Performance of ISIAMOD in Simulating Leaf Area Index, Biomass and Grain Yields of a Maize Crop under Deficit Irrigation.

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ABSTRACT

In this study, a simulation model known as Irrigation Scheduling Impact Assessment Model (ISIAMOD) was used to simulate leaf area index, cumulative biomass production, final biomass yield at harvest, and grain yield of a maize crop as affected by deficit irrigation scheduling practice. The simulated outputs were compared graphically and statistically with field measured data of the same parameters from an experimental trial conducted in 2005 irrigation season at Igurusi ya Zamani Irrigation Scheme (IZIS) in Igurusi, Mbeya, Tanzania. The model simulations were closely in agreement with field observed. The modeling efficiencies for all the parameters simulated were above 80%, the coefficients of variations between the simulated and measured parameters were below 20%, which is within acceptable range for agricultural field research. The model tendency to either over- or under predict all the parameters simulated were below 15%. The simulation performance was therefore considered good, and the model recommended for simulating the tested parameters for the maize crop under irrigation in the location it was evaluated.

(Keywords: : simulation model, irrigation scheduling, maize crop, leaf area index, deficit irrigation, ISIAMOD)

INTRODUCTION

Deficit irrigation is a scheduling method where irrigation is purposefully carried out not to fully meet water requirements of the crop, and plants are allowed to extract soil moisture beyond readily available water in the plant root zone, thereby undergoing some water deficits. Deficit irrigation is carried out either by withholding or skipping irrigation, thereby reducing the number of irrigation events, or reducing the amount of water applied per irrigation. The goal is to save water, labor, and in some cases energy, and increase crop water use efficiency, even though a reduction in crop yield sometimes occur (Kirda, 2002; Kriedemann and Goodwin, 2004).

Information on how crops respond to irrigation deficits (in terms of growth and yields) is vital to formulating appropriate deficit irrigation scheduling strategy for a given crop and location. According to Smith et al. (2002), water stress resulting from under-irrigation leads to less evapotranspiration (ET) in plants due to closure of the stomata, reduced assimilation of carbon, and decreased biomass production. Kang et al. (2002) also argued that when the water stress is not severe, the reduction of biomass production will have little adverse effect on ultimate yield and can lead to appreciable increase in productivity of water; but when the water stress is severe or occurs at the critical growth stages of a crop, the reduction in yield may be so high that the benefit and returns for water will be reduced. While it is possible to study the crop response to irrigation by conducting field trials, the application of computer-based simulation models to study the relationships among crop, soil, water and atmosphere have since proved to be cheaper, effective, less time demanding, and the results are also far reaching (Ines et al., 2001; Droogers et al., 1998). Once the model have been calibrated and validated for the crop and location of study the results from the application of the model can be taken as a representation of the real system.

Several works on model performance have been reported in the literature. In Eastern and Southern Africa, the performance of CERES-Maize model (Jones and Kiniry, 1986) in Kenya has been reported by Wafula and Okwach (2002). Ritches and Jones (1998) have reported the performance of what they called the Kenya version of the CERES-Maize (CMKEN). Harrington and Grace (1998) and Matthews (2002) also reported the evaluation of CERES-Maize in Malawi and South Africa, respectively. Tumbo et al. (2005) has evaluated the performance of the PARCHED-THIRST (Young et al., 2002) in simulating maize yield under rainwater harvesting in Tanzania. APSIM (McCrown et al., 1996) has been evaluated in Kenya (Okwach, 2002) and Zimbabwe (Dimes, 2002) for the maize crop. Other models like IRSIS (Raes et al., 1986), CROPWAT (Smith, 1992) have also been evaluated in the region, this time for irrigation scheduling practices.

The objectives of this study were to evaluate the performance of a computer model known as Irrigation Scheduling Impact Assessment Model (ISIAMOD) (Igbadun, 2006, 2012) to simulate some above-ground responses, which include crop biomass yield, leaf area index, and grain yield, of a maize crop cultivated under deficit irrigation; and to compare the model-simulated data with field-measured data. The output of this study is expected to increase understanding of the response of the maize crop to the deficit irrigation schedules imposed on the crop for the study area. They may also be useful in developing appropriate deficit irrigation scheduling strategy for irrigation farmers who cultivated maize crop in the study area.

