Journal of Agriculture and Ecology Research International
10(3): 1-16, 2017; Article no.JAERI.29611
ISSN: 2394-1073

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Effects of Coir Dust Mulch on Evapotranspiration of PH4 Maize in Coastal Region of Kenya

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Authors' contributions

This work was carried out in collaboration between all authors. Authors SMM and AMK wrote the protocol, designed, carried out the study in the field, collected the data and besides wrote the first draft of the manuscript. Authors AMK and WN assisted in statistical analysis, proof reading and literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JAERI/2017/29611
Editor(s):
(1) Petropoulos Spyridon, Department of Agriculture Crop Production and Rural Environment, University of Thessaly, Greece.
Reviewers:
(1) Hongchang Hu, Tsinghua University, China.
(2) Xin Lv, Shihezi University, Xinjiang, China.
(3) Gerson Araujo de Medeiros, Sao Paulo State University, Brazil.
Complete Peer review History: http://www.sciencedomain.org/review-history/17731

Original Research Article

Received 20th September 2016
Accepted 7th January 2017
Published 6th February 2017

ABSTRACT

Although the Coastal region of Kenya is awash with abundance of moisture bearing South Easterly monsoons, (and therefore tropical rainfall) from the adjacent vast Indian Ocean, heat stress, high velocity wind regimes are major factors limiting crop productivity in the region. Occurrence of these abiotic factors tend to occasion cloud free conditions, high atmospheric demand and vapor pressure deficit that results in increased soil moisture deficit, which more often coincides with critical stages of maize growth resulting in poor maize yields. A 2x3 randomized complete block design experiment was set in 2007 and 2008 seasons at Pwani university farm using PH4 maize variety and coir dust mulch treatments at two levels, with and without mulch, to evaluate effects of coir dust mulch in ameliorating the effects of high temperatures and high velocity wind regimes on soil moisture status. The results showed that PH4 maize evapotranspired at an average rate of

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157.5 mm and 151.3 mm per phasic growth stage in non-mulched and coir mulched maize crops, respectively during the relatively wetter season I; and by 156.3 mm and 151.0 mm in non-mulched and coir mulched maize crops, respectively during the relatively drier season II. Coir mulching reduced the average rates of water use per phasic growth stage by 3.9% and 3.4% during the relatively wetter and drier seasons I and II, respectively. The results showed that during the relatively wetter season I, between 534-549.6 mm of soil moisture had to be expended as basal evaporation before any tangible dry matter yields could be obtained, while during the relatively drier season, 167.7-190.1 mm had to be expended. This basal evaporation values represented 48.2% and 17.0% of long rain's total precipitation during seasons' I and II, respectively, indicating that much of the received precipitation was not effectively used for grain production, but mainly lost as non-productive component of seasonal evapotranspiration. The results also indicated coir mulching resulted in decreased seasonal evapotranspiration but significantly increased conserved 100 cm-profile soil moisture early in the season, when compared to non-mulched control treatments. This conserved moisture was available later in the season for increased dry matter and grain yields. Coir mulching increased WUE by 8.4%. The study showed that adoption of a simple agronomic practice of applying a 10 cm thick layer of coir dust mulch could increase maize productivity by 10.4% and help improve livelihoods of people in Coastal region.

Keywords: Coir mulch; evapotranspiration; Pwani hybrid; maize yields; coastal Kenya.

1. INTRODUCTION

The Coastal region of Kenya is known to have enormous agricultural arable land potential due to its proximity to the Western Indian Ocean, with the coastal strip receiving an annual average rainfall of about 1100 mm (Fig. 1). However, due to its location in lowland tropics, the region experiences high ambient temperatures and high velocity wind regimes, in particular, the East African low level jet winds, locally known as the June winds that reduce the effective rainfall through excessive evapotranspiration [1]. These June winds tend to re-visit the region annually and their occurrence more often tends to coincide with critical stages of maize growth, namely, floral to grain-set/filling stages, resulting in poor yields. This has rendered the region to be perennially food deficit, and therefore highly dependent on food relief.

Occurrence of June winds is known to result in subsidence that causes reduced rainfall probability, cloud free conditions and increased evaporative demand, which consequently results in drastic decline in profile soil moisture and increased soil moisture deficit especially during critical stages of maize growth [2]. Occurrence of moisture deficit during critical stages results in poor pollen grain formation, poor stigma receptivity to pollen grains, delayed silk formation and asynchrony, resulting in poor grain set [3].

Heat stress is known to be a major limiting factor to plant productivity [4]. The region's high ambient temperatures coupled with cloud free conditions results in increased atmospheric demand and high vapor pressure deficit (VPD) that results in high transpiration rates which cannot be met by plant transpiration pull [5]. This ultimately results in reduced rates of transpiration and therefore increased leaf temperatures which lead to stomatal closure and therefore reduced CO_2 assimilation. This in turn results in midday photosynthetic decline and therefore low yields [4].

Increased soil temperatures are known to result in increased rates of evaporation from the soil surface which limits available soil moisture for plant growth. Occurrence of June winds increases turbulence and further enhances loss of soil moisture through evaporation. This study was therefore conceived to evaluate the effects of coir dust mulch on evapotranspiration and yields of PH4 maize in coastal region of Kenya.

2. MATERIALS AND METHODS

2.1 The Site

A field experiment was set up at Pwani University Crop Science farm located 39.85° E and 3.62°S in Kilifi County during the 2007 and 2008 long rain seasons (Fig. 1). The field was under natural fallow for two years. The experimental period for each year ranged from, 26th April to 3rd August. Average maximum and minimum temperatures ranged 28-30°C, and 20-23°C respectively, while annual rainfall averaged 1100 mm. Soils were mainly sandy loam with pockets of clay loam, with an average pH of 5.5, but poor in organic matter [6,7,8].

