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Crop Water Productivity of Two Varieties of Cowpea (*Vigna unguiculata (l.)* Walp) Under Deficit Irrigation and Mulch

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Abstract
This report presents a study of yield and seasonal water use of two (2) varieties of cowpea (SAMPEA 7 and 9) under deficit irrigation and mulch cover in Samaru, Northern Nigeria. A field experiment was conducted at the Samaru irrigation field of IAR in 2010/2011 irrigation seasons using surface irrigation method. The experiments consisted of twelve (12) treatments each, replicated three times and laid in a Group Balanced Block superimposed on the Split-plot Design. The treatments comprised of two varieties of cowpea (SAMPEA 7 and 9), three levels of water application depths (50, 75 and 100% of weekly reference evapotranspiration (WRETo)) and two levels of mulching (no-mulch and black polyethylene material). The yield of the cowpea pods ranged from 0.29t/ha to 1.29t/ha. The highest yield was obtained from SAMPEA 7 treatment irrigated at 100% WRETo applying the BPM. The study showed that crop water use of the two cowpea varieties decreased with increase in irrigation deficit. The ETc of cowpea ranged from 187.6mm to 335.6mm for SAMPEA 9 and 191.3mm to 315.8mm for SAMPEA 7 with the least values occurring at 50% WRETo and NM. The highest crop water use efficiency and irrigation water use efficiency were, 3.76kg/ha-mm and 2.11kg/ha-mm respectively, for SAMPEA 7 variety and 2.94kg/ha-mm and 1.68kg/ha-mm respectively, for SAMPEA 9 variety. Kc values of fully irrigated treatments ranged from 0.25 to 0.72 and 0.26 to 0.75 for SAMPEA 7 and SAMPEA 9 respectively. Kc values of the deficit irrigated treatments varied from 0.19 to 0.54 and 0.20 to 0.56 for SAMPEA 7 and 9 respectively. The crop yield response factor (Ky) was found to be 1.10 for the BPM treatments and 1.22 for the NM treatments, these were within the range of 1.15 obtained by FAO (1979). SAMPEA 7 variety irrigated at 75% WRETo with BPM gives higher yield, thereby reducing the volume of water and increasing efficient use of water which is the major limiting factor during dry season farming in the region.
Key words: *Cowpea, deficit irrigation, mulching, crop water use (ETc), crop coefficient (Kc), yield response factor (ky).*

Introduction
Cowpea is drought tolerant and well adapted to sandy and poor soils, being deep-rooted cowpea performs well in sandy soils and is more tolerant to drought than soya beans, and does not tolerate excessively wet conditions or water-logging (Dadson *et al.*, 2003). However, best yields are obtained in well-drained sandy loam to clay loam soils with soil pH between 6 and 7. SAMPEA 7 (IT90K-82-2) is early maturing (70days), erect and a medium sized brown seed that is moderately resistant to insects, pests and diseases. Its yield is about 1500kg/ha and a good crop for dry season. SAMPEA 9 (IT90K-277-2) is medium maturing (75-80 days), a semi-erect and a medium white seed that has some level of resistance to insect and diseases (Utoh, *et al.,* 2005). For optimum productivity of cowpea, be it entirely irrigated or partly rain fed, it requires 360-450mm of water per season (Krishna, 2010). Short season summer crop of cowpea needs irrigation between 250-360mm during the season. Despite the potentials and importance of cowpea, there is little if any documented research information on cowpea production under irrigation.
Production practices of a crop under irrigation must necessarily be prescribed independently of its rain-fed counterpart because the two seasons are not comparable. Most of the agronomic research to date on cowpea has been focused on the rain-fed crop by the Institute for Agricultural research (IAR), Samaru, Zaria (Muhammad, 2011). With the recent screening and release of improved cowpea varieties that are high yield photo-insensitive and early maturing, nine varieties of cowpea for different ecologies have been developed and released for production by IAR. The most popular are SAMPEA 6 and SAMPEA 7 which are resistant to

many stress factors, and SAMPEA 9 which is dual purpose (high grain and fodder yields). Hall and Patel (1985) reported that early and erect cowpeas are preferred in dry environment and under irrigation because they flowered earlier (about 30days after sowing). Therefore, the present study was focused on SAMPEA 7 and SAMPEA 9.