MATERIALS AND METHODS

The Model Used in the Study

ISIAMOD is a crop growth cum irrigation scheduling simulation model. It was developed to simulate crop growth and yield, soil water balance components and water management response indices for arable crop under irrigation. ISIAMOD consist of eleven modules which were integrated in hierarchical manner to simulate crop growth process, soil water balance of a cropped field, and Water Management Response Indices (WMRI) which are used to explain the impact of an irrigation scheduling decision. The input data required in the model include weather, soil, crop, rainfall, and irrigation scheduling decisions. The minimum weather data required are daily maximum and minimum ambient temperatures for the duration of crop growth. Other weather parameters may include wind speed, maximum and minimum relative humidity, sunshine hour or solar radiation. The model uses the weather data to simulate reference evapotranspiration either by Penman-Monteith or Hargreaves Methods (as detailed in Allen et al., 1998) depending on available data. The soil input data include volumetric soil moisture content at field capacity and at wilting point, initial soil moisture contents, bulk density, and the percentage of sand in the soil texture. The crop input data include maximum rooting depth, maximum leaf area index, potential (non-water limited) harvest index, radiation use efficiency (RUE), radiation extinction coefficient, and peak crop water use coefficient (K_c). Others include crop base and optimum temperatures; leaf area index shape factors; water-limited harvest index adjustment factors; crop planting, emergence, and physiological maturity dates; days from planting for the start of each of the four crop growth stages, and fraction of the crop growth duration at which leaf area index started to decline. The four crop growth stages to be used in the model are crop establishment, vegetative, flowering and maturity (which include seed formation through to maturity). A unique feature of the model which makes it an improvement on existing model is the WMRI modules which generate the waters accounting indices, crop productivity indices and the seasonal relative deficit/losses indices used to define the level of impact of an irrigation scheduling decision on the crop and the environment.

ISIAMOD runs on daily time step from planting to maturity dates which are entered as part of the crop input data. The output simulated by the model include crop growth response like leaf area index, crop rooting depth, crop biomass, final harvest index and grain yield; soil water balance components such as daily soil moisture content, evaporation, transpiration, runoff, deep percolation, and rainfall interception. The crop yields and water balance components outputs are further processed by the model to generate the water management response indices. The detailed of model development, calibration and validation for a maize crop in the study area has been reported (Igbadun, 2006, 2012)

The Study Location

The field experiment was conducted at Igurusi ya Zamani Traditional Irrigation Scheme (IZTRS) at Igurusi (8.33^o S, 33.55^o E, 1100m a.m.s.l.), Mbarali District, Mbeya Region, Tanzania. The study area has a unimodal rainfall pattern which occurs between October and April with mean annual rainfall of 800 mm. The months of May to October are usually dry, but the weather favours the cultivation of arable crops like maize, cowpea, vegetables and fruits under irrigation. The mean daily maximum temperatures range from 28^oC to 32^oC, while the mean daily minimum temperatures range from 9.5^oC to 19.5^oC, respectively. The highest values are recorded in October and November while the lowest values are experienced in June and July. Table 1 shows the weather data for the irrigation season. The soil of the experimental site is alluvial deposit. The texture of a one-meter profile depth varied from sandy clay to clay loam. Table 2 shows some of the physical properties of the profile depth.

Description of Experimental Treatments

The field experiment was conducted during the 2005 irrigation season (June to October) in the study area. TMV1-ST maize variety was planted under various deficit irrigation scheduling on 6^{th} July. Details of the experiment have been reported by Igbadun et al (2007, 2008). The experiment consisted of eight treatments whose variation was based on frequency of irrigation. The description of the experimental treatments is shown in Table 3. Weekly irrigation frequency was maintained in Treatment 1 (labeled TR_{1111}) and was used as the reference treatment. In the other treatments, the weekly irrigation was maintained only at some growth stages, while at the other growth stages, the weekly irrigation was skipped after every other irrigation until the targeted growth stage duration elapsed. Three distinct phenological growth stages of the crop were considered. The stages include crop establishment to tasseling initiation stage (24–65 days after planting (DAP), referred to as the vegetative stage; the tasseling initiation to end of silking stage (66–94 DAP), referred to as flowering stage; and the grain filling to maturity stage (95–122 DAP), referred to as the grain filling stage in this study. Skipping of regular irrigation events was not observed at plant emergence to crop establishment (0–24 DAP). This was done purposely to allow the crops to be established before they are allowed to be subjected to moisture stress.

Each treatment was replicated four times. Two replicates per treatment were designated for monitoring of crop biomass yield during the crop growing season by destructive sampling while the other two were designated for other data which include photosynthetic active radiation (PAR), soil moisture content, dry matter yield at harvest and grain yield. The experimental layout was a randomized complete block design (RCBD). The treatments were randomized in each block with a treatment assigned to each block. The blocks were separated by a 1.5 m buffer strip, which constituted a walkway and a field-ditch. The plots sizes within the blocks were 3.5 m by 3.5 m and were separated by a buffer of about 1.0 m. Embankments of 0.3 m high were built around each plot to help retain and prevent runoff/spill over of the water applied. Therefore each plot constituted a basin.