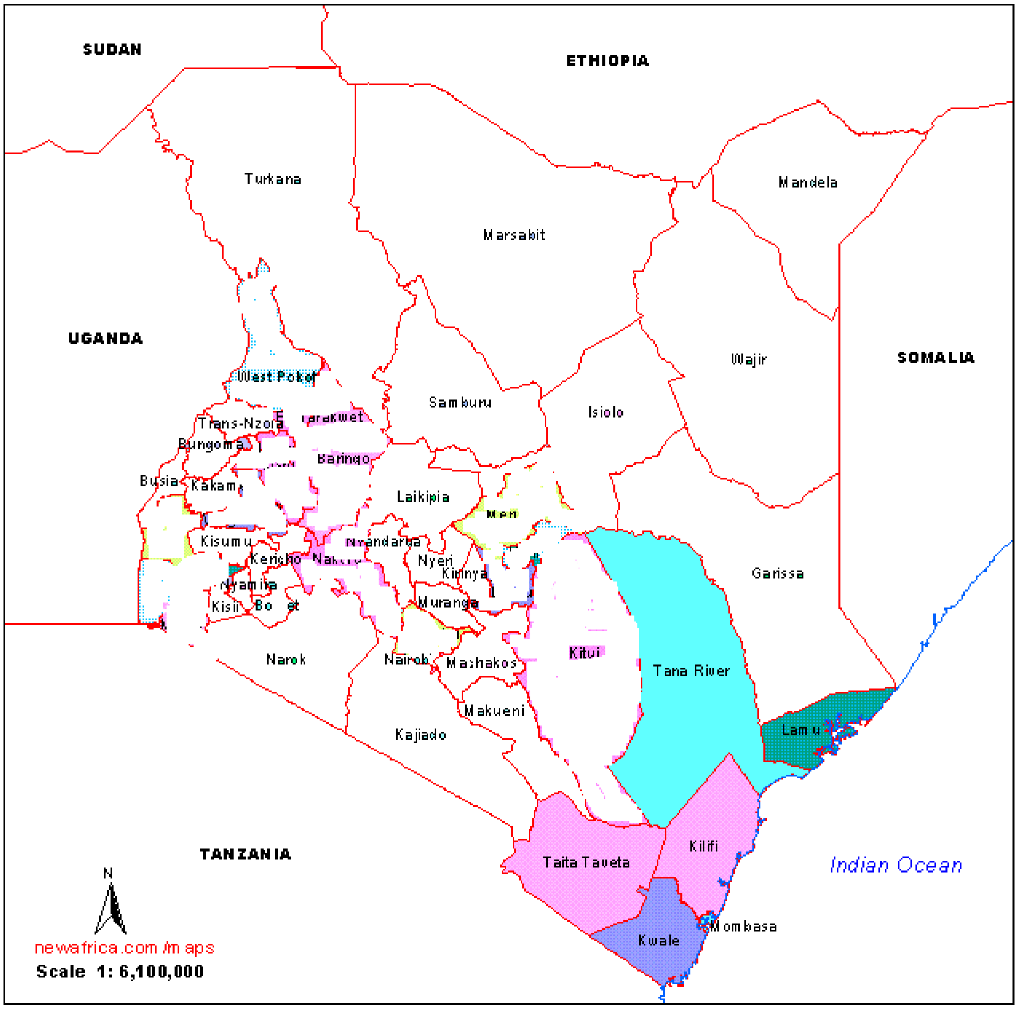

Fig. 1. Administrative map of Kenya, showing Coastal region of Kenya, the study area (shaded)
(Source: new Africa.com)

2.2 Materials

Pwani hybrid 4 maize, is a commercial maize variety and was obtained from local stockiest and planted in all experimental plots. It was of medium maturity period of 120 days and yield potential of 4.5 to 6.5 tons ha^{-1}. It had a tendency to give 2 cobs per plant in optimal conditions, and of good grain filling characteristics [8].

Kaolin powder was sourced from local stockiest, in packages of 100 gm tins, and was prepared to a suspension of 6% concentration by mixing 60 gm in a litre of clean water.

Coir mulch dust, a waste by-product of coconut industry, (obtained after de-husking the coconut fruit), was sourced from Cocos factory in Kilifi, who shred it into course and fine fiber. It is locally and readily available in coastal region of Kenya. It has low bulk density, and spongy. It is mainly used in making mattress, door-matts and is also used as a potting media in the horticulture industry.

Metered tap water was used for irrigated treatments (as supplementary irrigation), and was applied from 17:00 hours to 08:00 hours (to reduce losses due to hot sun) using KARI drip kit system, with emitters at every 0.3 m along the row, when the soil moisture in the plots receiving irrigation treatments fell below 75% field capacity. The amount of applied water (I, in equations 2-4) was determined from the difference in meter readings at start and end of the irrigation period.

2.3 Experimental Plot Layout and Design

A randomized complete block design experiment replicated three times, with plot sizes of 6 m by 4 m, and planted with PH4 maize at a spacing of 0.75 m by 0.3 m, two seeds per hill was set up during the start of long rains, towards end of April in 2007 and 2008 seasons. Thinning was done at 15 days after sowing to ensure one plant per hill to attain a plant population of 44,444 plants per ha. 108.7 kg of Di-ammonium phosphate (DAP) was used as basal fertilizer to supply 50 kg P_2O_5 ha^{-1} while 102.8 kg of Calcium ammonium nitrate (CAN) was used as top dress fertilizer to supply 55 kg N ha^{-1}. The plots were maintained weed free by manual rouging of any emerging weeds.

2.4 Treatments

Coir dust mulch was used at a rate of 7 tons ha^{-1} and was applied at 2 levels, namely, with mulch (M1) and without mulch (M0). For the plots receiving coir mulch treatment, a layer of 0.1 m coir dust mulch was applied by spreading the coir material within and between the plant rows, 7 days after germination.

The soil moisture treatment was at two levels; rain-fed, as W0; and irrigated treatments as W1, where metered supplementary irrigation was applied when the soil moisture content in the treatment plots fell below 75% saturation (or 37.5 mm ha^{-1}) using KARI drip kit system, with emitters at every 0.3 m along the row. Rainfall was measured using rain gauge at Institution's portable compact weather station.

Summary of treatments: M0 = No mulching; M1= Coir mulched; W0= rainfed; W1= irrigated treatments.

