2005 season where the ET_a ranged from 1.7 to 6.5 mm/day for TR₁₁₁₁ and 1.7 to 5.7 mm/day for TR₁₀₀₀. The peak actual evapotranspiration was between 86 and 100 days after planting in the two seasons, which was between silking and milk-dough stage of the grain formation process. Generally, the trend of the ET_a for all the treatments agrees with literature reports on ET_a of a maize crop (Doorenbos and Kassam, 1979; Kang et al., 2003), in which the values rises at vegetative growth stage progressively to the peak at flowering to grain filling, and decline gradually as the crop attain physiological maturity.

Table 4: Average daily actual evapotranspiration of the maize field in 2004 season

Growth stage Days after planting	Establishment			Vegetative					Flowering				Grain filling-Maturity				
	0-05	1-6	2-3	24	31	38	45	52	59	66	73	80	87	94-10	101	108	115
	1	2	3	30	37	44	51	58	65	72	79	86	93	0	107	114	126
Treatment	Daily actual ET values																
TR ₁₁₁₁	1.6	2.3	2.5	3.1	3.2	4.1	3.7	4.3	5.2	5.7	5.9	6.1	6.4	6.2	6.1	5.4	4.2
TR ₁₀₁₁	1.6	2.4	2.4	3.3	2.0	3.9	2.1	3.5	3.7	5.1	5.2	6.5	6.0	6.0	5.6	5.3	4.3
TR ₁₁₀₁	1.5	2.2	2.4	3.3	3.4	4.1	3.8	4.1	5.1	5.2	4.1	5.4	5.4	5.7	5.5	4.4	
TR ₁₁₁₀	1.5	2.5	2.5	3.2	3.6	4.0	3.7	3.9	5.1	5.3	5.4	5.9	5.7	3.2	4.9	2.5	
TR ₁₀₀₁	1.7	2.4	2.5	3.2	2.2	3.7	2.3	3.3	3.3	5.0	3.8	5.3	5.1	5.3	5.1	4	
TR ₁₀₁₀	1.6	2.1	2.4	2.9	2.2	3.8	2.1	3.3	3.3	5.1	5.1	5.8	5.9	3.5	4.4	2.7	
TR ₁₁₀₀	1.6	2.2	2.4	3.0	3.4	4.6	4.2	4.0	5.4	4.9	4.5	5.3	5.5	2.8	4.4	2.5	
TR ₁₀₀₀	1.5	2.4	2.5	3.5	1.9	3.5	2.1	3.3	3.3	4.4	2.7	5.3	4.7	3.2	4.5	2.6	
ET ₀	3.7	3.7	4.1	3.8	3.7	4.5	3.9	4.5	5.1	5.1	5.2	5.4	5.7	6.0	5.9	5.6	

Table 5: Average daily actual evapotranspiration of the maize field in 2005 season

Growth stage Days after planting	Establishment			Vegetative					Flowering				Grain filling-Maturity				
	0-03	04-09	10-16	20	27	34	41	48	55	66	73	80	87	94	101	108	115
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Treatment	Daily actual ET values																
TR ₁₁₁₁	1.7	2.3	2.6	2.3	2.3	2.9	3.7	4.6	4.2	4.8	6.6	6.5	6.3	6.2	5.6	3.9	
TR ₁₀₁₁	1.6	2.1	2.7	2.2	1.8	2.8	2.4	4.4	3.6	5.0	6.2	6.0	6.2	5.7	5.4	3.9	
TR ₁₁₀₁	1.7	1.7	2.3	2.2	2.2	2.5	3.3	4.3	4.1	4.4	5.8	4.3	5.8	5.7	5.1	4.2	
TR ₁₁₁₀	1.7	1.9	2.6	2.2	2.2	2.5	3.4	4.2	4.4	4.6	6.3	6.0	6.1	4.6	5.0	2.3	
TR ₁₀₀₁	1.6	2.1	2.5	2.1	1.9	2.7	2.7	3.3	3.2	4.4	5.3	3.6	5.2	5.0	4.7	3.0	
TR ₁₀₁₀	1.8	2.1	2.6	2.4	1.5	2.8	2.9	3.5	3.0	4.5	6.4	5.8	5.6	4.1	4.7	2.1	
TR ₁₁₀₀	1.6	2.3	2.5	2.2	2.2	3.7	3.2	4.7	4.2	4.3	5.4	4.3	4.7	3.8	4.3	2.8	
TR ₁₀₀₀	1.7	2.3	2.6	2.3	1.8	2.4	2.4	3.5	2.8	3.4	5.4	4.2	5.2	4.4	4.4	2.3	
ET ₀	4.0	3.9	3.8	4.2	3.7	3.3	3.8	4.9	4.6	4.5	5.7	5.4	5.7	5.8	5.8	5.4	

