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Modelling Soil Moisture Balance for Okra Cultivars in Makurdi Agro Climate Using Decision Support System for Agro Technology Transfer (DSSAT)

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Abstract: Soil moisture balance from okra (abelmoschus esculentus) field was performed on experimental plot of the Department of Agricultural and Environmental Engineering, Joseph Sanwuan Tarka University Makurdi -Nigeria. Field and laboratory experiments were conducted on four okra cultivars planted and irrigated by drip system at different levels (80% (I_1), 60% (I_2), 45% (I_3), and 15% (I_4)) according to the agronomic practices of okra. Decision Support System for agro technology Transfer (DSSAT) model for the Crop Environment Resource Synthesis (CERES) was used to model soil moisture balance by linear regression (multivariate analysis of variance, (MANOVA)) and validated. The soil was sandy loam with high field capacity (FC) at I_4 and nearly uniform drainage (D) except for I_4. Runoff (R) decreases from 35.71 for I_1 to 0.07 for I_4 implying that R, D and change in water storage (ΔS) are functions of the amount and duration of irrigation. The models reported an acceptable deviation from the ideal line of the R and ΔS at higher values confirming degree of the correlation between the observed and predicted dataset but experienced difficulties with estimating lower values due to lower magnitudes in irrigation. From the foregoing it is concluded that decreasing water application results in an increase in irrigation and the reverse is also true.

Keywords: Irrigation levels, okra, Makurdi agro climate, soil moisture balance, modeling

I. Introduction

Imbalance in water demand and supply for agriculture has drawn many attentions on model technologies and management innovations that can maximize irrigation water use [1] [2], [3], [4]. In the contemporary social, economic, institutional, climatic, soil and other environmental variables, plant growth and development has been influenced by the presence of adequate moisture, warmth and aeration in the soil [5]. Hence; soil moisture as a matter of fact integrates the water balance components of land surface hydrology [6], [7], and over time to develop antecedent hydrologic fluxes [8]. It can be used to determine soil moisture balance components (SMBCs) from a hydrologic balance which relates soil moisture losses to a dryness index, describing the partitioning of precipitation into evapotranspiration, runoff, and deep infiltration [9]. Climate, soil, and vegetation conditions of any ecology nurtured soil moisture dynamics and plant water stress in field experiments on ecosystem response to shifts in the rainfall regime, showing that plant crucially depends not only on the total rainfall during the growing season but also on the intermittency and magnitude of the rainfall events [10], [11].

Reducing the vulnerability of agriculture to climate change, and ultimately decreasing the risks associated to food security, requires integrated and sustainable water management, adaptation of cropping systems and management practices, adopting an efficient use of both rainfall and irrigation water. This is critical considering the steady increase of global population and the limitations on availability of natural resources, particularly in vulnerable agricultural areas with water scarcity [12], [13], [2], [14]. Although, soil water balance model for many crops exist, however the water balance application for okra field has not been investigated. Thus, most farmers do not know when to irrigate and what quantities of water to be used for irrigation and also when to apply the drainage system in their farm, this is because they do not have the knowledge of soil moisture behavior. Hence this study has generated set of data from the field and was used to model SMBFO by DSSAT model

II. Materials and Method

The Study Area

Based on Koppen's Scheme of Classification, Makurdi –Nigeria lies within the AW Climate (Tropical Savannah Climate) and experiences two distinct seasons, the wet/rainy season and the dry/summer season. The rainy season lasts from April to October with annual rainfall in the range of 100-200mm [15]. The dry season begins in November and ends in March. Temperatures in Makurdi fluctuate between 23 – 40 degrees Celsius [16]. The vegetation of the Makurdi consists of rain forests which have tall trees, tall grasses and oil palm trees with mixed grasses and trees that are generally of average height. The topography is mainly undulating plains with occasional elevations of between 1,500 m and 3,000m above sea level according to [16]. The main geological formations are sandy-loam shelf basement complex and alluvial plains. These together with its location in the transition belt between the north and south ecologies and a favourable rainfall pattern account for its support for a wide variety of crops [17]