2.5 Sampling and Data Collection

The soil moisture content at 0-15 cm depth was measured by gravimetric method as, per the equation given by [9]:

$$SWC\% = 100(SFW - SDW)/SDW \quad (1)$$

Where SFW and SDW were fresh and dry weight (in grams) of soil samples, respectively.

Beyond 20 cm depth, the soil moisture content was measured using neutron probe as described by [10], up to a depth of 100 cm, at intervals of 20 cm, and at 31, 49, 66, 83 and at 100 DAS. The neutron probe was first calibrated in situ using undisturbed core samples. Thereafter, it was inserted in pre-drilled holes in which PVC pipes, as access tubes were inserted to respective depths and counter readings taken.

Evapotranspiration was determined using water balance equation as described by [11], where change in available soil water content was related to evapotranspiration using the equations:-

$$\Delta S = (P + I + C) - (R + D + E + T) \quad (2)$$

I.e Change in soil moisture storage =Gains-Losses. Since E + T = ETc, then

$$ETc = I + P + C - D - R - \Delta S \quad (3)$$

Where ETc = actual evapotranspiration; ΔS = change in soil moisture content of the root zone, P = rainfall; I = irrigation input, R = run off from the field, D = downward drainage out of the root zone, E = evaporation from the soil, T = transpiration from plant canopy, C = capillary contribution from the water table. Given the flat nature of the terrain and sandy loam soils in the study area, run-off, deep drainage and capillarity contribution in equation 3 were considered to be negligible, resulting in Equation 4,

$$ETc = I + P - \Delta S \quad (4)$$

Temperature and % relative humidity were obtained from the University's portable weather station. Potential evaporation (ETo) was determined from collected data on daily maximum and minimum temperatures and % relative humidity and computed using ET software calculator.

2.6 Data Analysis

The collected data was analyzed using Genstat Discovery 4th Edition. The generated ANOVA tables of means, for 100 cm depth soil moisture, crop evapotranspiration and PH 4 maize dry matter and grain yields were separated and compared using Fisher's least significant difference (LSD) and Duncan's multiple range test.

3. RESULTS

3.1 Rainfall and Potential Evaporation Characteristics during Seasons I and II

Analysis of amounts of rainfall received during the study period indicated that the 2008 long rains season (season II) received 11% lower rainfall than the 2007 long rains season (season I) (Table 1). The 2007 long rain's season received 1107.5 mm of rainfall (or 71.2%), against the year's annual total rainfall of 1556.0 mm, while for the same period, the 2008 long rain's season received 987.5 mm (or 77.0%) against the year's annual total of 1283 mm (Table 1). Although season II long rains were lower by 11% the rainfall distribution was slightly better than in season I where over 57.8% of the season's long rains precipitation was received in May alone, and over 30% fell in three days (Table 1).

A look at the seasons' monthly rainfall and mean potential evaporation values in the region shows that in a whole year, only two months experienced positive moisture regime for crop growth, namely April and May, which fell within the long rains season (Table 1). In all other months, the potential evaporation exceeded received rainfall, implying deficit soil moisture situation for most of the year.

3.2 Effects of Coir Dust Mulch on Evapotranspiration of PH4 Maize

The results shows that during the relatively wetter and drier seasons I and II, seasonal evapotranspiration in coir mulched and non-mulched PH4 maize crops increased almost linearly as the maize crop advanced in age, from low initial values at the start of the season, to highest values at the end of the seasons, as described by the production functions shown in Fig. 2. The PH4 maize seasonal evapotranspiration increased at an average rate of 157.5 mm and 151.3 mm per phasic growth stage during the relatively wetter season I and by 156.3 mm and 151.0 mm during the relatively drier season II, in non-mulched and coir mulched maize crops, respectively (Fig. 2). The average rates of seasonal evapotranspiration per phasic growth stage during the relatively wetter and drier seasons I and II, were comparatively similar (Fig. 2). In coir mulched maize crop (Fig. 3), the average rates of seasonal evapotranspiration per phasic growth stage were lower than in non-mulched maize crop by 3.9% during the relatively wetter season I, and 3.4% lower during the relatively drier season II.

These average rates of seasonal evapotranspiration per phasic growth stage translated to daily rates of evapotranspiration that ranged from 4.9 mm early in the season to 9.3 mm day^{-1} (Table 2). The results indicate that during early stages of growth at 0-31 DAS, the daily rates of evapotranspiration were similar for same treatments, during the relatively wetter and drier seasons I and II, at 4.9 mm day^{-1} under coir mulched maize crops, and 5.0 mm day^{-1} under non-mulched conditions (Table 2). However, as the maize crop advanced in age, the daily rates of evapotranspiration increased towards a peak plateau at 49 DAS. In both seasons, the non-mulched maize crops displayed higher rates of evapotranspiration than coir mulched maize crop for similar stages of growth. Coir mulching resulted in reduced daily rates of evapotranspiration of about 4.3% during the relatively wetter season I, and 3.3% during the drier season II (Table 2). However, coir mulched maize crop displayed similar values of evapotranspiration rates for similar stages of maize growth during the wetter and drier seasons I and II (Table 2). By the 31st day after sowing (DAS) during the relatively wetter season I, about 534.2 mm and 549.6 mm of soil moisture were evapotranspired in coir mulched and non-mulched maize crops, respectively, while for the same period during the relatively drier season II, 167.7 mm and 190.1 mm of soil moisture were evapotranspired in coir mulched and non-mulched maize crops, respectively (Fig. 2).

At various stages of growth the relatively wetter season I had mean seasonal evapotranspiration values that were 55.0%; 42.8%; 33.5%; 30.8% and 29.4% higher than the relatively drier season II at phyto-periods 0-31; 31-49; 49-66; 66-83 and 83-100 DAS, respectively (Table 3).

In both seasons, significant differences in seasonal evapotranspiration between coir mulched and non-mulched maize crops, were only notable early in the season at 0-31 DAS phasic stage of maize growth. Thus, during the relatively wetter season I, coir mulched maize crop evapotranspired 675.4 mm of water that was significantly higher by 2% compared to non-mulched maize crop with 661.5 mm. However, during the relatively drier season II, coir mulched maize crop evapotranspired a significant 291.4 mm of water that was 6.2% lower than that evapotranspired by non-mulched maize crop with 310.8 mm, at 0-31 DAS period (Table 3).