Treatments where irrigation events were skipped fortnightly recorded lower average daily ETa in those weeks irrigation were skipped compared to the weeks when the treatments were irrigated. This was expected since evapotranspiration is directly a function of available moisture in the soil. The plots that were not irrigated had less moisture in the soil for crop uptake. It may also be noticed that in treatments where irrigation was skipped during the vegetative growth stage (Stage II) (TR₁₀₁₁, TR₁₀₀₁, TR₁₀₁₀, and TR₁₀₀₀), the daily ETa values were not only lower at the week irrigation event was skipped they were also lower compared to the fully irrigated treatment in the weeks irrigation was done. This trend may not be far from the fact that skipping irrigation at the vegetative stage resulted into moisture stress which affected leaf area index and subsequently ETa. The peak actual evapotranspiration for the treatments in which irrigation event was skipped during the flowering growth stage (TR₁₁₀₁, TR₁₀₀₁, TR₁₁₀₀, and TR₁₀₀₀) were also found to be 8 to 20 % less than the peak ETa of TR₁₁₁₁.

3.4 Crop Coefficients

Tables 6 and 7 show the weekly crop coefficients of the fully irrigated treatment (Kc) and the deficit irrigated treatments (Kc') values for the 2004 and 2005 seasons, respectively. The Kc increased from 0.44 and 0.42 at establishment growth stage to peak values of 1.14 and 1.15 at the early phase of the grain filling growth stage of the crop in 2004 and 2005, respectively. The Kc' of the treatment every other week from vegetative to maturity (TR₁₀₀₀) increased from 0.3 and 0.42 at establishment growth stage to peak values of 0.97 and 0.92 during the last phase of the flowering growth stage in 2004 and 2005 seasons, respectively. The means of the weekly crop coefficient ranged from 0.43 to 1.05 and from 0.42 to 1.04 in 2004 and 2005 seasons, respectively. The standard deviation ranged from 0.02 to 0.24 and 0.02 to 0.16 in 2004 and

Table 7: Crop coefficient (Kc) values for the maize crop for 2005 season

Growth stage	Establishment				Vegetative					Flowering				Grain filling-Maturity				
	0-03	0-4	10-16	1-7	24-30	31-37	38-44	45-51	52-58	59-65	66-72	73-79	80-86	87-93	94-100	101-107	108-114	115-122
Treatment	Crop coefficient (Kc) of fully irrigated treatment																	
TR ₁₁₁₁	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.9	1.0	1.0	1.1	1.1	1.1	1.1	0.9	0.7
TR ₁₀₁₁	0.4	0.5	0.5	0.6	0.5	0.6	0.6	0.7	0.7	0.8	1.0	1.0	1.1	1.1	1.0	0.9	0.8	0.7
TR ₁₁₀₁	0.4	0.4	0.5	0.7	0.7	0.6	0.6	0.8	0.8	0.9	1.0	0.8	1.0	0.8	1.0	0.8	0.8	0.7
TR ₁₁₁₀	0.4	0.4	0.6	0.6	0.6	0.6	0.7	0.8	0.8	0.9	1.0	1.1	1.1	1.1	1.0	0.8	0.8	0.4
TR ₁₀₀₁	0.4	0.5	0.6	0.6	0.5	0.6	0.6	0.7	0.7	0.8	0.9	0.9	0.9	0.6	0.9	0.8	0.5	0.5
TR ₁₀₁₀	0.4	0.5	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.8	0.9	1.1	1.0	0.9	0.9	0.8	0.3	0.3
TR ₁₁₀₀	0.3	0.5	0.6	0.6	0.6	0.6	0.7	0.8	0.8	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.5	0.5
TR ₁₀₀₀	0.4	0.5	0.5	0.6	0.6	0.6	0.6	0.7	0.7	0.8	0.9	0.9	0.7	0.9	0.9	0.7	0.4	0.4
Mean	0.4	0.5	0.6	0.6	0.6	0.7	0.7	0.8	0.8	0.9	1.0	1.0	0.9	0.9	0.9	0.8	0.5	0.5
SD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.0	0.0	0.1	0.1
CV%	5.2	9.8	8.1	8.0	7.3	16.2	13.5	16.1	13.8	18.8	9.0	16.8	9.5	20.3	10.1	17.6	9.5	27.2

