Response of soil moisture content, evapotranspiration, and yield of cowpea to varying water application

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Abstract: Moisture stress is an important factor affecting field-grown cowpea in the tropics, especially in the dry seasons, and irrigation is required for successful yields. Field experiment was conducted at Teaching and Research Farm of the Department of Agricultural Engineering, Federal University of Technology, Akure, during 2014 growing season using a completely confounded design with four replicates to evaluate the impact of soil moisture stress on the yields of cowpea under four different irrigation treatments. The treatments were 100%, 80%, 60% and 40% Full Irrigation Treatment (FIT). Soil moisture contents were determined biweekly using gravimetric method. Cowpea grain and biomass yields were measured after harvest. The yield response factor (K_y) was determined to evaluate the plant response to irrigation. The point where K_y and the ratio ratio of yield reduction and evapotranspiration (ET) reduction whcih are numerically equivalent was determined. The ET production function was implemented in matrix laboratory (MATLAB) to accurately determine the optimum soil moisture and irrigation water required for cowpea production. The results of the study indicated that 100% FIT excelled all other treatments at grain yield and biomass yield, where its yield was 1.06 t ha^{-1}, the 80%, 60% and 40% FIT produced 0.95, 0.89 and 0.71 t ha^{-1} respectively. The analysis of the results showed that soil moisture availability was significantly (p<0.05) affected by the irrigation treatments adopted, which in turn significantly (p≤0.05) affected the cowpea grain and biomass yield. The yield obtained at 40% FIT was significantly (p<0.05) different. The yield response factor of 1.24 was obtained, showing that cowpea is sensitive to water stress. The total amount of irrigation water and moisture content that resulted to the optimum yield were 151.12 mm and 0.1082 g g^{-1}, respectively. The result implies that 32% of total irrigation water applied during the growing season would be saved. The approach adopted, therefore, proved to be useful in estimation of possible irrigation water required for optimum production of cowpea.

Keywords: MATLAB, moisture availability, yield, yield response factor, optimum production

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1 Introduction

Cowpea (*Vigna unguiculata (L.) walp*) is one of the most widely adapted, versatile, and nutritious of all the cultivated grain legumes in West Africa. It is an important item in the diet of West Africans, as it is a rich source of plant protein. However, it is of major importance to the livelihood of millions of relatively poor people in less developed countries of the tropics (FAO, 2002). Islam et al. (2006) emphasized that all parts of the plant used as food are nutritious providing protein and vitamins, immature pods and peas are used as vegetables while several snacks and main dishes are prepared from the grains. It is eaten in various ways, either alone or mixed with maize, rice, fish or flour. The crop also has ability to maintain soil fertility through its excellent capacity to fix atmospheric nitrogen and thus does not require very fertile land for growth (Lobato et al., 2006; Peksen and Artik, 2004). Despite the nutritional and medicinal importance of the crop, its production especially in the humid and sub-humid regions of the tropical countries are largely limited to the rainy season of the year. However, with the increasing need of this crop, it is necessary to

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accelerate and expand its production all year round. This implies transforming the existing largely traditional or subsistent agriculture into modern agriculture through intense use of modern irrigation facilities (Smith, 2000).

Water plays an important role in the growth and production of crop. Water is becoming increasingly scarce resources in the West Africa sub-region (Fasimirin, 2007) and there is competition between municipal, industry users and agriculture for the finite amount of available water. The great challenge for coming decades in the dry season period will be focusing on increase food production by using less water (FAO, 2002b). The limited amount of water available for crops, especially during the dry season necessitates the need to practice deficit irrigation to save water and cost (English and Raja, 1996).