The detail of agronomic practices and the method used in measuring irrigation water application depths has been reported by Igbadun et al (2007, 2008). Water application was surface irrigation method. A total of 18 irrigations were carried out during the season for the reference treatment. In the other treatments, the number of irrigations ranged between 10 and 16, depending on the number of times irrigation was skipped per treatment. Table 4 shows the irrigation schedule for the season. Soil moisture content was monitored before and two days after every irrigation event in each plot throughout the crop growing seasoning using a Neutron Probe. The detailed methodology is also reported in Igbadun (2006) and Igbadun et al. (2007, 2008). The weekly evapotranspiration from each treatment was calculated from the soil moisture data using the soil moisture depletion technique (Michael, 1999). Evapotranspiration deficit was calculated as (Sunder et al., 1981):

$$ET_d = \left(1 - \frac{ET_{st}}{ET_{rt}}\right) \quad \textbf{(1)}$$

Where ET_d is evapotranspiration deficit; ET_{st} is evapotranspiration from stressed treatment, and ET_{rt} is evapotranspiration from reference treatment.

Table 1: Average Daily Weather Condition of the Study Location during the Cropping Seasons.

Month	Maximum Air Temperature (^oC)	Minimum Air Temperature (^oC)	Wind Speed (m/sec)	Open Pan Evaporation (mm/day)*
June	26.3	14.3	1.0	5.7
July	26.3	14.0	1.1	6.5
August	27.6	14.1	1.2	7.1
September	29.3	15.7	1.3	8.5
October	30.7	17.1	1.7	8.9

* Average open pan evaporation for five years (1989-1993)

Table 2: Some Soil Physical Properties of the Experimental Site.

Soil Profile Depth (mm)	Moisture Content at Field Capacity (m^3/m^3)	Moisture Content at Wilting Point (m^3/m^3)	Soil Bulk Density (dry) (g/cm^3)	Clay %	Silt %	Sand %	Soil Textural Class [a]
0-150	0.283	0.122	1.38	33	15	52	Sandy clay
150-400	0.301	0.164	1.40	35	15	50	Sandy clay
400-700	0.312	0.215	1.41	35	13	52	Sandy clay
700-1000	0.311	0.211	1.35	35	19	46	Sand clay loam

[a] USDA classification

Table 3: Description of the Experimental Treatments.

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

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

Table 4: Irrigation Schedule for the Season.

Growth Stage	Crop Establishment				Vegetative						Flowering				Grain Filling				Total No. of Irrigation Events	Total Water Applied (mm)
Week of Irrigation	0*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17		
Treatment Label	Water application depth per irrigation (mm)																			
1	30	30	30	30	40	40	40	40	40	50	50	50	50	50	50	50	50	30	18	750
2	30	30	30	30	40	X	40	X	40	X	50	50	50	50	50	50	50	30	15	620
3	30	30	30	30	40	40	40	40	40	50	50	X	50	X	50	50	50	30	16	650
4	30	30	30	30	40	40	40	40	40	50	50	50	50	50	50	X	50	X	16	670
5	30	30	30	30	40	X	40	X	40	X	50	X	50	X	50	50	50	30	13	520
6	30	30	30	30	40	X	40	X	40	X	50	50	50	50	50	X	50	X	13	540
7	30	30	30	30	40	40	40	40	40	50	50	X	50	X	50	X	50	X	14	570
8	30	30	30	30	40	X	40	X	40	X	50	X	50	X	50	X	50	X	11	440

* = Pre-planting irrigation; ** = The number of days between successive irrigation was 12 (the interval of irrigation was extended due to conflict of water) X = irrigation skipped

Table 5: Crop Input Parameters of the Model.

Parameters	Value
Maximum rooting depth	1.2 m
Maximum harvest index	0.34*
Harvest index adjustment factor for the flowering stage	0.45**
Harvest index adjustment factor for the maturity stage	0.5**
Radiation extinction coefficient	0.55**
Maximum leaf area index	$0.35 m^2/m^2$
RUE (establishment and vegetative stages)	0.25 g/MJ**
RUE (flowering and maturity stages)	0.23 g/MJ**
Base temperature	8^oC
Optimal temperature	24^oC
Fraction of the growth duration at which leaf area index starts to decline	0.75*
Days after planting at which establishment growth stage starts	0*
Days after planting at which vegetative growth stage starts	23*
Days after planting at which flowering growth stage starts	64*
Days after planting at which maturity growth stage starts	93*
Peak crop water use (kc) coefficient	1.2
Soil dependent transpiration constant	0.018 m/day**
Evaporation coefficient for bare soil	1.05
Growth shape factor GSF	1120
b = exponent in the LAI equation	-17.2

*= data obtained from field experimental data; ** = final values obtained through model calibration

Leaf area index determination

The leaf area index (LAI) was computed from data obtained from photosynthetic active radiation (PAR) measurement. PAR was measured using an Accupar Ceptometer (*Decagon Ltd, UK*) above and below the crop canopy fortnightly in each plot.