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Makurdi metropolitan is located in central Nigeria along the Benue River trough and lies between Latitudes 70 and 80N as well as Longitude 80 and 90 E. with average relief of 120 m [18]. The relative humidity ranges between 50 % and 80 % and are season dependent. The highest relative humidity occurs between June and September while the lowest is December to February [18]. Rich agricultural produce within Makurdi include yams, rice, beans, cassava, potatoes, maize, soya beans, sorghum, millet and cocoyam. Makurdi also hosts one of the longest stretches of river systems in the country with great potential for a viable fishing industry, dry season farming through irrigation and for an inland water highway [19].

Field Experiment

A 4 irrigation levels plot replicated by 3 cultivars of okra making a total of 12 experimental plots measuring 1m by 1m each were developed for contributing very good surface runoff to the downstream (Plate 1). Paving of the slope with burnt bricks was adopted to stabilize the slopping side in the boundary. A transverse 0.2 % non-erosive bed slope was adopted for the downstream portion of the plots in accordance with [20].

Plate 1: Experimental Plots Planted with Okra

The field capacity (Fc) at the experimental site was determined as the moisture content of the soil sample when drained completely (usually within 24 to 48 hrs) in accordance with the method described by [21], [21]. Field capacity was computed as in equation (1),

$$\mathrm{FC} = \frac{(\theta_{fc} - \theta_d)}{\theta_d} \qquad (1)$$

where;

θ_{fc} Is the weight of wet soil + Crucible

θ_d Is the weight of oven dry soil + Crucible

Permanent wilting point (PWP) for the experimental field is the lowest water content of soil measured after plant has stopped extracting water and were at or near premature death or became dormant as a result of water stress [22]. To determine the PWP under field conditions, an okra plant with a well-developed tap root system at their maximum vegetative growth was identified from each cultivar, water was withheld at the end of the experiment and the plant allowed wilting. The soil moisture at that point was determined by oven dry method at 105 – 110 ^{o}C as the PWP.

Deep drainage water was determined according to [23]as follows

$$D = \text{Amount of moisture above } \frac{FC}{2PWP} \qquad (2)$$

where:

D = Drainage (mm)

FC = Field capacity (mm)

PWP = permanent wilting point (mm).

The runoffs from the plots were conveyed through a pipe into a plastic sump for measurement at the end of every irrigation (Plate 1).

Change in soil water storage (ΔS) was estimated according to [24] as difference between the amount of water added (precipitation + Irrigation amount), and the amount of water lost (drainage + unsaturated flow or runoff + soil evaporation + root water uptake). For non-rainy period

$$\Delta S_i = I_T - I_i \qquad (3)$$

where;

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I_T is the total amount of water irrigated on each plot

I_i is the amount of water irrigated to each plot at ith level

Model Description

The water model in the Decision Support System for Agro technology Transfer (DSSAT) was represented by one-dimensional and linear water model below was adopted:

$$\Delta S = P + I - T - E - R - D \qquad (4)$$

where:

ΔS = Change soil water storage

P = Precipitation

I = Irrigation

T = Transpiration

E = Evaporation

R = Runoff

D = Drainage

The one-dimensional and linear water model computes the daily changes in soil moisture due to precipitation (P), irrigation infiltration (I), vertical drainage (D), unsaturated flow or runoff (R) and evapotranspiration as sets of data.

Estimation of Model Parameters

The DSSAT requires information to calculate processes such as root uptake (T), drainage (D), and soil water evaporation (E). However, due to lack of instrumentation, already established maximum root water uptake (0.03 cm^3) of water cm^{-1} of root day^{-1}, by [25], [26] for okra was applied. The set of data from the parameters were modeled by generalize MANOVA using Minitab 20 computer software.