Optimal water management strategies thus become an important factor due to limitations in the supply of irrigation water in dry seasons, especially as cowpea, the most important and staple food crop, receives priority in these dry seasons in Nigeria. Furthermore, water management becomes important in cowpea as both limited and excess supplies could affect crops yield in the tropics (Zaidi et al., 2007). Soil moisture is an important factor significantly impacting the yield of crops. Insufficient soil moisture hampers the growth, penetration and development of roots. The plants root is the part of plant organ responsible for the uptake of water from the soil (Kuchenbuch et al., 2006). Soil water depletion level affects the growth and yield in full and limited irrigation strategies and they are critical factors considered to be affecting food production in arid and semi-arid areas of the world. In addition, Tardieu et al. (1991) reported that crop yield reduction is due to the increase of soil mechanical resistance as a result of reduction water uptake by the root of crops under deficit irrigation conditions.

Another critical variable that plays critical role in limited and well-watered crop productions is the crop evapotranspiration (ET). ET is a major component of the agricultural water budget and it is a key factor to determine proper irrigation schedule and to improve water use efficiency in irrigated agriculture. Crop ET is a very important parameter in irrigation management (Payero et al., 2008; Irmak et al., 2008) for better irrigation scheduling and for efficient use of water resources, especially in the tropical region.

On the other hand, Doorenbos and Kassam (1979) introduced the yield response factor to describe the relationship between ET reduction and yield reduction. This yield response factor is important for irrigation water management. In the approach of Doorenbos and Kassam (1979), yield reductions, and ET deficits are expressed in relative terms based on maximum crop yield (y_{max}), and the corresponding ET at maximum yield ($ET_{\max}$). Thus, they derived an expression for relative yield decrease as $(1-Y_{act}/Y_{\max})=K_y(1-ET_{act}/ET_{\max})$, where Y_{act} and ET_{act} correspond to the actual yield and ET, respectively and $Y_{\max}$ and $ET_{\max}$ are maximum yield and maximum crop ET, which is attainable for crop grown under optimum condition respectively, and the K_y corresponds to the yield response factor. The response factor K_y was recommended for planning and operation of irrigation systems in limited/deficit as well as in fully-irrigated settings to evaluate the plant response to water. The application of the empirical relationship that exist between ET and yield of crop as reported by of Doorenbos and Kassam (1979) has not been fully and extensively used in research on crop water relations for the determination of crop optimum yield and irrigation water.

Considering the importance of ET, soil moisture to crop production, there is a need to determine the effect of soil moisture stress on cowpea yield. Innovative elements of the present study included the following aspects (1) for the first time, an algorithm comprising of existing empirical models from ET production function has been implemented and established using MATLAB - based computer program, to accurately determine the optimum soil moisture and irrigation water required for cowpea production, and (2) The effect of soil moisture availability on cowpea yield has been well reported.

2 Materials and methods

2.1 The study area

The field experiment was conducted during dry season 2014 (January - April) at Teaching and Research Farm of the Department of Agricultural Engineering, Federal University of Technology, Akure. The dry season spans from November to March, with the rainy season lasting from March to the end of October. Weather data for daily maximum and minimum temperatures, relative humidity, sunshine hours and wind speed were obtained from the Experimental Meteorological Station and were used to compute reference evapotranspiration (ET_o) using the FAO-Penman Monteith model (Allen et al., 1998). The weather data of the study location for the period is presented in Table 1.

The soil of the study area can be classified as sandy clay loam (USDA, 1999). It is a drained soil, characterized by a high sand content (65.6%-70%) in the top 0.3 m with bulk density ranging from 1.26-1.51 g cm^{-3}. The measured field capacity and wilting point of soil at the experimental site are 0.21 and 0.08 on dry basis respectively. Some physical and chemical soil properties are given in Table 2.