The PAR data collected were used to compute leaf area index (LAI) for each treatment using a re-arranged form of Yang *et al*. (2004) equation given as:

$$LAI = -\frac{1}{REXF} \ln\left(1.0 - \frac{BPAR}{APAR}\right) \quad \textbf{(2)}$$

Where BPAR is photosynthetic active radiation measured below the crop canopy, just above the ground level; APAR is photosynthetic active radiation measured above the crop canopy; LAI is leaf area index, and REXF is radiation extinction coefficient, taken as 0.55 for the maize crop [26].

Cumulative Biomass Yield Measurement

The biomass production was monitored throughout the crop growing season. Destructive sampling was done fortnightly from the start of the vegetative growth stage to crop maturity by cutting the above ground biomass from an area of 1.35m^2 in the designated plots. The samples were oven-dried for 72 hours at 65^oC (Adiku et al., 2001) to constant weight and weighed.

Biomass Yield at Harvest and Grain Yield Measurement

Three middle rows in each plot constituting an area of 2.25 m by 3.5 m were harvested by cutting the aboveground dry matter in each plot and weighed. The three middle rows were harvested in order to minimize border effect on the yield results. After weighing the dry matter, the maize cobs were removed from the stalks, threshed and weighed to obtain the grain weight. The ratio of the grain yield to the biomass yield at harvest constituted the harvest index of each plot.

Input Data to the Model

The input data used in running the model include daily weather data (maximum and minimum temperatures and wind speed (summary given in Table 1) obtained from the weather station in the study area; soil input data from the experimental site (Table 2), irrigation scheduling observed for each treatment (Table 4), and crop input data (Table 5). The weather data were used by the model to compute daily reference evapotranspiration based on the FAO-Penman-Monteith model (Allen, et al., 1998); relative humidity and solar radiation were estimated from the temperatures data as detailed in FAO-56 (Allen, et al., 1998). The model runs from the date of planting to date of physiological maturity.

Comparing Model Simulated and Field Measured Data

The comparison between the model predicted values and the field-measured values was carried out using statistical indices like the root mean square error (RMSE), coefficient of variation (CV), modeling efficiency (EF) and coefficient of residual mass (CRM). These statistical indices were selected to adequately evaluate the model performance. The RMSE, CV, EF and CRM were given (Mahdian and Gallichard, 1995; Krause et al., 2005; Nash and Sutcliffe, 1970, and Antonopoulos, 1997)

$$RMSE = \left[\frac{1}{n}\sum_{i=1}^{n}(P_i - O_i)^2\right]^{0.5} \quad \textbf{(17)}$$

$$CV = 100 * \frac{\left[\frac{1}{n}\sum_{i=1}^{n}(P_i - O_i)^2\right]^{0.5}}{O_m} \quad \textbf{(18)}$$

$$EF = 1 - \frac{\sum_{i-1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - O_m)^2} \quad \textbf{(19)}$$

$$CRM = \frac{\sum_{i=1}^{n} O_i - \sum_{i=1}^{n} P_i}{\sum_{i=1}^{n} O_i} \quad \textbf{(20)}$$

where, P_i is model predicted values, O_i is observed values, O_m is mean of observed values, and 'n' is number of data.

RESULTS AND DISCUSSION

Leaf Area Index, Biomass and Grain Yields of the Maize Crop

Table 6 shows the field measured evapotranspiration, peak LAI (PkLAI), grain yield and biomass yield at harvest for each treatment. The Table also shows calculated seasonal evapotranspiration deficits SET_d, percent reduction in PkLAI, percent grain and biomass yield losses at harvest. The SET_d varied from 4.5% in Treatment 2 to 22 % in Treatment 8 while the reduction in PkLAI, grain and biomass yield losses varied from 1.8 % to 15.8 %, 12.0 % to 62.6 %, and 4.5 % to 45.0 %, respectively.

A comparison of the crop response parameters of the treatments in which irrigation were skipped at one growth stage only (Treatments 2, 3 and 4) shows that although there was no statistical significant difference in seasonal evapotranspiration between Treatments 2 and 4, and by extension their SET_d, there were significant differences ($P<0.05$) between their PkLAI, grain and biomass yield losses. Treatment 2 recording higher losses in LAI and biomass yield while Treatment 4 showed a higher grain yield loss. The SET_d in Treatment 2 occurred largely during the vegetative growth stage of the maize crop when irrigations were being skipped. It retarded the vegetative growth and in turn affected LAI and final biomass yield. A similar magnitude of SET_d occurring at grain filling stage only when the crop vegetation is already well established (as in Treatment 4) did not affect LAI and biomass production significantly but grain yield.