The soil moisture balance for okra (SMBFO) was developed from water (DSSAT) for the Crop Environment Resource Synthesis (CERES) using the set of data from the field experiments and Minitab 16 statistical package.

Model Validation

To validate the water balance models, the predicted (p) results of components of water balance, such as soil water storage, evapotranspiration, deep percolation from root zone to buffer zone were compared with the observed (o) by plotting.

III. Results

Data set for modeling

Table 1 is the result (data sets) for the model imputes parameters **(**I, R, D, E, T ΔS) generated from the field experiment

From Table 1, the change in ΔS was nearly uniform irrespective of the okra cultivar. However, cultivar P_2 demonstrates the highest ΔS_2 meaning that the particular species does not demand much water during this period in Makurdi agro climate. P_4 consequently has very low ΔS_4 meaning that the amount of water taken by the plant nearly equal the amount of water supplied in as much as evapotranspiration, runoff and deperculation remain constant.

Modeling SMBFO

The data set for impute parameters in Table 1 were tested on the DSSAT model by multivariate analysis of variance (MANOVA) using general linear MANOVA by MINITAB software and the result shown in Table 2. We can see from Table 2 that $\mathbf{\Delta S_1}$ has a statistically significant effect on **I, R, D, E, T** ($F (1, 2) = 4.77$; $p < .005$; $\mathbf{\Delta S_2}$ ($F (1, 2) = 3.56$; $p < .005$; $\mathbf{\Delta S_3}$ ($F (1, 2) = 5.39$; $p < .005$.and $\mathbf{\Delta S_4}$ ($F (1, 2) = 4.83$; $p < .005$. The results for between subject effects for the model input (Table 1) show coefficient of determination (R^2) been 0.705; 0.640, 0.729 and 0.708 for ΔS_1, ΔS_2, ΔS_3, and ΔS_4 respectively for the corrected model. The total output is the sum of the individual output which is 1 and the corrected total (rest of the output) which is 3.

Table 1: Soil Moisture Balance Parameter for Surface Drip (SD) Irrigation during 2021 and 2022

	I_1 (80%)	Irrigation amount (mm)	Runoff (mm)	Drainage (mm)	E	T	Change in soil moisture
P1	I_1 (80%)	160	35.00	2.50	8.678	0.03	113.5
	I_2 (60%)	90	13.51	1.41	8.678	0.03	115.3

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	I_3 (45%)	30	5.60	1.65	8.678	0.03	116.15
	I_4 (15%)	13	0.53	2.0	8.678	0.03	114.93
P2	I_1(80%)	160	30	1.47	8.678	0.03	66.01
	I_2 (60%)	90	34.76	2.58	8.678	0.03	74.86
	I_3 (45%)	30	16.19	5.62	8.678	0.03	64.97
	I_4 (15%)	13	5.71	2.83	8.678	0.03	66.77
P3	I_1 (80%)	160	35.10	0.85	8.678	0.03	13.77
	I_2 (60%)	90	15.71	2.57	8.678	0.03	13.79
	I_3 (45%)	30	4.40	3.21	8.678	0.03	13.73
	I_4 (15%)	13	0.63	2.83	8.678	0.03	15.41
P4	I_1 (80%)	160	35.71	3.18	8.678	0.03	1.49
	I_2 (60%)	90	10.95	4.73	8.678	0.03	2.35
	I_3 (45%)	30	5.71	3.18	8.678	0.03	2.80
	I_4 (15%)	13	0.07	2.91	8.678	0.03	1.95

Table 2: ANOVA for Test of Between Subject Effects for Water Balance Model Imputes