Table 1. Monthly rainfall, potential evaporation and net moisture regime during study period, in seasons I (2007) and II (2008) in Kilifi (in mm)

Season	2007				2008			
	Rainfall	% of L/Rain's rainfall	Potential evaporation	Net moisture regime	Rainfall	% of L/Rain's rainfall	potential evaporation	Net moisture regime
Month								
January	1.5	0.1	210	-208.5	28.5	2.9	220.5	-192
February	0.5	0	197	-196.5	2	0.2	216.85	-214.85
March	15.5	1.4	215	-199.5	127	12.9	230.8	-103.8
April	184	16.6	186	-2	74	7.5	195.3	-121.3
May	640.5	57.8	171	**469.5**	463.5	46.9	179.55	**283.95**
June	198	17.9	156	**42**	188	19	150.6	**37.4**
July	67.5	6.1	156	-88.5	104.5	10.6	163.8	-59.3
L/R Totals	1107.5	100	1291	-183.5	987.5	100	1357.4	-369.9
August	148		175	-27	50.5		190	-139.5
September	121.5		191	-69.5	43		205.4	-162.4
October	60.5		202	-141.5	34		212.1	-178.1
November	25		195	-170	160		204.75	-44.75
December	93.5		205	-111.5	8		215.25	-207.25
Year totals	1556		2259	-703	1283		3742.3	-2459.3

Table 2. Daily rates of seasonal evapotranspiration of PH4 maize in Kilifi, Kenya

Stages of maize growth in DAS	Daily rates of evapotranspiration in mm			
	Season I		Season II	
	Coir mulched maize crop	Non-mulched maize crop	Coir mulched maize crop	Non-mulched maize crop
0-31	4.9	5.1	4.9	5
31-49	8.9	8.8	8.9	9.2
49-66	8.9	9.3	8.9	9.2
66-83	8.9	9.3	8.9	9.2
83-100	8.9	9.3	8.9	9.2

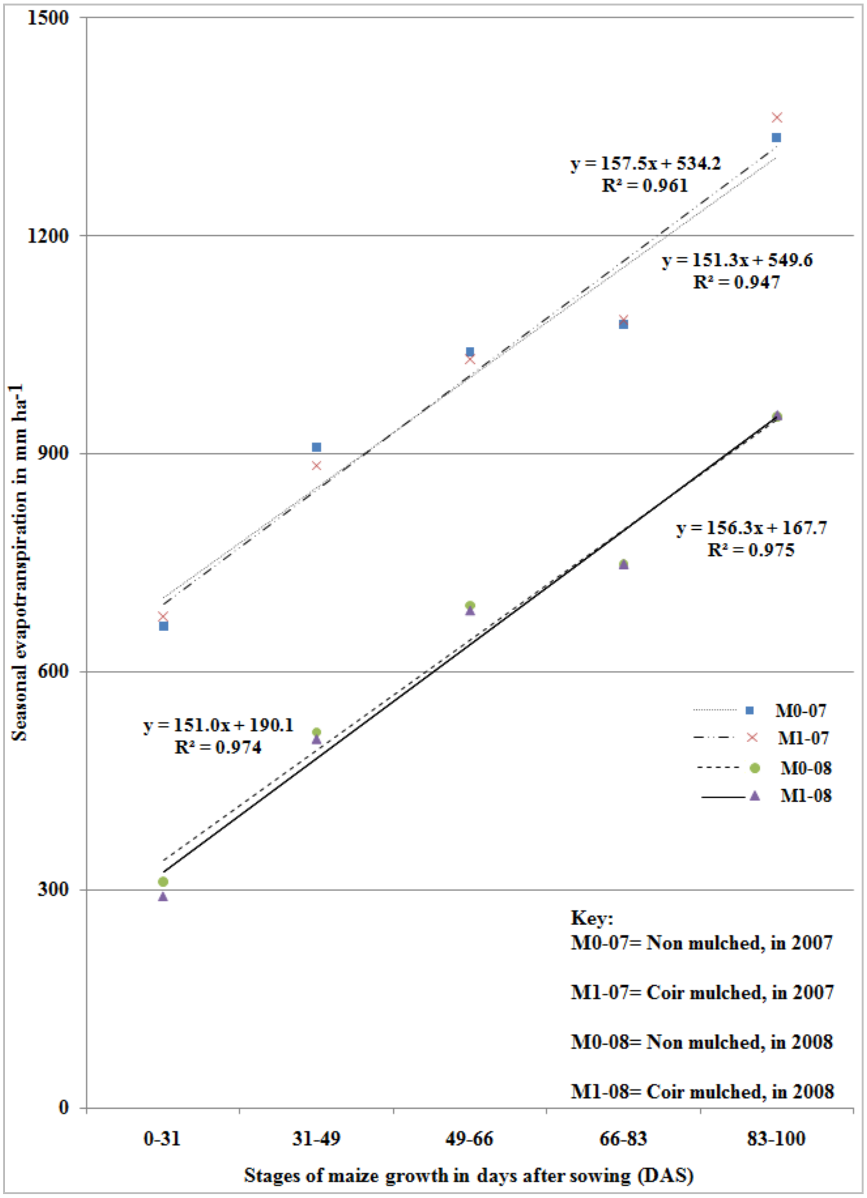

Fig. 2. Effects of coir dust mulch on seasonal evapotranspiration of PH 4 maize during the relatively wetter and drier seasons I and II, in Kilifi

Although there were no significant differences in seasonal evapotranspiration beyond 31 DAS, the coir mulched maize crop in both seasons maintained relatively lower levels of seasonal evaporation, but significantly higher levels of conserved soil moisture between the growth periods 31- 49 and 49 – 66 DAS.