A comparison of the crop response of those treatments in which irrigation was skipped in any two growth stages (Treatments 5, 6, and 7) reveals that such scheduling practice will produce similar SET_d (as there were no significant differences in their SET). However, when the pair of growth stages in which irrigation is skipped excludes the flowering growth stage, LAI, grain and biomass yields are less affected compared to any other pairing which includes the flowering growth stage. The trend of the results reveal that evapotranspiration deficits which goes from the vegetative growth stage into the flowering stage or from flowering to grain filling stages severely reduces LAI, grain and biomass yield loss. These results agree with those reported by Pandey et al. (2000), who observed that deficit irrigation during the early vegetative growth modestly reduced LAI, plant height, crop growth rate and total biomass of the maize crop. They also noted that deficit irrigation during the late vegetative and reproductive growth stages severely reduced these growth parameters. Relieving moisture stress during the flowering growth stage by adequate irrigation will ameliorate the impact of stress on the growth and yields of the maize crop during the vegetative and grain filling stages.

Comparison of Simulated and computed Leaf area index

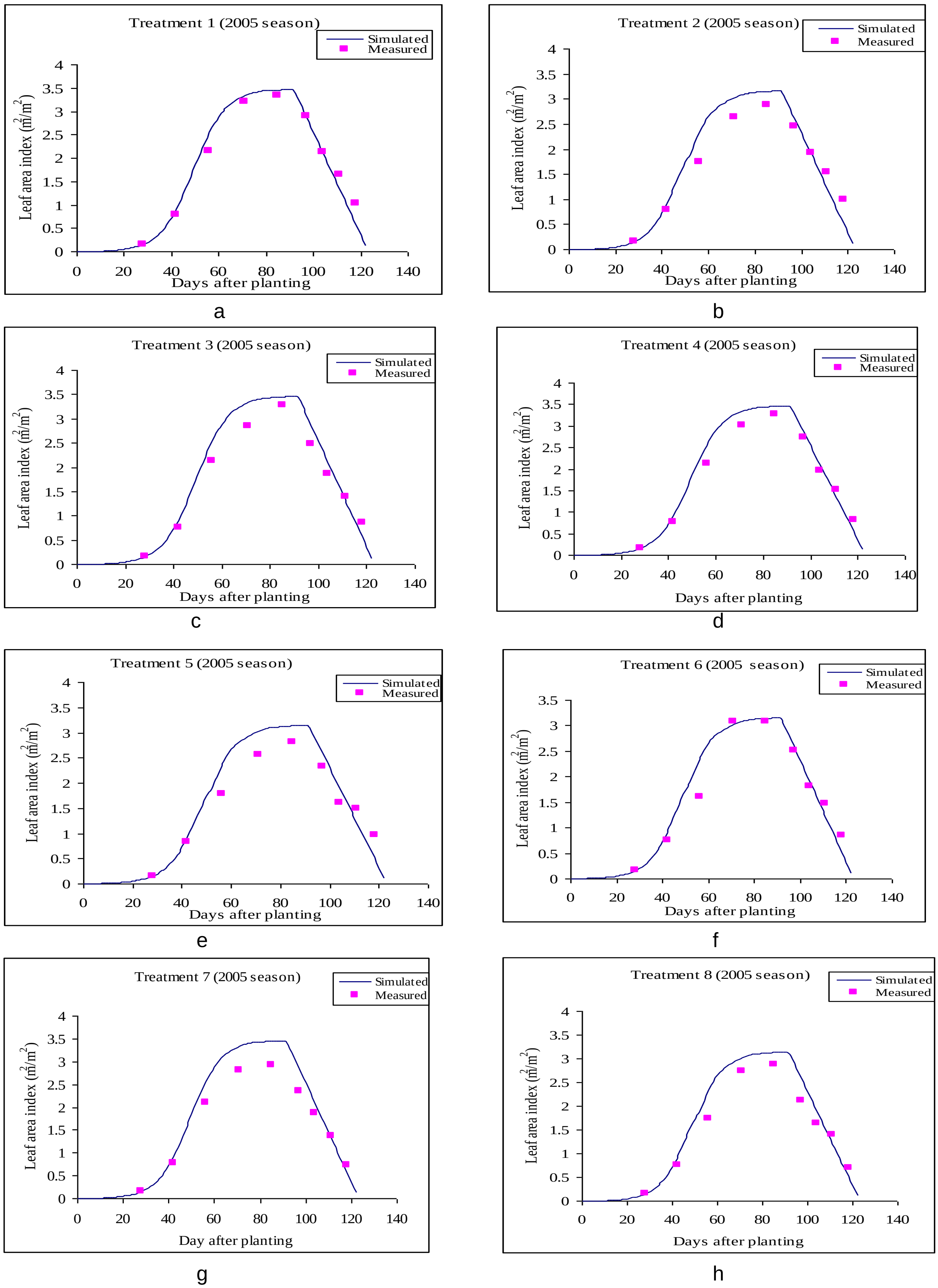
Figure 1 (a-h) show the graphical comparisons of the simulated and computed leaf area index (LAI). The computed LAI were based on Eq.2 while the simulated LAI were based on Eqs.11 to 16. It may be observed from the Figures that there is fairly close agreements between simulated and field obtained observed leaf area