Source	Dependent Variable	Type III Sum of Squares	Df	Mean Square	F	Sig. D
Corrected Model	ΔS1	5600.016[a]	1	5600.016	4.771	0.161
	ΔS2	5414.501[b]	1	5414.501	3.563	0.200
	ΔS3	5938.525[c]	1	5938.525	5.390	0.146
	ΔS4	5661.970[d]	1	5661.970	4.839	0.159
Intercept	ΔS1	14824.161	1	14824.161	12.629	0.071
	ΔS2	15906.801	1	15906.801	10.467	0.084
	ΔS3	15404.750	1	15404.750	13.983	0.065
	ΔS4	15331.031	1	15331.031	13.102	0.069
Error	ΔS1	2347.549	2	1173.774		
	ΔS2	3039.373	2	1519.686		
	ΔS3	2203.370	2	1101.685		
	ΔS4	2340.218	2	1170.109		
Total	ΔS1	17431.403	4			
	ΔS2	19093.796	4			
	ΔS3	17908.276	4			
	ΔS4	17908.408	4			
Corrected Total	ΔS1	7947.565	3			
	ΔS2	8453.874	3			
	ΔS3	8141.896	3			
	ΔS4	8002.187	3			

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a. R Squared = .705 (Adjusted R Squared = .557)
b. R Squared = .640 (Adjusted R Squared = .461)
c. R Squared = .729 (Adjusted R Squared = .594)
d. R Squared = .708 (Adjusted R Squared = .561)

Table 3 is the multivariate test design of intercept and ∆S parameters for the different levels of irrigations. The results were exact for Wilks' Lambda, at 0.05 level of significance The **multivariate tests** table is an attestation to the actual result of the one-way MANOVA. To determine whether the one-way MANOVA was statistically significant we looked at the "Sig.D" column. From Table 2 the "**Sig.**" value was .000, which means $p < .005$. Therefore, we can conclude that the model impute variable were significantly dependent on amount of irrigation ($p < .005$).

The general estimable function is unity as the estimated marginal means increases gradually for I and R with increasing ∆S. The trend however fluctuates in D with the highest value of 5.5 at ∆S of 1_3, and 70 (Figure 1 - 5). The trends were uniform for E and T for all values of ∆S. This shows that the mean for I, R, D, E, T were statistically significantly different between **∆S** ($p < .005$) Mean values were statistically significantly different between **∆S** ($p < .005$), These differences can be easily visualized by the plots generated by this procedure, as shown in Figure 1- 5:

Table 3: The Multivariate Test Design of Intercept and water balance parameters

Multivariate Tests[a]						
Effect		Value	F	Hypothesis df	Error df	Sig.
Intercept	Wilks' Lambda	.019	26.274[b]	2.000	1.000	0.137
I1	Wilks' Lambda	1.000	.[b]	.000	1.500	0.000
I2	Wilks' Lambda	1.000	.[b]	.000	1.500	0.000.
I3	Wilks' Lambda	1.000	.[b]	.000	1.500	0.000.
I4	Wilks' Lambda	1.000	.[b]	.000	1.500	0.000.
R1	Wilks' Lambda	1.000	.[b]	.000	1.500	0.000.
R2	Wilks' Lambda	1.000	.[b]	.000	1.500	0.000.
R3	Wilks' Lambda	1.000	.[b]	.000	1.500	0.000.
R4	Wilks' Lambda	1.000	.[b]	.000	1.500	0.000.
D1	Wilks' Lambda	1.000	.[b]	.000	1.500	0.000.
D2	Wilks' Lambda	1.000	.[b]	.000	1.500	0.000.
D3	Wilks' Lambda	1.000	.[b]	.000	1.500	0.000.
D4	Wilks' Lambda	1.000	.[b]	.000	1.500	0.000.
E	Wilks' Lambda	1.000	.[b]	.000	1.500	0.000.
T	Wilks' Lambda	1.000	.[b]	.000	1.500	0.000.
a. Design: Intercept + I1 + I2 + I3 + I4 + R1+ R2 + R3 + R4 + D1 + D2 + D3+ D4 + E + T						
b. Exact statistic						

Model validation

The results for validation of the new model are demonstrated by the plot of the observed vs the predicted as can be seen in Figure 6 - 8. From the plots there were linear correlation and nonlinear correlation between predicted and observed model parameters at different levels of irrigations.