Mulching is well known to be one means of conserving soil moisture and reducing evaporation from the top soil area. Mulching can be done with organic or inorganic materials like polyethylene sheets. According to Rhu *et al.*, (1990) and Kashi *et al.*, (2004), besides conserving soil moisture, polyethylene mulch also increases soil temperature and moisture in early spring, reduce weed problems and certain insect pest and also simulate higher crop yields by more efficient utilization of soil moisture.

Two important parameters commonly required in determining crop water requirement and prediction of yield-water response to deficit irrigation are crop coefficient (Kc) and yield response factor (Ky). Crop coefficient is the ratio of crop actual evapotranspiration (ETc) to a reference evapotranspiration (ETo) which can be calculated using the FAO-Penman Monteith method (Allen *et al.*, 1998). The Kc integrates the crop and soil conditions that make a given crop's evapotranspiration more or less than the reference evapotranspiration. On the other hand, the yield response factor (Ky) is a ratio of relative yield reduction to relative evapotranspiration deficit. It is the factor that integrates the weather, crop and soil conditions that make crop yield less than its potential yield in the face of deficit evapotranspiration.

The objective of this study was to estimate the crop water productivity of two varieties of cowpea (SAMPEA 7 and 9) and to determine the yield response factors of the two cowpea varieties. It is anticipated that the information generated in this study will be useful for developing crop water requirements for the two irrigated cowpea varieties under deficit irrigation regimes and for the overall improvement of irrigation water management in the study area.

Materials and Methods

Description of the Study Area

The field experiment was conducted during the 2011 dry season at the Irrigation Research Farm of IAR. in Samaru, Zaria, (11^0 11'N, 7^0 38'E) at an altitude of 686m above sea level in the Northern Guinea savanna zones. Several meterological information of the site was collected from the Institute for Agricultural Research meteorological station located 150m away from the experimental plots and given in Table 1, it shows that maximum temperature ranges from 36-39°C, while minimum temperature ranges from 18-23°C, which is quite higher considering the range of minimum and maximum temperatures for cowpea production of 28-30°C (Dugje *et al.*, 2009). Table 2 presents information on physical properties of the experimental plot which was predominantly sandy loam in texture.

Table 1: Average Monthly Weather data for Samaru, (Feb;-May, 2011) irrigation cropping season.

Month	Max.Tempt. °C	Min. Tempt. °C	Humidity (%)	Sun shine (hrs)	Windspeed (Km/day)	Pan Evapo.(mm)	Solar Rad.[a] MJ/m^2/day	ET_o[b] (mm)
February	36.4	18.3	20.4	7.4	131.9	12.5	19.3	6.3
March	38.6	19.6	13.0	7.1	161.1	14.9	20.1	8.8
April	38.4	22.3	31.6	6.7	187.5	14.3	20.1	8.2
May	38.4	22.3	64.5	7.0	212.1	10.5	19.9	5.7

Source: I.A.R Meteorological Station

a. *Average monthly Solar radiation for 10 years (2000-2010), using Modified Penman Monteith*
b. *Average monthly ET_o for 10 years (2000-2010) using Modified Penman Monteith*

Table 2: Physical Properties of soils at various depths at IAR Irrigation Research Farm.

Depth (cm)	FC (%)	PWP (%)	Bulk Density (g/cm^3)	Clay (%)	Silt (%)	Sand (%)	Textural Class [a]	K (cm/s)
0-30	14.72	9.42	1.58	12	30	58	Sandy Loam	0.32
30-60	14.81	10.16	1.61	16	30	54	Sandy Loam	0.27
60-90	17.74	13.47	1.62	32	24	44	Clay Loam	0.07

a. Based on USDA textural classification.

Treatments and Experimental Design

The experiment consisted of twelve (12) treatments each, replicated three times and laid in a Group Balanced Block in Split-plot Design (Kwanchai and Arturo, 1983), carried out on cowpea crop cultivated under controlled deficit irrigation. Different water doses were applied according to the water requirement with reference to weekly ET_o at each stage of the crop cycle. The treatments consists of a three-factor experiment comprising of, two cowpea varieties (IAR SAMPEA 7 and 9), three levels of regulated deficit irrigation (water application depths 100%, 75% and 50% of weekly reference evapotranspiration ($WRET_o$) applied on weekly basis, referred to as I_{100}, I_{75}, and I_{50}) and two levels of mulching (No mulch NM and Black polyethylene mulch BPM). Table 3 gives further description of the experimental treatments.