Table 6: Seasonal Evapotranspiration, Crop Growth Parameters and their Corresponding Reduction Due to Evapotranspiration Deficits.

Treatment	SET (mm)	Peak LAI (m^2/m^2)	Grain Yield (kg/ha)	Biomass Yield at Harvest (kg/ha)	SETd (%)	Reduction in PkLAI (%)	Yield Loss (%)	Biomass Yield Loss (%)
1 (TR_{1111})	514.2 a	3.35 a	4349.2 a	12672.7 a	0.0	0.0	0.0	0.0
2 (TR_{1011})	491.2 b	2.89 c	3828.6 b	11401.2 b	4.5	13.7	12.0	10.0
3 (TR_{1101})	468.0 c	3.29 a	3257.1 c	11673.7 a	9.0	1.8	25.1	7.9
4 (TR_{1110})	488.6 b	3.28 a	3352.2 c	12104.8 a	5.0	2.0	22.9	4.5
5 (TR_{1001})	450.6 c	2.82 c	2476.2 d	8575.2 d	12.4	15.8	43.1	32.3
6 (TR_{1010})	441.1 c	3.08 b	2844.4 c	10534.9 c	14.2	8.1	34.6	16.9
7 (TR_{1100})	439.9 c	2.94 c	2431.7 d	9026.4 d	14.4	12.2	44.1	28.8
8 (TR_{1000})	398.9 d	2.87c	1625.4 e	6966.7 e	22.4	14.3	62.6	45.0

Table 7: Statistics of the Comparison between Simulated and Measured Leaf Area Index.

Statistical indices	Treatments							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
RMSE (m^2/m^2)	0.24	0.32	0.29	0.23	0.35	0.29	0.35	0.32
CV (%)	12.3	19.2	16.4	12.5	21.4	17.0	20.7	20.4
EF	0.95	0.86	0.91	0.95	0.96	0.91	0.86	0.87
CRM	0.01	-0.05	-0.09	-0.06	-0.09	-0.03	-0.14	-0.12



Figures 1 a-h: Comparison of Model Simulated and Field Observed LAI.

were also very good (> 80%), which implies a close agreement between model simulated and index for all the treatments. The simulated LAI came to a peak about the same period in the crop-growing season as the field experiments. However, in few cases the simulated peak values were higher than field measured values, which implies that the model had over predicted LAI under such treatment.

Table 7 shows the statistical indices of the comparison between the simulated and measured LAI. The RMSE ranged between 0.23 and 0.35m^2/m^2, which were large implying a good measure of degree of precision between the simulated and field-observed data. The coefficients of variation (CV) were all less than 30 %, which can be classified as moderate and within acceptable range for agricultural field experiments. The modeling efficiencies (EF) were also very good (> 80%), which implies a close agreement between model simulated and field-measured data. The coefficient of residual mass (CRM) which is a measure the degree of over- or under- prediction of the model, confirmed that the model over predicted LAI by between 3 and 14 % for the entire deficit irrigated treatments. Only for the fully irrigated treatment that the model under predicted by 1 %. These percentages of under- or over-predictions are however within acceptable range.

The performance of the model in simulating LAI compared favourably with those reported by Cavero *et al*. (2000) when they compared simulated and measured LAI of irrigated maize in Zaragoza, Spain using $EPIC_{phase}$ and a modified version of $EPIC_{phase}$ models. They obtained RMSE of 1.08 and 0.52 m^2/m^2 for $EPIC_{phase}$ model and modified $EPIC_{phase}$ model, respectively. Based on the high correlation between the simulated and field observed data, ISIAMod can be regarded to have performed well in simulating LAI of the maize crop.