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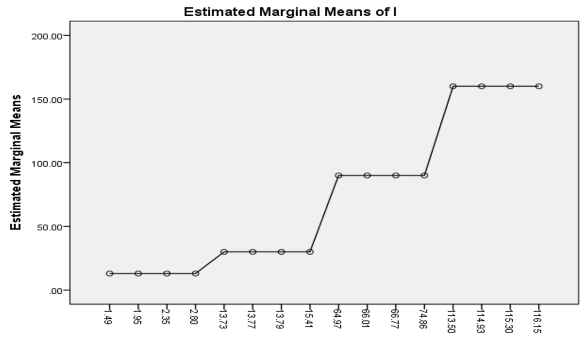
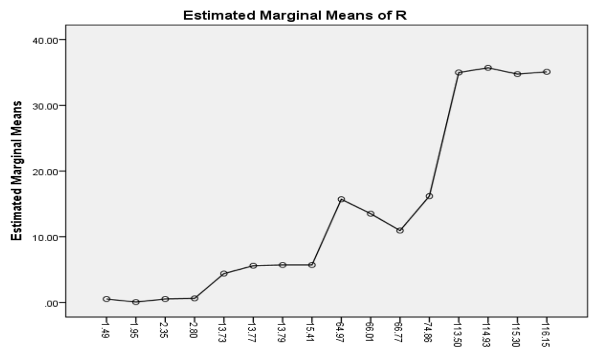


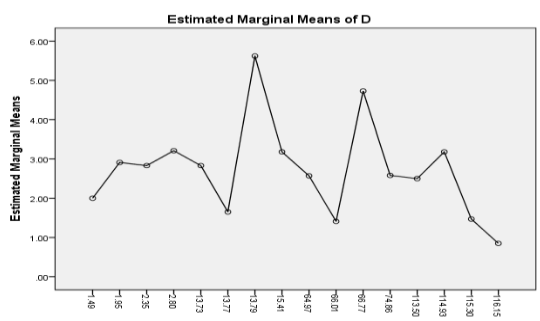
ΔS

Fig 1: Estimated Marginal Means for I



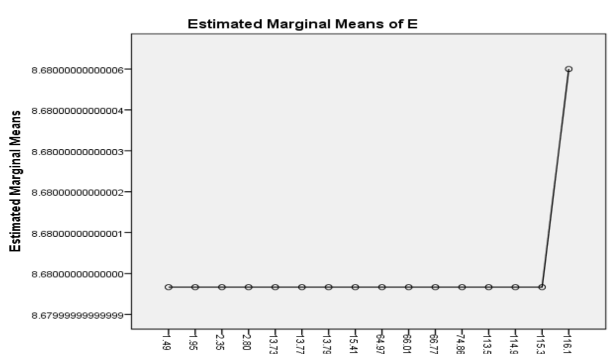
ΔS

Fig 2: Estimated Marginal Means for runoff (R)



ΔS

Fig 3: Estimated Marginal Means for (D)



ΔS

Fig 4: Estimated Marginal Means for (E)

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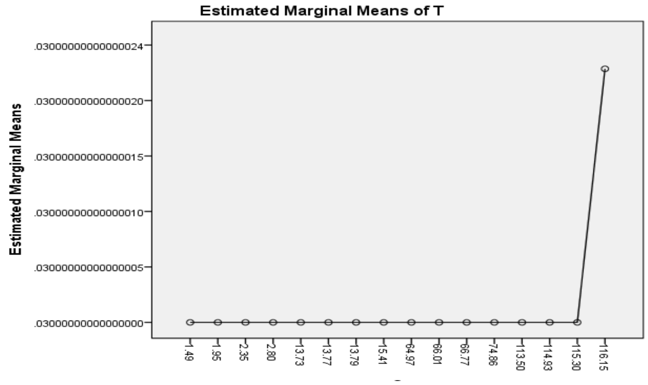