Thus, non-mulched maize crop lost more (but insignificant) soil water than coir mulched maize crops during these phasic growth periods (Table 3). However, at later stages of growth, between phasic growth stages 66-83 DAS and 83-100 DAS, the coir mulched (M1W0) maize crop maintained relatively higher levels of seasonal evaporation, having a 2.1% higher seasonal evapotranspiration than non-mulched maize crop and attaining the highest final water use of 1362.7 mm in season I and 952.9 mm in season II, and highest grain yields (Table 3). The maize crop in non-mulched control (M0W0 treatment) evapotranspired a final 1333.5 mm and 950.8 mm of water during seasons I and II respectively.

A look a periodic evapotranspiration values at various phasic stages of maize growth indicated that during the relatively wetter season I, coir mulching resulted in significantly higher levels of periodic evapotranspiration that were 2.1%; 10.5%; 29.7% and 7.9% higher than non-mulched maize crop, at 0-31; 49-66; 66-83 and 83-100 DAS, except at 31-49 where the non-mulched maize crop evapotranspired 18.2% more water (Table 3).

Fig. 3. Coir mulched maize crop, during season I (2007) in Kilifi

The results also showed that at the periods when coir mulched maize crop appeared to have reduced water use levels (at 31-49 and 49-66 DAS), the 100 cm-depth soil moisture appeared to be significantly high (Table 3). Thus, the coir mulched treatments maintained significantly higher 100 cm - depth soil moisture that were 10.6%; 6.8%; 12.1% and 17.9% more than those of non-mulched treatments at 31-49; 49-66; 66-88 and 83-100 DAS. These levels of soil moisture were however observed to decline as the maize crop advanced in maturity (Table 3 and Figs. 4 and 5).

A scrutiny of water use at successive stages of maize growth revealed that between the period 49-66 DAS and 66-83 DAS, there was a drastic decline in the amounts of evapotranspired water in both seasons (Figs. 2, 4 and 5). This coincided with decline in 100 cm depth soil moisture to lowest values of 29.0 mm in non-mulched maize crop, and 34.2 mm in coir mulched maize crop (Table 3 and Figs. 3 and 4).

Although the 11% higher rainfall of season I resulted in an average increase in seasonal evapotranspiration of 38.3%, it occasioned 13.7% increase in PH4 maize grain yields averaging 5.1tons ha^{-1} compared to season II where 4.4 tons ha^{-1} of grain were obtained (Table 4). Coir mulching in season I resulted in increase in grain yields of 9.4%, and 4.4% during season II (Table 4). During the relatively drier season II WUE was 24.3% higher than during the wetter season I. Coir mulching during season I increased water use efficiency (WUE) by 8.1% and by 4.4% during the drier season II.

Towards end of the season, coir mulched maize appeared to senesce much earlier than non-mulched maize crop that retained their green coloration long after attainment of physiological maturity (Fig. 6). A look at the final roots of the coir mulched maize crop at the end of the season showed that bulk of the rooting system was concentrated in the upper soil surface at interface with coir material, forming a root ball matt. However the roots of the non-mulched maize crop appeared singly and extending into deeper layers of the soil profile (Fig. 7).

4. DISCUSSION

The results have indicated that the long rains received in 2007 were higher by 11% than those received in 2008. This pattern of long rains rainfall is in line with the trend of rainfall in the region reported by [1] where (considering the amounts of long rains alone, rather than total rainfall) a year of higher rainfall is followed by a year of lower rainfall. This therefore re-affirms similar observation that the region’s long rains (falling in March-July period) are under constant modulation by the Quasi-Biennial Oscillation (QBO), a global weather phenomena related to the larger El Nino-Lanina (ENSO) activities [12,13,14].

Since the amount of rainfall and therefore soil moisture determines the amounts of evapotranspiration, water use and yields by the maize plants, it follows that years of higher rainfall have higher levels of evapotranspiration and therefore yields, since the amounts of evapotranspired water is parabolically related to accumulated dry matter and consequently grain yields [15]. Similarly, years of lower rainfall tend to have lower levels of evapotranspiration and therefore low yields. Consequently the levels of maize grain yields in the region resonate in response to Quasi-Biennial Oscillation signals received in the region [14]. This has implications in planning for agricultural resource use in the region, especially for annual crop farming, and makes it possible to predict and forecast expected maize yield in the region.

Table 3. Effects of coir mulch treatments on periodic, seasonal evapotranspiration and profile soil moisture of PH 4 maize in seasons I and II in Kilifi

Seasons	Season I (Apr 26th – 3rd Aug 2007)						Season II (Apr 26th – 3rd Aug 2008)					
DAS	**0**	**0-31**	**31-49**	**49-66**	**66-83**	**83-100**	**0**	**0-31**	**31-49**	**49-66**	**66-83**	**83-100**
Treatments												
Coir mulch	**Periodic Evapotranspiration (in mm)**											
M0		661.5b	246.1a	130.9a	38.5b	256.5b		310.8a	206a	174.2a	56.6a	203.2a
M1		675.4a	207.7b	146.2a	54.8a	278.6a		291.4b	216.1a	176.8a	63.7a	204.9a
Mean		668.5	226.9	138.6	46.7	267.6		301.1	211.1	175.5	60.2	204.1
Lsd (5%)		4.8	24.2	23.9	5.2	8.6		3.5	16.3	2.0	18.7	1.4
Sed		1.1	5.6	5.6	1.2	2.0		0.8	3.8	0.5	4.3	0.3
	Seasonal evapotranspiration (in mm)											
M0		661.5b	907.6	1038.5	1077	1333.5		310.8a	516.8	691	747.6	950.8
M1		675.4a	883.1	1029.3	1084.1	1362.7		291.4b	507.5	684.3	748	952.9
Mean		668.5	895.4	1034	1080.7	1348.3		301.1	512.15	687.65	747.8	951.85
Lsd 5%		4.8	29	52.9	58.1	66.7		3.5	19.8	21.8	40.5	41.9
Sed		1.1	6.7	12.3	13.5	15.5		0.8	4.6	5.1	9.4	9.7
			NS	NS	NS	NS			NS	NS	NS	NS
	100 cm-depth moisture content (in mm)											
M0	326.2a	260.7a	249.0b	161.4b	225.2b	29.0b	119.7b	213.9b	131.4	128.8	126.3b	26.6
M1	328.0a	248.6b	275.4a	172.4a	252.5a	34.2a	121.6a	235.2a	142.6	137.5	128.0a	26.6
Mean	327.1	254.6	262.2	166.9	238.9	31.6	120.6	224.5	137.0	133.1	127.2	26.6
Lsd (5%)	2.52	3.94	14.87	6.73	8.02	0.02	0.79	2.62	15.12	15.37	1.33	0.02
Sed	0.586	0.915	3.460	1.560	1.860	0.005	0.183	0.609	3.514	3.572	0.310	0.004
	NS								NS	NS		NS