Comparison of Simulated and Field-Measured Biomass Production

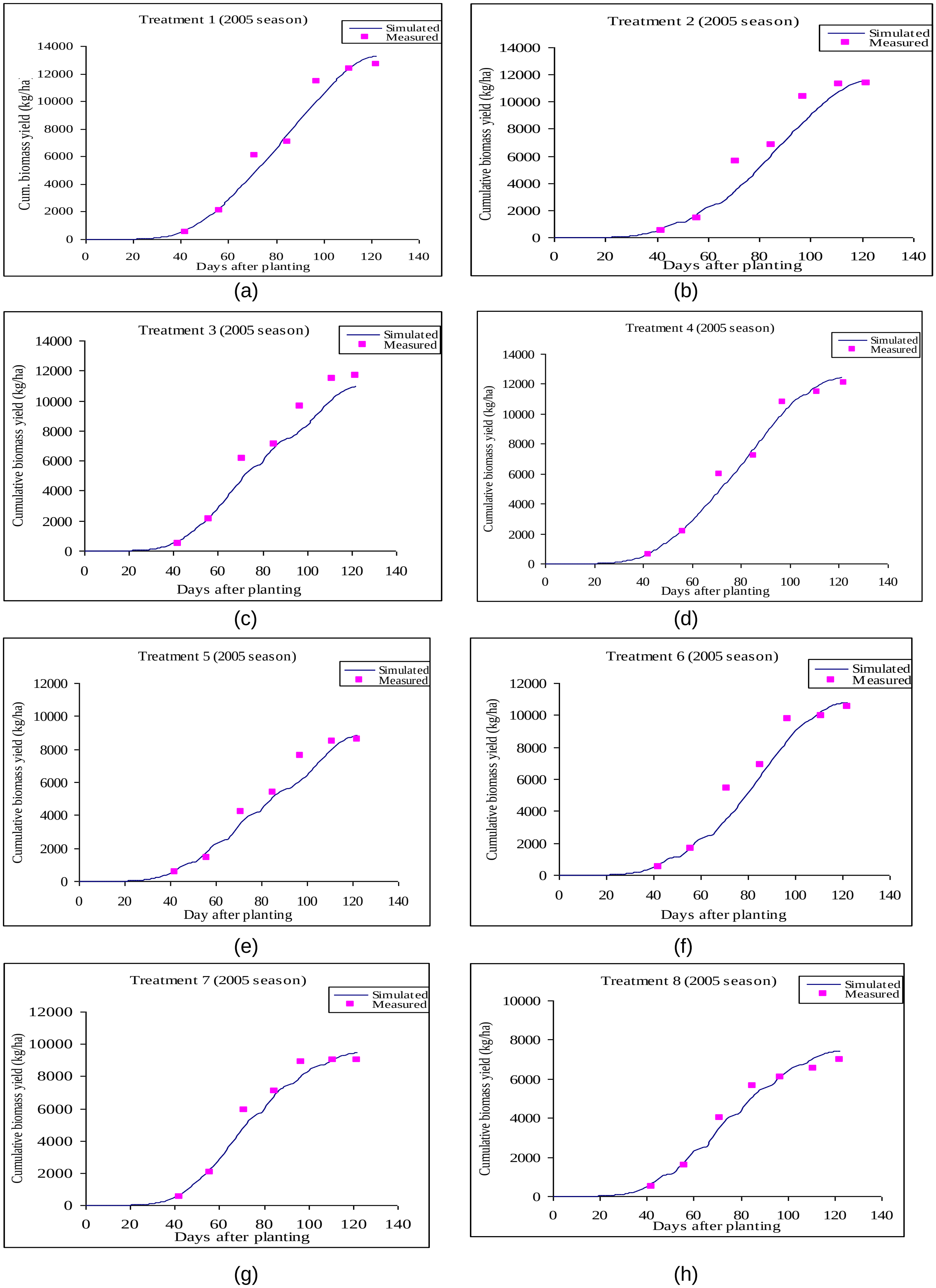
Figures 2 (a-h) show the graphical comparisons of simulated and field measured cumulative biomass production. There was good agreement between measured and simulated data for all the treatments. The trend of the cumulative biomass yield graphs was similar to what Stockle et al. (1994), Arora and Gajri, (2000), and Yang *et al*. (2004) obtained for maize crop using CropSyst, SUCROS, and Hybrid-Maize models, respectively. A wave-like pattern can be noticed in the graphs of those treatments (Treatments 2 to 8) in which irrigation were skipped at one growth stage or another. The step-like shape occurred during the periods of the crop growth when irrigation was skipped. The step-like trend was an indication of little or no increase on cumulative biomass at that period.

This suggests that withholding the regular weekly irrigation resulted in slow growth and biomass accumulation, until subsequent irrigation when moisture was sufficiently available to the plant. These results confirm the findings of Pandey *et al*. (2000).