Table 1 Average monthly weather data for the study area (Jan – April, 2014)

Month	T_{max}, °C	T_{min}, °C	RHmean, %	RHmin, %	Wind speed, m s^{-1}	Rs, MJ m^{-2}·day	ET_o, mm day^{-1}
Jan	32.86	21.31	64.25	57.64	1.57	17.77	4.35
Feb	34.06	22.22	61.85	56.94	1.76	18.27	4.81
March	31.32	22.99	75.05	69.39	1.94	18.12	4.31
April	30.90	22.73	76.97	70.85	1.83	18.72	4.31

Table 2 Physical and Chemical Properties of the Soil of the Experimental Field

Soil depth	Sand, %	Silt, %	Clay, %	Textural class	Bulk density, g cm^{-3}	Organic carbon, %
0-10 cm	70	21	9	Sandy clay-loam	1.36	0.78
10-20 cm	68	19	13	Sandy clay-loam	1.48	0.68
20-30 cm	65.6	20	14.4	Sandy clay-loam	1.51	0.62
Soil depth	Oganic matter, %	Potassium, cmol kg^{-1}	Magnessium, cmol kg^{-1}	Nitrogen, %	Magnessium, cmol kg^{-1}	pH
0-10 cm	1.35	0.24	1.2	0.44	1.2	5.8
10-20 cm	1.17	0.26	0.9	0.52	0.9	6.8
20-30 cm	1.07	0.29	0.8	0.61	0.8	6.2

2.2 Rainfall and depth

Figure 1 shows the varying depth of rainfall recorded during the growing season. A total of 13 rainfall events were recorded. The rainfall depths measured ranged from 1.13 to 42 mm. The lowest rainfall was recorded at 16 DAP in February during the initial stage and highest rainfall of 42.04 mm at 29 DAP in February.

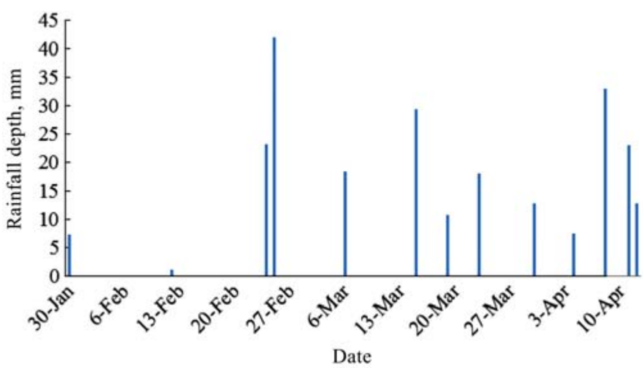


Figure 1 Rainfall Recorded at the Experimental Field during Cowpea Growing Season

2.3 Field experimentation

The field of experiment was carried out between 28th January and 13th April, 2014. Cowpea variety "*Ife Brown*" was planted at the recommended spacing of 30 cm on rows, 60 cm apart. The plots were planted with cowpea with a spacing of 0.6 m inter row by 0.3 m intra row. Weeds and insect pests were controlled as necessary using standard procedures. Seeds were planted and thinning was first done two weeks after planting to reduce the crop to two per stand. Thinning was carried out manually at 2 weeks after planting to attain a spacing of 30×60 cm. An experimental plot (13×13 m) was ploughed, harrowed and divided into four treatments. Each treatment was divided into four plots (2.7×2.7 m) to make a total of 16 plots and leaving 0.5 m space between each plot. Different irrigation regimes; 100% FIT, 80% FIT, 60% FIT and 40% FIT were adopted.

Two sprinklers (Rain Bird 30 TNT heads), with 1 m risers each were arranged diagonally at the corner of each irrigation level to form a part circle irrigation water coverage pattern in each treatment block. A total of eight sprinklers heads were used to irrigate the crop field. The sprinklers were set to throw water at an angle of 90° in each treatment. The sprinklers produced a wetted radius of approximately 6 m to irrigate cowpea in each of the irrigation treatment at an approximate operational pressure of 250 kPa and average discharge per sprinkler was 0.49 $m^3 h^{-1}$.

Irrigation timings were based on the soil water content of the fully-irrigated treatment such that a total of 24.7 mm of irrigation was applied when the soil water in the root zone in the reference plot (100% FIT) was depleted by about 40%. Thus, a total of 24.7, 19.8, 14.8, and 9.9 mm of irrigation water was applied in each irrigation to 100%, 80%, 60%, and 40% FIT treatments, respectively.