NB: Means followed by the same letter are not statistically significant at 5% level

Table 4. PH 4 maize grain yield, seasonal water use and WUE

Treatments	Season I			Season II		
	Grain yield (ton ha^{-1})	**Seasonal water use (mm ha^{-1})**	**Water use efficiency Kg $ha^{-1}mm^{-1}$)**	**Grain yield (ton ha^{-1})**	**Seasonal Water use (mm ha^{-1})**	**Water use efficiency (Kg $ha^{-1}mm^{-1}$)**
M0	4.8	1333.5	3.6	4.3	950.8	4.5
M1	5.3	1362.7	3.9	4.5	952.9	4.7
Mean	5.1	1348.1	3.7	4.4	951.9	4.6
Lsd (5%)	0.76	66.7		0.32	41.9	
Sed	0.37	15.5			9.7	

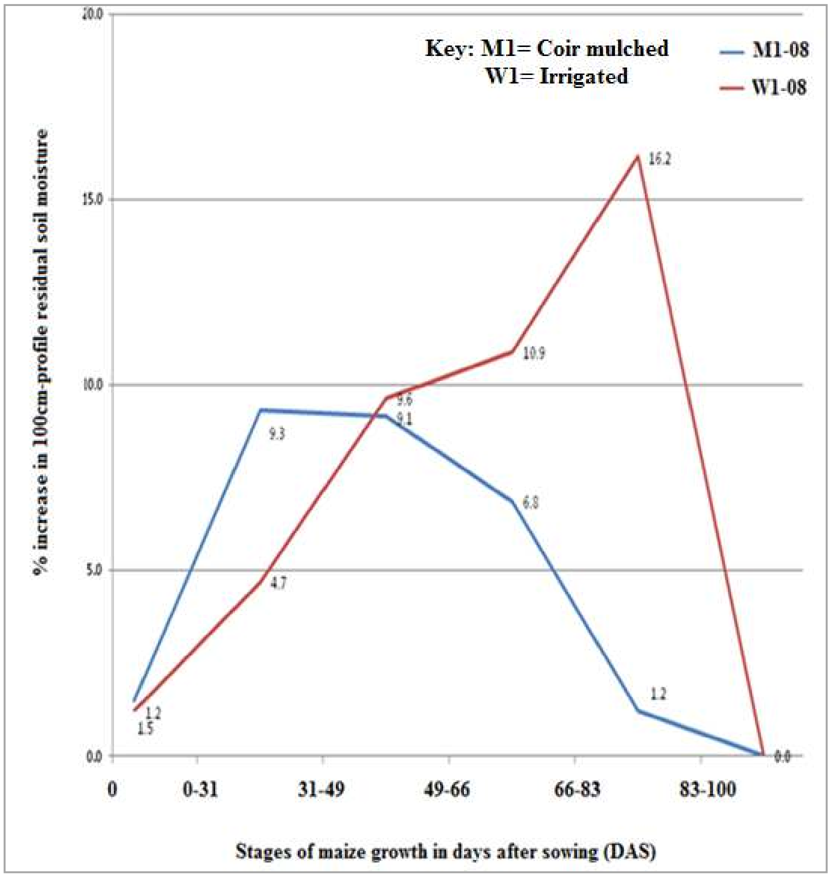

Fig. 4. Complementary relationship between coir mulched and irrigation treatments on 100 cm-profile soil moisture due to PH4 maize growth during the relatively drier season II

The results also revealed that for most part of the year, potential evaporation exceeded received rainfall, and that only two months, namely April and May, experienced positive moisture regimes. This implies deficit soil moisture situation for crop growth and therefore reflects a constraint in crop production and therefore food security in the region especially when the critical stages of maize growth fall outside this window (Table 1). This to some extend could explain why the short rains that occur between September to December are rarely used for annual crops production since potential evaporation far exceeds received rainfall [6]. This revelation suggests that supplementary irrigation can strategically be planned to target critical stages of maize growth, namely floral stages, from booting stage through tasseling, silking to grain-set stages.

The study has shown that at least 534.2 mm and 167.7 mm of water has to be expended (evaporated) at the start of both seasons' I and II, respectively. This reflects basal evaporation, the amount of moisture that has to be evaporated to meet the high atmospheric demand in the region before any tangible maize yields can be obtained [16]. Given that the total amount of rainfall received during the long rains period (M arch-July) for the wetter season I (2007) was 1107.5 mm, this implies that by the 31st day after sowing, almost 50% of the received soil moisture evaporated before any tangible yields were formed, suggesting the need for moisture conservation early in the season, by using all available means including coir mulching.

During the relatively drier season II, 167.7 mm, representing 17.0% of the 987.5 mm received long rains precipitation was expended as basal evaporation. This basal seasonal evaporation was observed to be 65.4% - 68.6% lower than that of the relatively wetter season I. This shows that, the higher the amounts of rainfall received, or the wetter the year, the higher the levels of basal evaporation. This suggests that during relatively wetter seasons in Coastal region of Kenya, higher amounts of soil moisture are lost to the atmosphere (to meet the high atmospheric demand) before any substantial amounts of dry matter can be obtained, a phenomena attributed to low altitude of the region and therefore high ambient temperatures [13].

A scrutiny of the rainfall distribution during season I indicated that much of this basal evaporation (534.2 mm) was met from initial rainfall received early in the season during the months of March (15.5 mm) and April (184.0 mm), and the remainder 334.7 mm was met from the peak rainfall received in the month of May (640.5 mm) (Table 1). These loses left a total of only 571.3 mm of the received long rain's precipitation, being inflows from the months of May (305.8 mm); June (198.0 mm) and July (67.5 mm), to sustain the maize crop to maturity.