2005 seasons, respectively, while the coefficient of variability ranged from 4.4 to 31 % and 5.2 to 27.2 % in 2004 and 2005 seasons, respectively. The K_c attained peak in the early weeks of the grain filling growth stage, while the K_c' attained peak in the last weeks of the flowering growth stage. The implication of these trends is that applying deficit irrigation at any growth stage of the maize crop causes crop coefficient to peak early (at flowering growth stage), while the crop coefficient of the maize crop attains peak at grain filling stage (milk to soft dough stage) when the crop is fully irrigated in all the growth stages.

The peak K_c of the fully irrigated treatment, which were 1.14 and 1.15 in 2004 and 2005 seasons, respectively, came very close to K_c values reported in literature for maize crop: Allen et al. (1998) quoted 1.15 and 1.20 for sweet corn and field grain corn, respectively; Sharma (2006) quoted 1.23 and Zhao and Nan (2007) quoted 1.30 for maize in Karnal, India and North-western China, respectively. The average K_c values (average of the growth periods and the two seasons) for the establishment, vegetative, flowering and grain filling stages were 0.53, 0.82, 1.10, and 1.06, respectively, while the average K_c value at physiological maturity was 0.74. Classifying the K_c values into $K_{c(\text{initial})}$ for establishment growth stage, $K_{c(\text{mid})}$ for the flowering to grain filling stage, and $K_{c(\text{end})}$ for physiological maturity/harvesting in accordance with Allen et al. (1998) gave $K_{c(\text{initial})}$ as 0.53, $K_{c(\text{mid})}$ as 1.12, and $K_{c(\text{end})}$ as 0.73. The $K_{c(\text{mid})}$ was from 79 to 101 days after planting. These values are close to those given by Allen et al. (1998) for maize which were 0.3-0.5 as $K_{c(\text{initial})}$, 1.15-1.20 as $K_{c(\text{mid})}$ and 0.35-0.65 as $K_{c(\text{end})}$. As noted by Allen et al. (1998), $K_{c(\text{initial})}$ is very much dependent on frequency of irrigation and soil type, while $K_{c(\text{end})}$ is dependent on whether the maize is harvested green or left to dry on the field. The $K_{c(\text{end})}$ in this study was however much higher than that of Allen et al. (1998) range. The reason for this is not quite clear; perhaps the length of time the crop was allowed to dry before harvesting (four weeks after attainment of physiological maturity) was not long enough compared to the length of time Allen *et al* envisaged.

For the treatments subjected to deficit irrigation in two or more successive growth stages, it was noticed that the peak K_c' did not exceed 1.00. This was because the peak crop water uses of those treatments were below atmospheric water demand (reference evapotranspiration). This can be associated with the moisture stress caused by the deficit irrigation schedule. A comparison of the growth stages K_c and K_c' showed that the average crop coefficient of treatments where irrigation was skipped only at vegetative was about 17 % less than the fully irrigated treatment. The average crop coefficient of the treatment where irrigation was skipped only at flowering growth stage was 12.6 % less than that of the fully irrigated treatment, while that of the treatment where irrigation was skipped after every other irrigation at grain filling stage only was 14 % less than the crop coefficients of the fully irrigated treatment. When irrigation was skipped after every other week in two successive growth stages, the crop coefficients of such treatments were far more less.