2.4 Measurement procedures

Soil moisture content at depths 0-10, 10-20 and 20-30 cm were determined from each plot in each of the treatment bi-weekly. The soil moisture contents were measured by using the gravimetric method (Lascano, 2000). The Soil bulk density (g cm^{-3}) was determined by the core method (Blake and Hartage, 1986). Samples were dried at 105°C for 24 h in a forced air oven. Crop actual evapotranspiration was determined from sowing to harvest using soil water balance equation (Hillel, 1998) as shown in Equation (1).

$$ET = I + P \pm \Delta S \pm D \pm R \quad (1)$$

where, ET is the crop evapotranspiration (mm); I is applied irrigation (mm); P is the precipitation during the period of experiment (mm); ΔS is the change in soil moisture storage (mm); D and R are excess moisture drained from soil (mm) and run off from soil surface (mm) respectively. Drainage and run off were measured from a drainage lysimeter (Igbadun, 2012).

Cowpea grain and biomass yield were determined at maturity. The grain yield was harvested in batches from the field. The yield of the cowpea was weighed using weighing balance. The production functions were established from the empirical relationship between relative evapotranspiration as a function of relative irrigation and relative yield.

ET- yield functions were established from the relationship below (Equations (2) and (3)):

$$Y = f\,(ET) \quad (2)$$

$$\frac{Y_{act}}{Y_{\max}} = f\,\frac{ET_{act}}{ET_{\max}} \quad (3)$$

The yield response factor K_y is the slope of the relative yield reduction versus relative evapotranspiration deficit as described by Doorenbos and Kassam (1979). The relationship is expressed mathematically (Equation (4)) and yield response factor is calculated as;

$$\left(1 - \frac{Y_{act}}{Y_{\max}}\right) = K_y \left(1 - \frac{ET_{act}}{ET_{\max}}\right) \quad (4)$$

where, $Y_{\max}$ = Maximum Yield; Y_{act} = Actual harvested yield; ET_{act} = Actual evapotranspiration; $ET_{\max}$ = Maximum evapotranspiration; K_y = Yield response factor; $\left(1 - \frac{Y_{act}}{Y_{max}}\right)$ = Seasonal yield relative reduction; $\left(1 - \frac{ET_a}{ET_m}\right)$ = Seasonal actual evapotranspiration relative reduction (mm).

2.5 Statistical analysis

Statistical analysis, ANOVA was performed on soil moisture contents and yield, based on different irrigation water managements imposed on the crop using Minitab (version 17.0). Mean comparison between treatments and their replicates were determined at 5% level of significance using Tukey's test. Linear interpolation between the ratio of relative yield and relative ET reduction, and the yield response was used to accurately determine the optimum irrigation water and moisture content using MATLAB 2013 software.

3 Results and discussion

3.1 Water applied

Before planting, 24.7 mm irrigation water was applied to all treatments to bring the soil water content in 0-30 cm soil depth up to level of field capacity. Irrigation schedule was started measuring of soil water content by gravimetric method. The highest amount of water recorded at 100% FIT treatment was 463.16 mm while the minimum amount was 243.6 mm in the 40% FIT treatment. During the growing season, the total amount of rainfall recorded was 240.05 mm.

3.2 Effect of irrigation on soil water dynamics

The average soil moisture content measured at treatments 100%, 80%, 60% and 40% FIT from 7-77 days after planting (DAP), from the soil depth of 0-0.3 m at interval of 10 cm are illustrated in Table 3. Under all treatments, the top soil layer (0-0.1 m) showed the lowest water content throughout the growing season as a consequence of soil water evaporation, while the soil moisture content was highest at 0.2-0.3 m soil layer.