Therefore, these results suggests that despite the high amounts of rainfall received in the region, ranging from 900-1200 mm, much of this precipitation is not effectively used for grain production, but is mainly lost as non-productive component of seasonal evapotranspiration, namely, soil evaporation and evaporative cooling of the maize plants [17-19]. [19] observed that surface evaporation accounted for 25-50% of total evapotranspiration.

It can therefore be said that Kilifi County and much of the Coastal region of Kenya suffers from high levels of atmospheric demand occasioned by high ambient temperatures prevalent in the region, and occurrence of June winds, which reduces effective rainfall. This therefore limits the available soil moisture for crop growth and partly explains the poor grain yields in the region of 0.4-1.0 tons ha^{-1} [8]. This high basal evaporative demand is a major drawback to efficient crop production in Kilifi county and Coastal region at large. It limits the region's productivity potential and ability to attain maximum water use efficiencies since much of the soil moisture and over 48% of received rainfall is lost long before any substantial dry matter production can occur. Similar high values of basal evaporation have been reported by [16,20], whose values ranged from 216.0 mm to 418.0 mm.

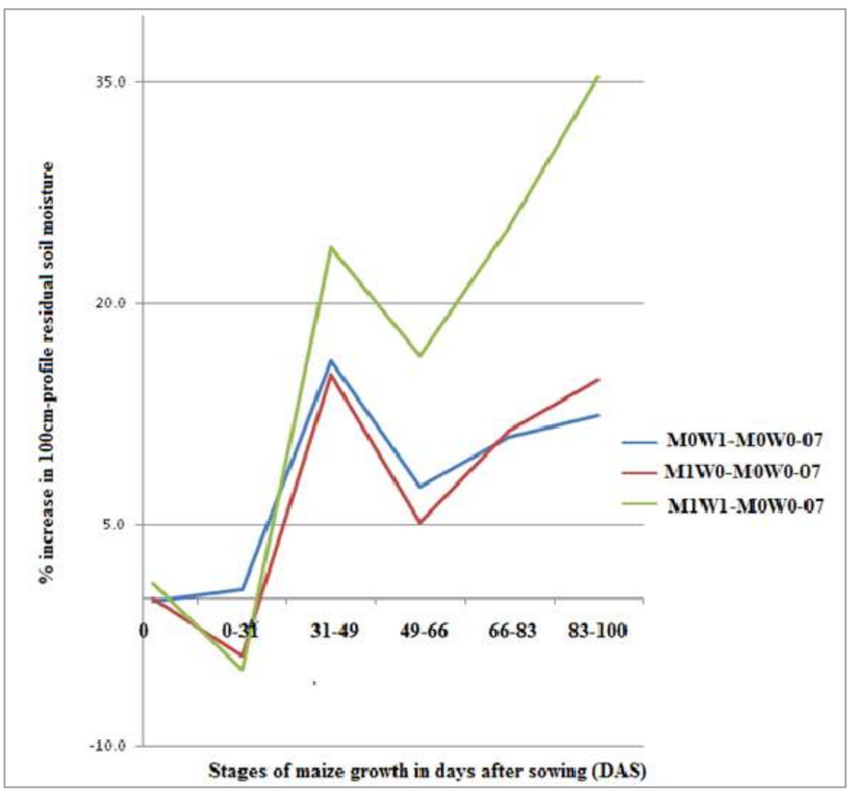

Fig. 5. Contributions to 100 cm-profile soil moisture by treatment combinations of coir mulch and irrigation over control treatment (M0W0) under PH4 maize during the relatively wetter season I. Note the depressions occasioned by occurrence of June winds at 49-66 DAS

Fig. 6. Coir mulched maize crop senesced mulch earlier than non-mulched and irrigated maize crop, with non-mulched and irrigated maize crop retaining their green coloration long after physiological maturity

Fig. 7. PH 4 maize roots in a) coir mulched treatments (formed root ball matt) and b) non-mulched treatments, showing plain elongated roots

Daniel and Yair [20] reported that there was a threshold seasonal evapotranspiration of 250–300 mm below which production was negligible and above which production increased linearly with the amount of applied water. [16] had observed that this threshold seasonal evapotranspiration was dependent on the amount of initial irrigation or available rainfall, with highest levels of irrigation or rainfall resulting in highest basal seasonal evaporation. These high basal seasonal evaporation values are a common characteristic in most wet and dry climates, and also in arid and semis arid regions. This partly explains the low levels of food production prevalent in Coastal region of Kenya despite the observed high annual rainfall [6].

During the growing period there was drastic decline in the amounts of evapotranspired water in both seasons between the period 49-66 DAS and 66-83 DAS. This decline was initiated by occurrence of high velocity June winds that resulted in reduced rainfall and increased atmospheric drought [2]. This in turn resulted in decline in profile soil moisture to lowest values. Figs. 4 and 5 shows that even application of irrigation could not stop decline in profile soil moisture occasioned by occurrence of June winds. However, irrigation moderated the degree and depth of decline in soil moisture levels.

Coir mulching was observed to moderate the levels of basal evaporation. Thus, during the relatively wetter season I, coir mulching resulted in 2.8 % lower basal evaporation than in non-mulched conditions. Thus, coir mulching early in the season resulted in 9.2 % higher levels of conserved soil moisture. During the relatively drier season II, coir mulching early in the season resulted in 11. 8 % more conserved soil moisture than under non-mulched conditions (Figs. 4 and 5). These observations are in line with those made by [19,21] who observed that although surface evaporation accounted for 25-50% of total evapotranspiration, mulching resulted in significant reductions in evaporation leading to higher levels of conserved soil moisture and grain yields (Tables 3 and 4).