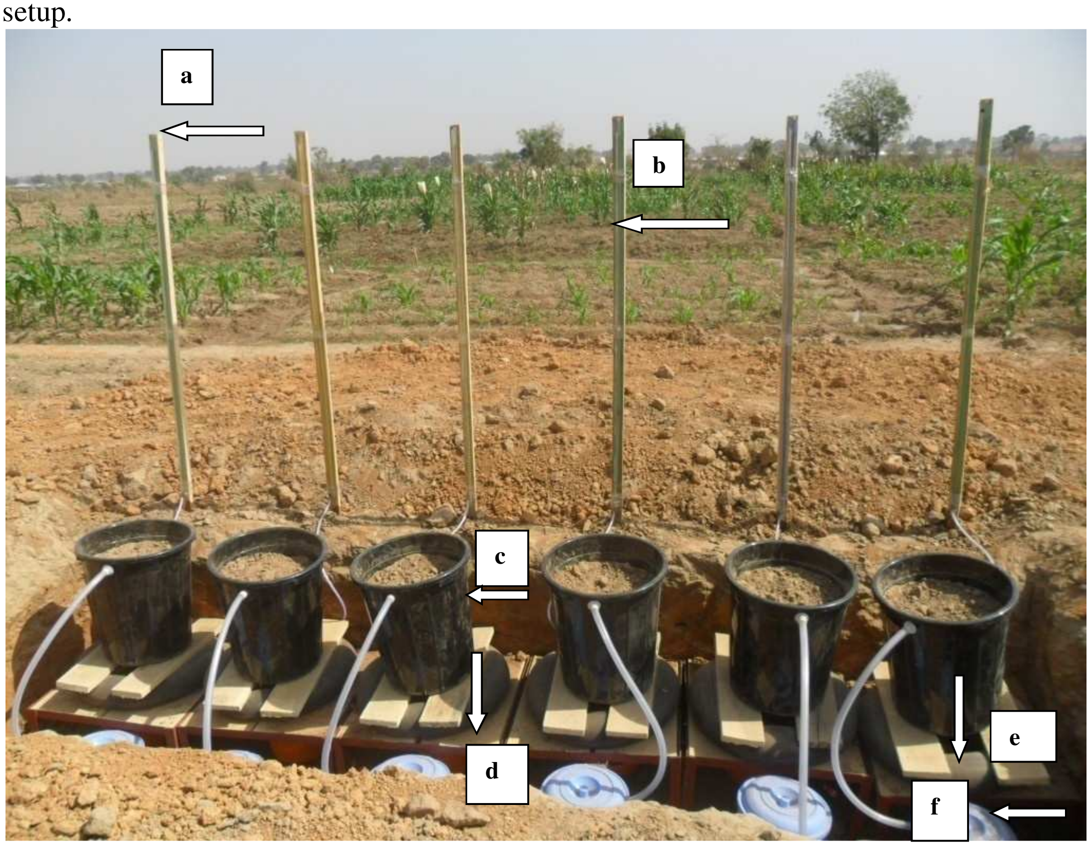
Table 3: Description of the experimental treatments

Treatment No.	Treatment combinations	Description of treatment combinations
1.	V_1,I_{100},NM	Sampea9 Variety, 100% weekly ET_o and no mulch
2.	V_1,I_{100},BPM	Sampea9 variety, 100% weekly ET_o and black polyethylene mulch
3.	V_1,I_{75},NM	Sampea9 Variety, 75% weekly ET_o and no mulch
4.	V_1,I_{75},BPM	Sampea9 Variety, 75% weekly ET_o and black polyethylene mulch
5.	V_1,I_{50},NM	Sampea9 Variety, 50% weekly ET_o and no mulch
6.	V_1,I_{50},BPM	Sampea9 Variety, 50% weekly ET_o and black polyethylene mulch
7.	V_2,I_{100},NM	Sampea7 Variety, 100% weekly ET_o and no mulch
8.	V_2,I_{100},BPM	Sampea7 Variety, 100% weekly ET_o and black polyethylene mulch
9.	V_2,I_{75},NM	Sampea7 Variety, 100% weekly ET_o and no mulch
10.	V_2,I_{75},BPM	Sampea7 Variety, 100% weekly ET_o and black polyethylene mulch
11.	V_2,I_{50},NM	Sampea7 Variety, 50% weekly ET_o and no mulch
12.	V_2,I_{50},BPM	Sampea7 Variety,50% weekly ET_o and black polyethylene mulch