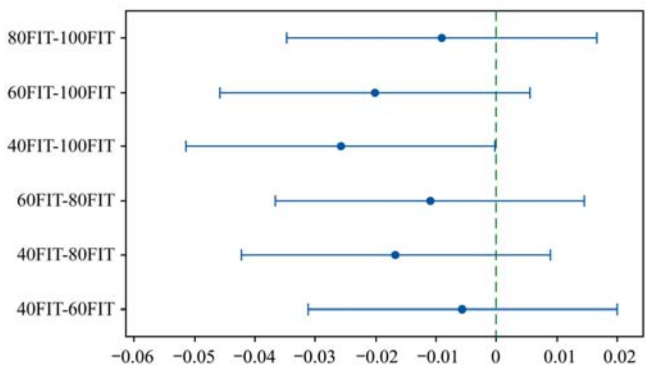
Table 3 Mean moisture content Calculated at different soil depths throughout the growing season (mm)

Treatments	Soil depth		
	0-10	10-20	20-30
100% FIT	15.14a	18.61ab	20.68c
80% FIT	14.24a	17.59ab	19.72c
60% FIT	13.04a	16.09ab	18.12c
40% FIT	11.83a	14.39ac	16.67d

Note: Mean followed by the same letter(s) in a column is not significantly different at $P \leq 0.05$.

Differences in soil water content appeared with irrigation events were function of irrigation treatments adopted. The availability of soil moisture was affected by the level of irrigation treatment and rainfall event that occurred during cowpea growing season. The soil moisture content was significantly ($p \leq 0.05$) affected as a result of different irrigation treatments adopted at 10-20 cm and 20-30 cm soil depth, but does not affect the soil moisture at depth of 0-10 cm among treatments ($p>0.05$). This indicates that the Plant water uptake in the 40% FIT treatment was mostly concentrated in the 0 to 0.1 m. Under the 100% FIT, water was uniformly up taken from the soil layers of 0-0.3 m deep.

The adopted irrigation treatments had a significant ($p<0.05$) impact on soil moisture contents (Figure 2).



Note: If an interval does not contain zero, the corresponding means are significantly different.

Figure 2 Graphical representation of ANOVA analysis for soil moisture content measured during the growing season

While the soil moisture content at field capacity was 0.21 g g^{-1}, they were 0.1261, 0.1155, 0.1034 and 0.0972 g g^{-1} (n = 18) at irrigation treatments of 100%, 80%, 60% and 40% FIT. Analysis of Variance (ANOVA) showed that the mean soil moisture content of 0.097 g g^{-1} was significantly ($P<0.05$) different. This may have effect on the yield of cowpea due to the stress level. The soil moisture at 100%, 80%, 60% and 40% were by 40% , 45%, 51% and 54% lower than the value of field capacity, respectively, and hence would have subjected the crop to excessive soil moisture stress at 40% FIT, while it may be moderate at the 60% FIT because it slightly exceeded 50% of depletion from the field capacity

3.3 Effect of soil moisture content on the evapotranspiration, grain and biomass yield of cowpea measured in each irrigation treatment

Table 4 shows the irrigation amount, actual evapotranspiration, grain yield and the biomass production of cowpea obtained during the experiment. The crop seasonal actual evapotranspiration for cowpea was highest at 100% FIT with a value of 397.52 mm and were 371.76, 335.38 and 295.96 mm in treatment 80% FIT, 60% FIT and 40%FIT, respectively. Therefore, the crop seasonal actual evapotranspiration of cowpea estimated at the study area ranged from 295.96-397.52 mm. This range of values are much higher than those seasonal ET range of 131 to 255 mm and 159.5 to 262.5 mm reported by Moroke et al. (2011) and Adekalu (2006) respectively and a much lower value than the result of 457.70 mm reported by Hashim et al. (2012). These higher values of actual seasonal ET measured from the study area may be as a result of rainfalls that accompany the irrigation events.