During early stages of maize growth, the daily rates of seasonal evapotranspiration were quite low, at 5.1 mm $ha^{-1}day^{-1}$. This may have been attributed to the fact that the bulk of evaporation took place from the bare exposed soil surfaces since the maize crop was still young and much of the leaf canopy was not fully developed [3]. However, as the maize crop advanced in age, the bulk of the seasonal evapotranspiration was obtained from the expansive leaf canopy as it closed up, and the rates of water use increased to highest values of 8.9-9.1 mm $ha^{-1}day^{-1}$.

Use of coir mulch was able to reduce these high rates of daily water use by 4.3% (from 9.3 to 8.9 mm $ha^{-1}day^{-1}$) and by 3.3% (from 9.2 to 8.3 mm $ha^{-1}day^{-1}$) during the relatively wetter and drier seasons, respectively (Table 2). However, coir mulching reduced the high daily evapotranspiration rates to similar values in both seasons irrespective of whether it was a wetter or drier season, suggesting effectiveness of coir mulch in regulating soil moisture and temperature conditions. Thus, the simple practice of coir mulching can be an effective tool in conserving substantial amounts of soil moisture for increased grain production and maintaining relatively low soil temperatures in these hot climatic conditions of Coastal Kenya.

It can therefore be stated that as crops grow, the initial soil water loss is through evaporation, particularly when the leaf area does not cover the ground [3]. However as the leaf canopy (Leaf area index) and root mass increase with maturity, soil moisture extraction by the roots increase through the process of transpiration [17]. This explains why, beyond the 66-83 DAS phyto-phasic growth period, especially during the relatively drier season II, the maize grown in coir mulch benefited more from higher levels of conserved soil moisture than the non-mulched maize crop, accounting for the observed higher grain yields (Table 4).

The coir mulched maize crop in both seasons maintained relatively lower levels of seasonal evaporation, but significantly higher levels of conserved soil moisture between the growth periods 31-49 and 49-66 DAS. However, at later stages of growth, between phasic growth stages 66-83 DAS and 83-100 DAS, the coir mulched (M1W0) maize crop maintained relatively higher levels of seasonal evaporation, resulting in a 2.1% higher seasonal evapotranspiration than non-mulched maize crop and attaining the highest final water use of 1362.7 mm in season I and 952.9 mm in season II. This suggests that the reduced seasonal evapotranspiration noted early in the season at 31-49 and 49-66 DAS resulted in significantly higher levels of conserved soil moisture that was later available for crop growth and yield formation as exemplified by the increased water use noted at later stages of maize growth (Table 3). This is further collaborated by the fact that during the various phasic stages of maize growth during the relatively wetter season I, coir mulching resulted in significantly higher levels of periodic evapotranspiration than non-mulched maize crop (Table 3). This suggests that, during early part of the season, coir mulching helped by insulating the soil from excessive heating by solar radiation, and in the process reduced heating of the soil. This reduced soil heat load, thereby reducing rates of evaporation, an observation also reported by [19,21,22]. It can therefore be stated that coir mulching in Coastal Kenya results in favorable soil moisture relations.

Figs. 3 and 4.0 on % increases in 100 cm depth soil moisture due to coir mulching and irrigation treatments revealed that use of coir mulch during a relatively drier and wetter seasons resulted in increase in conserved soil moisture during early part of the growing season when rainfall was ample, of between 9.1% and 15.2%. However, this moisture levels declined during subsequent growth periods as the maize crop advanced in age for increased transpiration, nutrient uptake, assimilation and translocation of photosynthates. This ultimately resulted in the observed increases in grain yields of 9.4% and 4.4% during the relatively wetter and drier seasons' I and II, respectively.

That, coir mulching increased the amount of conserved soil moisture can be attested by the observation that during the phasic growth stages when coir mulched maize crop had declining water use, the 100 cm profile soil moisture was noted to be on the increase. This suggests that although coir mulching of maize crop resulted in low levels of water use between the period 49-66 DAS, it resulted in significantly higher amounts of conserved soil moisture, which was used by the maize plants during later stages of growth. This therefore resulted in the observed highest final water use of 1362.7 mm and highest grain yields of 5.3 tons ha^{-1}.

The observations in this study are in agreement with similar studies by [21,23-26]. [22] reported that mulching lowered soil temperatures, reduced evaporation, and improved soil fauna activity and soil structure resulting in better infiltration, reduced run-off and improved water use efficiency. Besides, [27,28] had observed that a 5-10 cm layer of mulch prevented weed seedling growth by inhibiting light penetration to the soil surface, where lower weed prevalence significantly improved water use efficiency. [21] Similarly observed that soil mulching resulted in substantial decreases in evapotranspiration early in the growing period, enhancing soil moisture conservation which later in the season supported increased transpiration and crop growth resulting in final higher seasonal evapotranspiration and increased yields.

The observed early senescing of coir mulched maize crop compared to non-mulched and irrigated maize crops could have been attributed to the fact that during much of the growing period, the coir mulched maize crop concentrated most of its roots at the upper moist 0-20 cm soil surface at interface with coir material, with little or no roots directed towards deeper layers of soil profile. Thus, when rains subsided and soil moisture deficit conditions set in, the coir mulched maize crop roots experienced drought shock, while non-mulched and irrigated maize crop had their roots well developed into deeper layers where they could obtain soil moisture at periods of drought.

5. CONCLUSION

The study has shown that coir mulching can result in reduction of the excessive daily evapotranspiration rates and maintain significantly higher levels of conserved soil moisture during early stages of the growing season and also buffer the growing crop from fluctuations in soil moisture during dry spells. This results in increased water use (evapotranspiration) by maize crop at later stages of the growing season, resulting in increased grain yields.

The study has also shown that the conserved soil moisture starts diminishing to significant levels beyond 49^{th} and 66^{th} DAS depending on the season, suggesting that beyond these stages of maize growth, supplementary irrigation would be advantageous. This implies that coir mulching of maize crop can complement irrigation practices in the region, especially at critical stages of maize growth.

This study shows that adoption of a simple agronomic practice of applying a 10 cm thick layer of coir dust mulch early in the season as a soil moisture management strategy can help turn-around maize productivity and livelihoods of people in Coastal Kenya and other regions of limited rainfall, by making use of coir fiber, hitherto considered as an agricultural waste and an environmental pollutant.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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