Setting up the micro-lysimeters

The weighing type micro-lysimeters were made from locally available materials. It was set up to estimate the evapotranspiration of cowpea. The lysimeter setup consisted of a lysimeter tank, weighing system, wooden platform, runoff, and drainage collectors. The lysimeter tank is a plastic container measuring 50cm by 42cm depth and diameter respectively. Several Holes were drilled on the lysimeter tank bottom, to provide outlets for runoff and drainage water. The outlets were covered with filtering materials (wire mesh) to prevent soil particles from entering the collectors while still allowing water flow. The runoff and drainage collectors are also plastic containers (buckets) of depths 32cm and 12cm respectively and of diameters 28cm and 25cm respectively. The runoff water from the lysimeter tank flow under gravity into the runoff collector (placed at a lower elevation) through the plumb fittings and rubber hose connecting them.

The weighing system of the lysimeter comprises of a water-filled size 13 rim Michelin automobile tube connected to a graduated manometer glass tube using a rubber hose. The valve cover and the valve of the tube were removed and the tube filled with water through the rubber hose connected to its mouth and the other end to the mouth of the nozzle of the water sprayer. The water-filled tube was then connected to the manometer glass tube through the rubber hose. Care was taken so that much water in the tube was not lost in the process of fixing the rubber hose to the glass tube. The valve cover of the tube was also used to cover the top of the glass tube to prevent precipitation from entering into it, and also to minimize evaporation in it which would affect the accuracy of the weighing system. Plate 1 further illustrates the micro lysimeter setup.



* (a) = wooden pole, * (b) = glass manometer tube, * (c) = lysimetre tank, * (d) = wooden platform, * (e) = automobile tube, * (f) = plastic runoff collector

Plate 1: The Micro lysimeters set-up

Agronomic Practices

The experimental sites were ploughed, harrowed twice and then divided into three replications with each consisting of two sub-plots of about 9.6m^2. Cowpea seeds were sown by hand, 3 to 4cm deep in the field and also in the micro-lysimeter tanks filled with soil from the field on the 22nd February, 2011. The lysimeters were filled with repacked soil and effort was made to simulate the environment cropped with cowpeas in which the lysimeters was to be installed.

Six (6) micro-lysimeters were constructed and installed in the middle of the six (6) sub-plots. Thirty-six (36) micro-lysimeters were installed in the main plot, one lysimeter for each variety, to measure the evapotranspiration. Three (3) lysimeters were installed (without crop) in the farm to estimate the rate of evaporation. A total of Thirty-nine (39) micro-lysimeters were used for the set up.

The agronomy practices carried out in the field was also done at the same time to the crops in the micro-lysimeters. Single super phosphate (SSP) fertilizer application of 30kg/ha was applied on the 12th March 2011, at least fifteen days (15 DAP) after planting, as recommended by the Food and Agricultural Organization (FAO, 2005). 75ml of Dimethrin insecticide and 30g of Benlate (Benomyl) were also applied by spraying, twenty-one days (21 DAP) after planting to control insect pests and diseases. The insecticide spraying was done at two weeks interval until sixty-four days (64 DAP) after planting. Weeding was done manually and adequately controlled during the entire growth stages of the plant. Also weeds growing in and around the micro-lysimeters were removed as they appear. The crops attained physiological maturity at about 70days after planting.

Results and Discussion

Grain Yield

Table 4 shows the statistical treatment means of cowpea grain and dry matter yield, which were significantly different at 5% level of probability with respect to the varieties, deficit irrigation levels and mulch. Yields of treatments at I_{100} are significantly different from that of I_{75} and I_{50}. In general, the cowpea yield declined with decrease in percent irrigation levels from 100-50%. Under the cowpea varieties, the treatments means of SAMPEA 7 (V_2) performed better than SAMPEA 9 (V_1) with the highest grain and dry matter yields of 0.88t/ha and 3.22t/ha respectively. Considering the irrigation treatments, the highest grain and dry matter yields were obtained at I_{100} with 1.07t/ha and 3.37t/ha respectively, followed by I_{75} with 0.82t/ha and 3.11t/ha and the least at I_{50} with 0.47t/ha and 2.68t/ha.