Table 4 Cowpea biomass yield (t ha^{-1}) during the 2014 (Jan.-April) growing season

Treatments	Irrigation amount, mm	Evapotranspiration, mm	Grain yield, t ha^{-1}	Biomass yield, t ha^{-1}
100% FIT	223.11	397.52	1.06±0.26a	6.95±1.02a
80% FIT	178.87	371.76	0.95±0.06a	6.62±1.32a
60% FIT	133.87	335.38	0.89±0.11a	4.54±2.21a
40% FIT	89.24	295.96	0.71±0.19c	3.48±1.39b

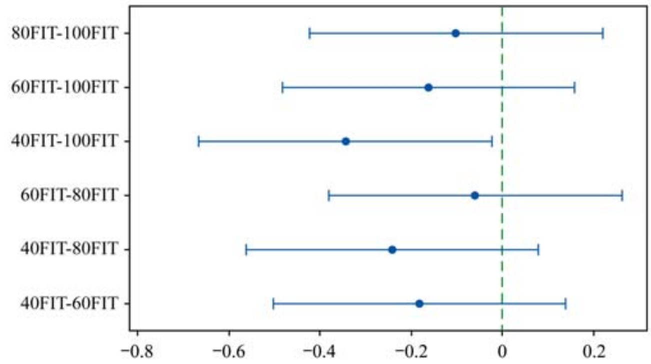
Note: Means in each column bearing the same letter are not significantly different at 5% level of probability by Tukey's test.

The cowpea grain yield harvested from treatments; 100%, 80%, 60%, and 40% FIT at the experimental site ranged from 0.62 to 1.27 t ha^{-1}. This compares favourably to the range of 0.38 to 1.88 t ha^{-1} reported by Adekalu and Okunade (2006) for the same variety. The average grain yield measured ranged from 0.71 to 1.06 t ha^{-1}, while biomass yield measured, ranged from 3.48 to 6.95 t ha^{-1} respectively.

During the growing season, there was general increasing trend in grain yield and biomass with increasing irrigation amounts. All irrigated treatments had significantly higher yields than 40% FIT at the 5% significance level (α=0.05). In general, the fully irrigated treatment (100% FIT) had the greatest numerical yield than all other treatments. The irrigation impact on the grain and biomass yield compared to the 40% FIT, induced an increase in the grain yield of 33%, 16%, 25.26% and 20.22% for the 100% FIT, 80% FIT and 60% FIT. At 40% FIT, soil moisture availability to the crop was inadequate for full growth and development. As a result, yield was significantly reduced under this treatment as compared with the 100%, 80% and 60% FIT.

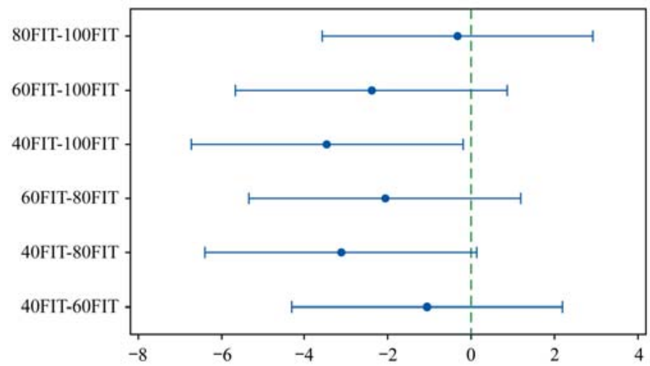
The biomasses were of 49.93%, 47.43% and 23.34% for the same treatments relative to the 40% FIT. This is in line with the submission of several researchers (Stewart et al*.*, 1975; Dwyer and Steward, 1984; Traore et al*.*, 2000) who reported that reduction in moisture availability can also cause reduction in the total biomass and grain yield.

Figures 3 and 4 showed that grain and biomass yields of cowpea are significantly (p<0.05) different. This implies that about 40% of irrigation water could be saved. The yield obtained at 40% FIT may have been adversely affected by the soil moisture stress. Interestingly, the average soil moisture content was adversely affected at 40% FIT when subjected to 5% level of probability using Tukey's test. This showed that soil moisture availability affected and imparted the grain and biomass yield of the cowpea. A soil water deficit during the vegetative stage had the least effect on crop yield, but may adversely affect during the fruiting stage. This may have resulted in a significantly lower yield at the 40% FIT. The yield obtained at treatments 80% and 60% FIT was almost similar to that of the control treatment (100% FIT), which was adequately watered throughout the season (Table 4).