For example, the average K_c' of the treatment where irrigation was skipped at vegetative and flowering growth stages (TR_{1001}) and at flowering and grain filling stages (TR_{1100}) were found to be 24 % and 30 % less than K_c , respectively. Treatment in which irrigation was skipped at three successive growth stages (TR_{1000}) had its average K_c' reduced by 30 % at the end of the grain filling stage. The reasons for these reductions are not far fetch. Delaying or skipping irrigation reduces moisture available in the soil for crop uptake. Thus evapotranspiration for such period is lower compared to atmospheric evaporative demand; hence the drop in crop coefficient values. The K_c' (end) of the treatments where irrigation was skipped in two or more successive growth stages were about 40 % less than that of the K_c . This may not be far from the fact that plant leaves senesces and eventual drying up of biomass took place faster in the treatments compared to the fully irrigated treatment. The results of this study infer that when irrigation is withheld at any growth stage, the crop coefficient of the maize crop will fall between 17 % and 30 % below that which will be obtained under full irrigation condition. Withholding irrigation in two or more successive growth stages drastically reduces crop coefficient values to about 40 %.

The average water stress coefficients (K_s) of the four growth stages for 2004 and 2005 seasons are shown in Tables 8 and 9, respectively. The K_s at crop establishment growth stage were approximately 1.00 since no deficit irrigation was imposed at that stage. The K_s were also found to be about 1.00 (= 0.90) in all the other growth stages where deficit irrigation were not imposed. It was however noticed that in Treatment TR_{1001} , even when deficit irrigation was not imposed at grain filling growth stage, K_s values of 0.80 and 0.81 were recorded in 2004 and 2005 seasons. This may be due to the fact that water applied after the deficit was withdrawn was not sufficient to raise the soil moisture content to field capacity. Therefore, water stress effect was still noticed. The water stress coefficient values was noticed to range from 0.74 to 0.83 where deficit irrigation was imposed in one growth stage only and from 0.68 to 0.77 when the deficits were imposed in more than one growth stages.

Table 8: Water stress coefficient (K_s) for the four growth stages observed in 2004 season

Treatment	Growth stages			
	Establishment	Vegetative	Flowering	Grain filling
TR_{1111}	1.00	1.00	1.00	1.00
TR_{1011}	1.00	0.78	0.92	0.97
TR_{1101}	1.00	1.00	0.80	0.96
TR_{1110}	1.00	1.00	0.94	0.74
TR_{1001}	1.00	0.77	0.74	0.88
TR_{1010}	1.00	0.76	0.93	0.75
TR_{1100}	1.00	0.99	0.75	0.70
TR_{1000}	1.00	0.76	0.65	0.68

Table 9: Water stress coefficient (Ks) for the four growth stages observed in 2005 season

Treatment	Growth stages			
	Establishment	Vegetative	Flowering	Grain filling
TR ₁₁₁₁	1.00	1.00	1.00	1.00
TR ₁₀₁₁	1.00	0.83	0.98	0.96
TR ₁₁₀₁	1.00	0.93	0.83	0.94
TR ₁₁₁₀	1.00	0.95	0.98	0.82
TR ₁₀₀₁	1.00	0.78	0.75	0.81
TR ₁₀₁₀	1.00	0.79	0.90	0.74
TR ₁₁₀₀	1.00	0.98	0.77	0.71
TR ₁₀₀₀	1.00	0.74	0.76	0.74

4.0 CONCLUSION

This study presented crop coefficient values for the TMV1-ST maize variety cultivated under deficit irrigation scheduling in Mkoji sub-catchment of Rufiji river Basin in Tanzania in 2004 and 2005 irrigation seasons. The crop coefficient for the two seasons showed similar trend and very close values were observed at different growth stages, which make them consistent with seasons of cultivation, and thus reliable. Withholding regular irrigation at any crop growth stage reduces crop coefficient by between 17 to 30 %, while withholding regular irrigation at two or more successive growth stages of the maize crop reduces crop coefficient by about 40 % and the peak crop coefficient ($K_{c\ mid}$) will not exceed 1.0. The water stress coefficient (Ks) resulting from deficit irrigation at any one growth stage only of the maize crop will be between 0.74 to 0.83, while deficit irrigation at two or more successive growth stages will be between 0.68 to 0.77. The crop and water stress coefficients developed from this study could be used in irrigation systems planning and design for the study area in Tanzania and other areas with similar soil and climatic conditions.

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