Under mulching, it can be noticed that the highest grain and dry matter yield was obtained by the BPM mulched treatment which recorded 0.89t/ha and 3.18t/ha respectively. In general, SAMPEA7 at 100% ETo and using the BPM mulch gave the highest yield compared to SAMPEA 9 at any irrigation and mulch levels. The increased grain yield was mainly due to adequate soil moisture availability to the growth stages of crop and effective nutrients uptake throughout the crop growth stages since both the inputs exerted beneficial effect on yield contributing factors.

Table 4: Grain and dry matter yield of cowpea as affected by variety, irrigation and mulch during 2011 dry season

Treatment	Grain yield (t/ha)	Dry matter yield (t/ha)
Variety		
SAMPEA 7	0.88a	3.223a
SAMPEA 9	0.69b	2.877b
SE±	0.025	0.045
Irrigation		
I_{100}	1.07a	3.37a
I_{75}	0.82b	3.11b
I_{50}	0.47c	2.68c
SE±	0.031	0.056
Mulch		
BPM	0.89a	3.18a
NM	0.68b	2.92b
SE±	0.026	0.045

Means followed by the same letter(s), in a column of any treatment group are not significantly different at 5% probability level, I_{100}=0% deficit, I_{75}=25% deficit, I_{50}=50% deficit; NM= No mulch, BPM= black polyethylene mulch

Evapotranspiration

Table 5 shows the weekly and total (ETc) of the various treatments (mm) across the various growth stages. It shows differences in the amount of water consumed daily by cowpea due to transpiration through the plant foliage and evaporation from the surfaces of the leaves and adjacent soil surface. There was a gradual rise in the ETc for the NM treatments from the initial stage to the mid-season stage, and these was due to high wind velocity, increase in the available soil moisture and loses of water from the plant foliage thereafter, the ETc starts declining immediately after the mid-season stage across the two cowpea varieties.

The total ETc ranged from 187.6 to 335.6 mm day^{-1} across the two varieties (SAMPEA's 7 and 9). This range of values are much higher than those seasonal ETc range of 131 to 255mm and 159.5 to 262.5mm reported by Moroke *et al.*, (2011) and Adekalu, (2006) respectively and a much lower value than the result of 457.70mm reported by Hashim *et al.*, (2012). A comparison of the weekly and total ETc on the bases of irrigation treatment indicated that weekly crop water use (ETc) decreased with increase in deficit irrigation. The average daily peak consumptive use of the treatments given full irrigation (I_{100}) was 5.3mm day^{-1} and 6.3mm day^{-1} at the mid-season stage for SAMPEA 7 and SAMPEA 9 respectively. Liyanage *et al.*, (1992) observed that lysimeters measurement showed a peak daily evapotranspiration of cowpea during early pod filling stage and averaged to be about 8mm. The highest ETc obtained show that Cowpea needs much more application of water during the fruiting stage than at emergence (initial stage) and senescence. Similar observation was reported by (Aboamera, 2010; Souza *et al.*, 2005). He reported an increase in evapotranspiration of cowpea, during the fruiting (mid season stage) using the water balance method.

The decrease in crop consumptive use due to deficit irrigation ranged from 2 to 37% for SAMPEA 7 and 1 to 40% for SAMPEA 9, with the highest values in the range occurring at I_{50} treatments. The pattern of decrease in consumptive use (ETc) as a result of deficit irrigation was expected since deficit irrigation reduces the amount of water available in the soil for plant uptake. The study however reveals that applying water at 75% ETo, reduces peak consumptive use of the cowpea crop by about 15% in SAMPEA 7 and 20% in SAMPEA 9. More so, if water is applied at 50% ETo, the peak consumptive use of the cowpea crop will be reduced by about 37% in SAMPEA 7 and 40% in SAMPEA 9.

However, a careful study of the trend of the weekly ETc reveals that in the two crop varieties, the total ETc of the NM treatments, irrespective of irrigation regime, were about 1 to 2% higher than the mulched treatments at the initial stage, 33% higher than the mulched treatments at the development stage, 36 to 43% higher at the mid-season stage and 10 to 17% higher at the late-season stage. At the development stage, both SAMPEA's 7 and 9 were 33% higher than the mulched treatments.