Note: If an interval does not contain zero, the corresponding means are significantly different.

Figure 3 Graphical representation of ANOVA for cowpea grain yield



Note: If an interval does not contain zero, the corresponding means are significantly different.

Figure 4 Graphical representation of ANOVA for cowpea biomass yield

The relationship between relative moisture content, relative yield and ratio of yield reduction/ET reduction is presented in Table 5.

Table 5 Relationship between average moisture content, relative moisture content (MC$_r$), relative yield (Y_r) and ratio of yield reduction/ET reduction

Treatment	Moisture content (MC)	MC_r	ET_r	Y_r	Yield reduction/ ETreduction
100% FIT	0.12613	1	1	1	0
80% FIT	0.11553	0.91595	0.94	0.9	1.6
60% FIT	0.10338	0.81964	0.84	0.84	1
40% FIT	0.09722	0.77081	0.74	0.67	0.97

The deficit irrigation increases the ratio of ET_a over yield. Similar relationship is observed between the relationship between relative moisture content and relative yield. This is in line with the report of Geerts and Raes (2009) who reported that if crops have certain phenological phases in which they are tolerant to water stress, the deficit irrigation can increase the ratio of ET_a over yield. Otherwise, yield can increase the ratio of yield over ET_a by either reducing the water loss by unproductive evaporation, and/or by increasing the proportion of marketable yield to the total biomass production and/or by increasing the proportion of total biomass production to transpiration due to hardening of the crop. The relative evapotranspiration increases over the relative yield for cowpea.

3.4 Yield Response Factor of Cowpea

Yield response factor (K_y) was determined from the crop production function. The slope of the relative yield reduction and relative evapotranspiration reduction is the yield response factor (Figure 5). The relationship between the yield reductions versus relative evapotranspiration reduction showed that cowpea is responsive to water stress (i.e greater than one).

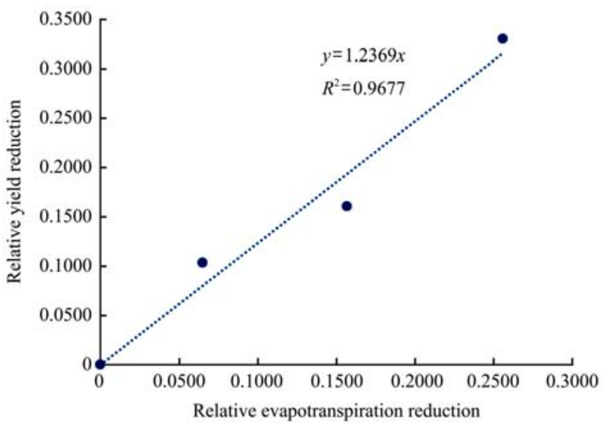


Figure 5 The graph of relative evapotranspiration reduction versus relative yield reduction of cowpea

The yield response factor, K_y of cowpea obtained was 1.24. This value shows that cowpea is sensitive to water stress. The value compares favourably with value of 1.15 reported by Doorenbos and Kassam (1979) for bean.

The results of previous research may show a wide range of variability of K_y due to some prevailing factors related to the environmental and management conditions and other factors (soil fertility agricultural practices, variety pest and diseases) other than water. Aforementioned result clearly indicates that the K_y values show substantial variation between different locations under different management conditions. Also, crop yield response to irrigation and ET (crop production functions) can vary substantially from one location to another as a function of similar factors, creating a need for these functions to be developed for local climatic and soil and crop management conditions. Furthermore, deficit irrigation and full irrigation may potentially have different effect on the yield of ife brown hybrid than traditional ones, potentially resulting in different K_y value. Therefore, application of K_y values developed in different regions may result in errors when it is used for estimation of relative yield in other locations with different number and length of growth stages. Knowledge of the sensitivity of cowpea to water stress over the whole growing season or during a specific growth stage has to be widely used in the studies that have objectives to develop deficit irrigation strategies as well as to determine the yield response factors of cowpea.