ΔS

Figure 5: Estimated Marginal Means for T

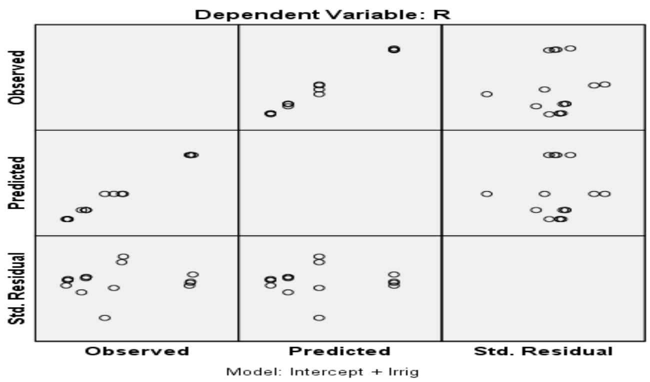

Fig 6: Residual Plots for R

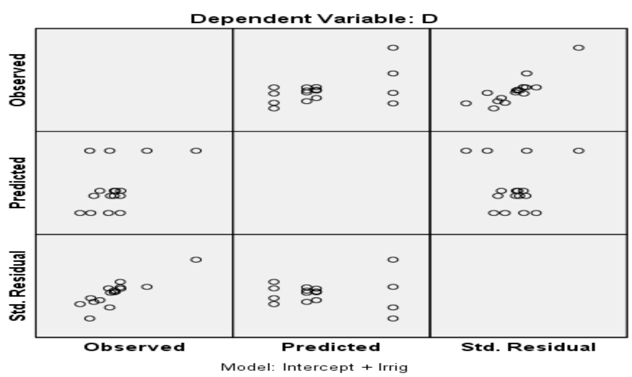

Fig 7: Residual Plots for drainage (D)

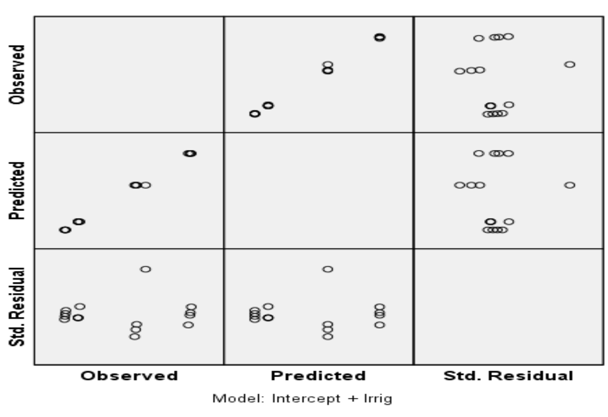

Figure 8: Residual Plots for irrigation (I)

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IV. Discussion

Parameter estimation for prediction

The soil moisture balance parameters considered in the experiment were P, I, R, D, E and T. No rainfall was recorded because the study period coincides with the dry season, the irrigation were scheduled for 160, 90, 30 and 13 mm as I_1, I_2, I_3 and I_4, respectively. The results indicated a decreasing order of D, R, and ΔS from I_1 to I_4 as attested to by the plot in Figure 9 (P_1- P_2). ETc and Kc were nearly uniform from their plots indicating that it does not depend largely on the amount of irrigation however to an extent on the prevailing climatic variables and the nature of the soil. Runoff decreases from 35.71 for I_1 schedule to 0.07 for I_4. This implies that runoff D and ΔS are functions of the amount and duration of irrigation in as much as other factor and the soil conditions remain the same.