Yield response factor

The computation of the relative yield decrease was done with reference to the fully irrigated treatment in order to be consistent. The relative yield decrease $(1-\frac{Ya}{Ym})$ and relative seasonal crop water use (SCWU) – $\left(1-\frac{ETa}{ETm}\right)$ deficit were noticed to increase with increase in irrigation deficit in the mulched and or no-mulch practices. Figures 1 and 2 show the yield response factors (Ky) for NM and BPM treatments respectively, obtained by plotting the pooled data of the relative yields and relative seasonal crop water use. The Ky values were obtained as 1.22 and 1.10 for the NM and BPM respectively. The Ky values obtained in this study closely agrees with Doorenbos and Kassam (1979) which gave seasonal Ky value of cowpeas as 1.15.

Table 5: Average weekly and total evapotranspiration of the cowpea crop in 2010/2011 irrigation season

Treatment			Initial stage			Development stage			Mid-Season stage				Late-Season stage		
			Days After Planting												
			1-5	6-14	15-21	22-28	29-35	36-42	43-49	50-59	60-63	64-70	71-79	80-90	Total
V_1	NM	I_{100}	10.9	20.1	20.4	26.0	29.0	33.2	36.5	56.4	25.3	35.6	24.6	17.6	**335.6**
		I_{75}	12.6	20.3	18.3	20.8	21.7	22.8	26.2	41.1	19.1	24.6	21.2	18.3	**267.0**
		I_{50}	10.9	20.9	18.1	15.7	16.5	16.8	17.5	27.9	12.2	17.3	12.9	13.5	**200.2**
	BPM	I_{100}	10.9	20.8	18.9	15.2	18.4	19.7	20.2	30.3	13.5	19.9	18.7	18.2	**224.7**
		I_{75}	10.8	20.9	18.5	15.0	16.3	18.8	20.6	31.2	13.8	19.7	18.5	16.0	**220.2**
		I_{50}	11.2	20.9	17.3	14.9	14.0	14.4	15.2	25.1	12.2	15.6	13.4	13.5	**187.6**
V_2	NM	I_{100}	11.4	20.9	18.1	26.4	27.0	29.5	31.7	48.2	21.1	33.7	28.0	19.9	**315.8**
		I_{75}	11.2	21.2	18.0	21.3	22.5	23.6	26.0	40.0	18.2	25.5	20.8	18.9	**267.1**
		I_{50}	11.4	21.4	17.8	15.7	16.8	15.4	17.0	26.5	12.0	16.1	14.0	12.9	**197.0**
	BPM	I_{100}	11.2	20.9	17.3	15.4	18.1	19.4	19.7	29.1	12.7	20.9	18.6	18.0	**221.3**
		I_{75}	11.4	20.3	18.4	15.2	16.2	17.9	19.5	29.0	12.8	20.7	18.5	16.1	**216.0**
		I_{50}	11.2	20.6	17.6	15.3	15.8	15.8	15.6	25.1	11.3	15.8	13.6	13.6	**191.3**

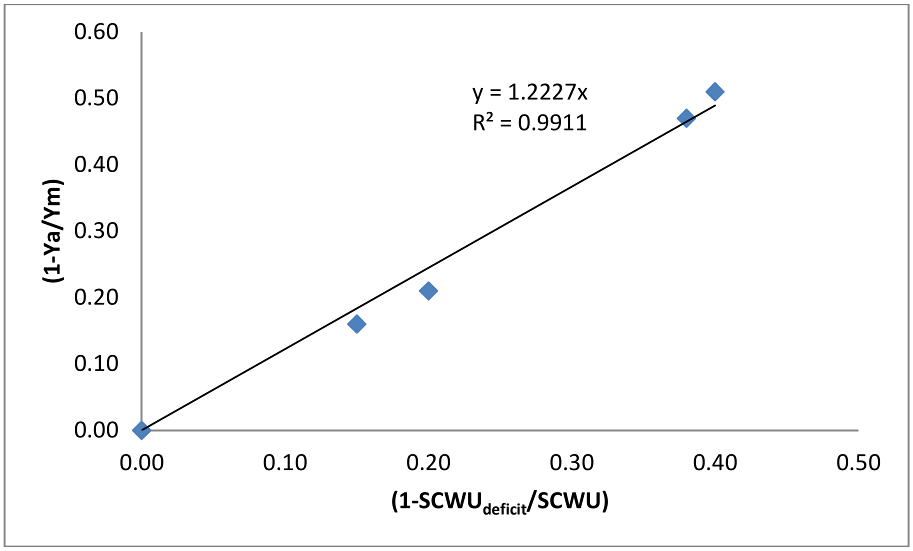


Figure 1: Yield response factor (Ky) of the no-mulch treatment.