Table 8 shows the statistics of the comparison between simulated and measured biomass yield for the 2005 season. The modeling efficiencies (EF) were quite high (>90 %) However, a tendency of over prediction was noticed for Treatments 2, 3 and 6. Nevertheless, the general performance of the model in simulating biomass yield was high. The EF obtained compared closely with values reported by Panda et al (2004) when they compared field measured biomass yield of when they compared field measured biomass yield of irrigated maize in Kharagpur, India, with those simulated using CERES-Maize model. They reported EF of 0.96. However, the RMSE value of this study was quite higher than that reported by Panda et al (2004) who reported the RMSE of 202 kg/ha.

Comparison of Simulated and Field Measured Biomass Yield at Harvest and Grain Yield

Figure 3 shows the comparison between simulated and measured final biomass yield at harvest, while Figure 4 shows similar comparison for grain yield. The coefficients of determination (r^2) were high for both parameters. The RMSE, CV, EF, and CRM of the comparison between simulated and measured the biomass yield at harvest were 448.4 kg/ha, 4.32%, 0.94, and -0.02, respectively. The indices indicate a good prediction of the final biomass yield by the model. The tendency of the model to over predict final biomass yield was only 2 %. The RMSE, CV, EF, and CRM of the comparison between simulated and measured



Figures 2 a-h: Comparison of Simulated and Field Measured Biomass Production.

Table 8: Statistics of the Comparison between Simulated and Field Measured Cumulative Biomass.

Statistical indices	Treatments							
	1	2	3	4	5	6	7	8
RMSE (kg/ha)	767.3	1113.4	973.3	557.7	661.7	894.0	526.9	394.6
CV (%)	10.26	16.41	14.00	8.77	12.76	13.98	8.68	8.82
EF	0.97	0.93	0.94	0.98	0.99	0.94	0.97	0.99
CRM	0.02	0.09	0.10	0.02	0.06	0.07	0.03	-0.01

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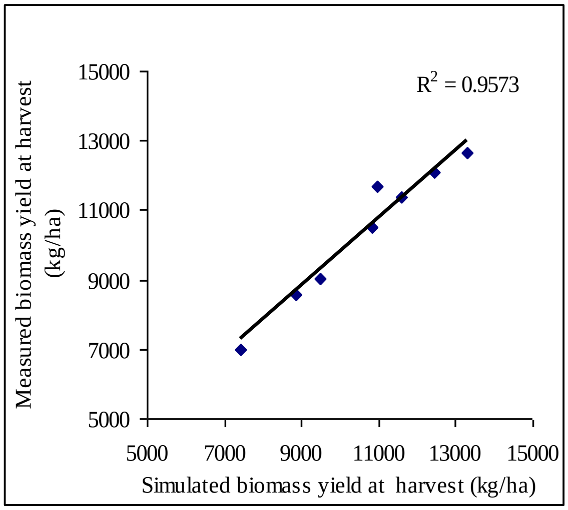

Figure 3: Comparison of Simulated and Measured Biomass Yield at Harvest.

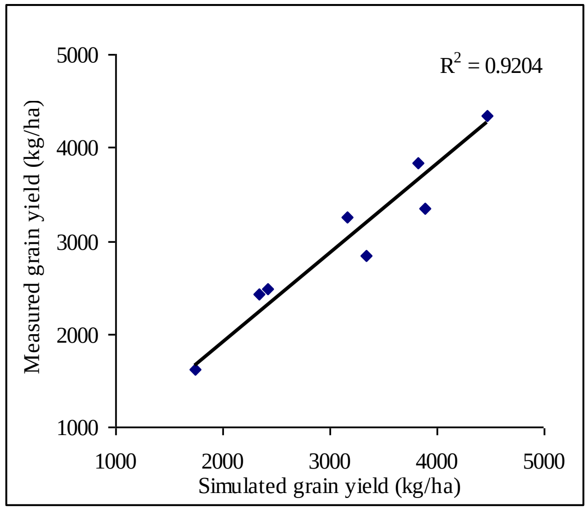

Figure 4: Comparison of Simulated and Measured Grain Yield.

the grain yield were also obtained as 270.8 kg/ha, 8.96%, 0.89, and -0.04, respectively. The indices also indicate a good prediction of the grain yield by the model since the tendency to over predict was only 4%. The close agreement between model simulated and measured grain yield implies that the model adequately simulated grain yield of the maize crop.

CONCLUSION

A physical based simulation model was used to simulated crop response to deficit irrigation scheduling practice for maize crop in IZTRS in Igurusi, Mbeya, Tanzania. The model simulation closely agreed with field observed leaf area index, progressive biomass production, final biomass yield at harvest and grain yield. The modeling efficiencies for all the parameters simulated were above 80%, the coefficient of variations between the simulated and measured parameters were below 20% which is within acceptable range for field crop. The model tendency to either over- or under predicts all the parameters simulated for very below 10 %. The simulation performance was therefore considered as good.

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