3.5 Relationship between yield response factor and the yield reduction/ET reduction for optimum water determination

Table 5 showed that the yield response factor of 1.24 for cowpea obtained fall between the values of 1.6 and 1 of yield reduction and ET reduction ratio, corresponding to a value between treatment 80% and 60% FIT, respectively. The amounts of water applied at these treatments correspond to 178.49 and 133.87 mm, respectively. The linear interpolation showed that irrigation water of 151.12 mm is numerically equivalent to the point where yield response factor and ratio of yield reduction and ET reduction are equal. The result showed that exactly 32% (70.39 mm) of irrigation water could be saved. This water could be used to irrigate additional land. Interestingly, the 32% of irrigation water that could be saved is in the neighbourhood of about 40% of irrigation water statistically analysed, which is significantly different (Figure 6). The moisture content at this point was 0.1082 g g^{-1}. This result showed the optimum soil moisture needed for the production of cowpea is 0.1082 g g^{-1}. Average moisture content obtained at treatments 60% and 40% FIT were lower than the optimum moisture content by 4.5% and 10%, respectively. But moisture content at the 60% was closer to the optimum moisture content obtained.

The yield parameters (grain yield and biomass) of cowpea were responsive to soil moisture stress. The results showed that cowpea yields were significantly decreased with increasing soil moisture stress, while the onset of and date to full flowering were significantly delayed by higher soil moisture stress levels. Similar reduction in yield of cowpea due to soil moisture stress has been reported by several other researchers (Abidoye, 2004; Kerbauy, 2004).

4 Conclusion

The study showed that soil moisture was adversely affected by the different irrigation treatments. Therefore, Cowpea grain yield was significantly affected by soil moisture availability under the different irrigation treatments.

Based on the results obtained from the study on the effect of soil moisture content and ET and on the yield components of cowpea, it was concluded that:

1) Soil moisture availability is an important factor affecting cowpea yield in the tropics.

2) The result from the study showed that the relationship between the ratio of yield reduction and ET reduction, and the yield response factor was fully established for determining optimum soil moisture and irrigation water required for cowpea production.

3) The MATLAB based algorithm predicted the optimum soil moisture, ET and irrigation water required for cowpea production.

4) The optimum moisture content of 0.1082 g g^{-1} and irrigation water of 151 mm were required for cowpea production in the study area.

The MATLAB based algorithm developed by adopting linear interpolation approach can be used to determine optimum soil moisture, ET and yield of cowpea in other regions of different or similar climate.

The Matrix Laboratory (MATLAB) Algorithm for Cowpea Optimum Production

```
t = xlsread('data', –1); % data comprising of ET
y = xlsread('data', –1); % data comprising of yield
k = xlsread('data', –1); % data comprising of soil moisture
n = xlsread('data', –1); % data comprising of irrigation depth
i = 1:4;
ETreductionnn = t(i) –t(1);
ETreductionn = t(1);
ETreduction = ETreductionnn./ ETreductionn;
YIELDreductionnn = y(i)–y(1);
YIELDreductionn = y(1);
YIELDreduction = YIELDreductionnn./YIELDreductionn;
EWPPP = (YIELDreduction./ETreduction); % Where EWPPP is the ratio of yield reduction and ET reduction (Doorebos and Kassam, 1979)
% To calculate yield response factor
m = [zeros(size(ETreduction)) ETreduction];
slopeinnt = m\YIELDreduction;
slopeinnnt = slopeinnt(2)*1;
qqq = slopeinnt(2)*ETreduction; % where yield response factor is slopeinnt(2)
% To calculate optimum soil moisture
w = interp1(EWPPP,k,slopeinnt(2)); % w is the optimum soil moist5ure
% To calculate optimum irrigation water depth
B = interp1(EWPPP,n,slopeinnt(2)); % where B is the optimum irrigation depth
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