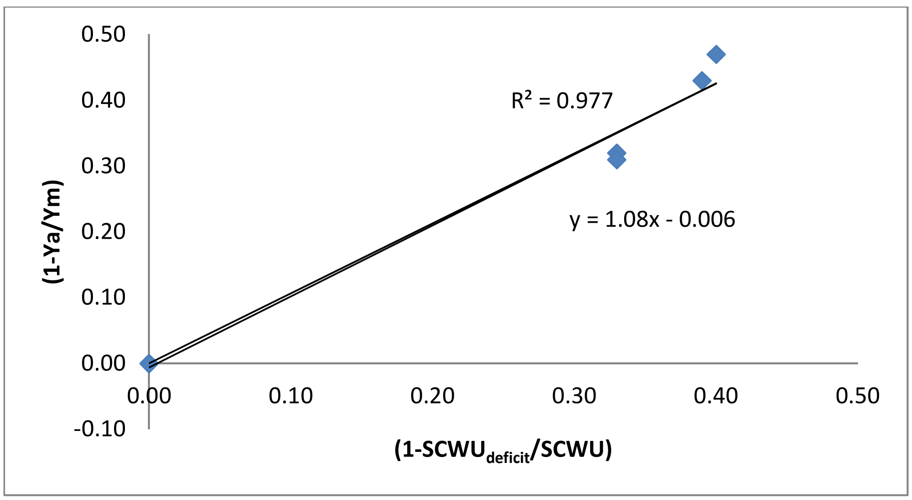


Figure 2: **Yield response factor (Ky) of the black polyethylene mulch treatment.**

The coefficient of determination (r^2) for the NM was 0.991 and 0.977 for BPM treatments. Before implementing a deficit irrigation programme, it is necessary to know crop yield responses to water stress, either during defined growth stages or throughout the whole season (Kirda and Kanber, 1999).

The treatment with the higher Ky value will suffer a greater yield loss than the treatment with a lower Ky value. When different crops are cultivated, yield response to water deficit in different individual growth periods is of major importance in the scheduling of available but limited supply in order to obtain highest yield. According to Doorenbos and Kassam (1979), Ky<1.0 indicates that the decrease in yield is proportionally less with increase in water deficit, while yield decrease is proportionally greater when Ky>1.0.

The results of this study show that with or without mulch, the yield decreases of the cowpea crop were proportionally greater with increase in evapotranspiration deficit. It is however noticed that the Ky value of the no-mulch treatment was higher than the mulched treatment by about 10%. This implies that the proportional decrease in yield under the no mulch condition was much higher than the mulched condition. It also suggests that mulching helped to cushion the impact of the deficit irrigation on yield. Among the two cowpea varieties, SAMPEA 7 cushioned the relative decrease in yield as a result of water deficit more than SAMPEA 9. This further confirms that SAMPEA 7 is more tolerant to water stress than SAMPEA 9.

Grain Yield – Seasonal Crop Water Use

The grain yield – seasonal crop water use relationship was established using the least square method. The line of best fit was drawn to establish linear relationship between grain yield and seasonal crop water use for the no mulch treatments. A linear relationship was found between the yield and seasonal crop water use as;

$$Grain\ yield = 0.003ETc - 0.339 \quad (1)$$

From figure 3, it reveals that an evapotranspiration threshold of 146mm is required before grain yield initiation. Water use also had a positive correlation with the grain yield.