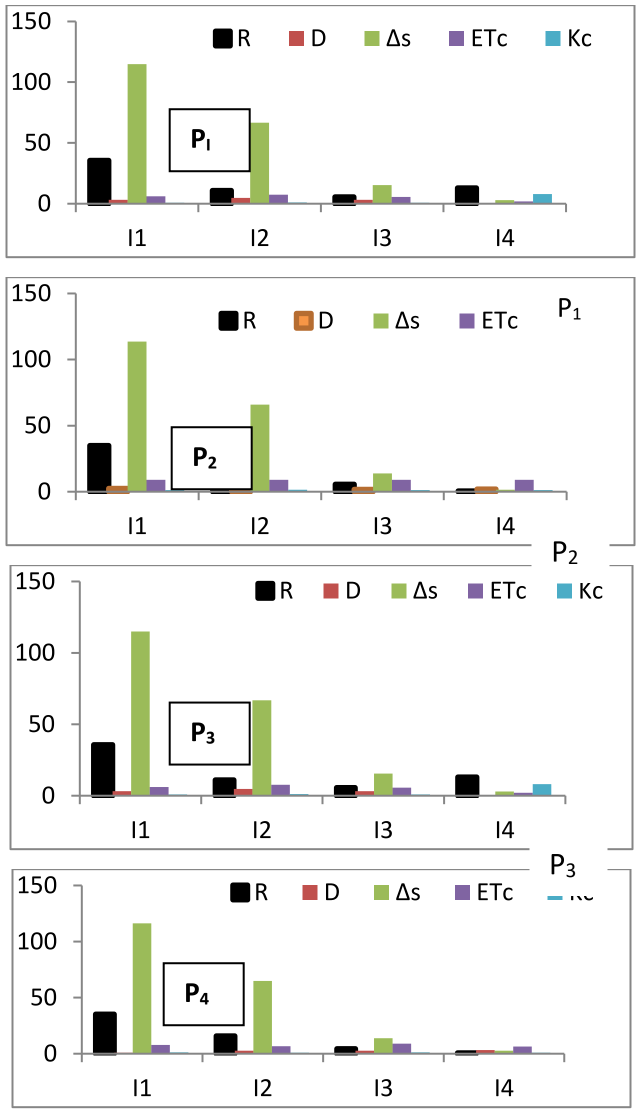

Figure 9(P_1- P_2). Response of ΔS and Kc to irrigations level for Okra cultivars

There is no relationship between D and the irrigation levels as it is purely a function of the soil characteristics and the plant characteristics. Crop root uptake of the okra was based on the maximum 8.678 established for the plant from previous research while the evapotranspiration was calculated as 0.03 from pan experiment at the site.

Modeling and Model

The modeling process was based on already established DSSAT model for the CERES. The DSSAT provided for net irrigation for the entire plot throughout the season (December - February) which is off-rainy season.

The corrected or modified SMBFO provided for components like irrigation (I) runoff (R), drainage (D) and evapotranspiration (ET) for evaluation of change in water storage (ΔS). ΔS is defined as the amount of water readily available for crop for extraction from its root zone [27] and depends on soil types, depth and distribution of roots within the soil mass [28]. Though the model outputs were similar in trend, however they were contrary to the findings of [29] who reported higher values than the values

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obtained from this study. The model recorded ΔS which varied from 5600.016 mm in I_2 to 5661.970.18 mm in I_4. This shows a significant correlation between irrigation and ΔS with Sig.d between 0.161 and 0.159 from I_1 to I_4

V. Conclussion

Makurdi agro-ecological zones of Nigeria experiences variation in available soil moisture under different irrigation schedule. The SMBFO model has proved that I, R, and D were positively significant implying that they are the major contributors to ΔS while E and T are dependent on the prevailing climatic condition of the study area. Most significant from the interaction of the model parameters is I followed with R then D. Plot of observed vs predicted reported an acceptable deviation from the ideal line of the R and ΔS at higher values, this is confirming degree of the correlation between the observed and predicted dataset. However, in some cases, the low values of the R, ΔS, D and ETc failed to be simulated accurately using the standalone predictive models. Yet, the developed hybrid models revealed better degree of correlation as it can be observed for the models. The values presented here belong to the predicted/observed values of all growth stages putted together. It is therefore recommended that this study be extended to;

1 Different soils locations of Nigeria
2 Different climate location in Nigeria

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