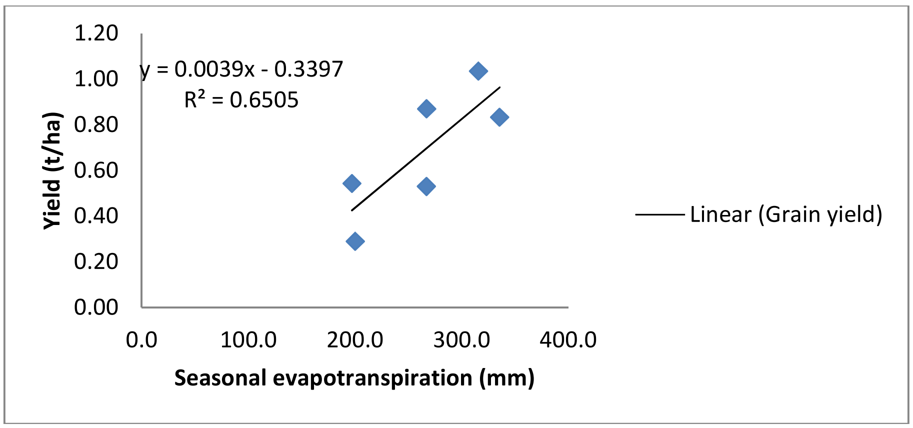


Figure 3: Grain yield and seasonal crop water use relationship for No mulch.

Figure 4 is the grain yield of black polyethylene mulch (BPM) plotted against the seasonal evapotranspiration which gave the linear equation below with coefficient of regression (r^2) as 0.552.

$$Grain\ yield = 0.014ETc - 2.212 \quad (2)$$

The seasonal evapotranspiration ranged from 187mm to 225mm and the grain yield ranged from 0.42t/ha to 1.29t/ha.

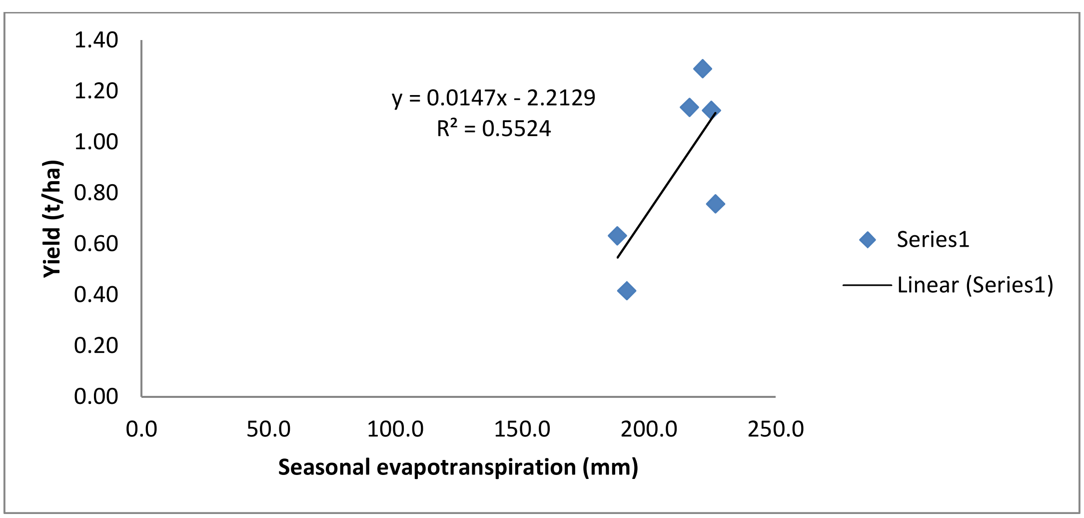


Figure 4: Grain yield and seasonal crop water use relationship for BPM mulch

Conclusion

The following conclusions were drawn from the results of this study:

1. The highest yield for cowpea SAMPEA 7 variety was with BPM of 1.29t/ha and the least was 0.42t/ha with 100% and 50% WRETo respectively. While the highest yield for cowpea SAMPEA 9 variety was with BPM of 1.12t/ha and the least was 0.29t/ha with 100% and 50% WRETo respectively. Also, the highest crop water use (CWU) for cowpea SAMPEA 7 was the NM with 315.8mm and the least was the BPM with 191.3mm of 100% and 50% WRETo respectively. While the highest CWU for cowpea SAMPEA 9 was the NM with 335.6mm and the least was the BPM with 187.6mm of 100% and 50% WRETo respectively.
2. The yield-water use relationship for the cowpea varieties was established. A linear relationship was found between the yield and seasonal crop water use. It reveals that an evapotranspiration threshold of 146mm is required before grain yield initiation. Water use also had a positive correlation with the grain yield. The yield response factor (Ky) were obtained as 1.22 and 1.10 for the NM and BPM respectively.

Acknowledgments

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