DEVELOPMENT OF DEFICIT IRRIGATION SCHEDULLING STRATEGIES FOR MAIZE CROP UNDER GRAVITY-DRIP IRRIGATION SYSTEM

BY

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JUNE, 2016

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BY

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A THESIS SUBMITTED TO SCHOOL OF POST GRADUATE STUDIES, AHMADU BELLO UNIVERSITY ZARIA, IN PARTIAL FULFILMENT FOR THE REQUIREMENTS FOR THE AWARD OF DOCTOR OF PHILOSOPHY IN AGRICULTURAL ENGINEERING

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JUNE, 2016

DECLARATION

I hereby declare that this work in the thesis entitled **'DEVELOPMENT OF DEFICIT IRRIGATION SCHEDULLING STRATEGIES FOR MAIZE CROP UNDER GRAVITY-DRIP IRRIGATION SYSTEM'** has been carried out by me and it is a record of my research work. This work has never been presented or accepted in any previous application for the award of higher degree. All sources of information are acknowledged by means of references.

..... Date.....

OIGANJI EZEKIEL

CERTIFICATION

This thesis entitled "**DEVELOPMENT OF DEFICIT IRRIGATION SCHEDULLING STRATEGIES FOR MAIZE CROP UNDER GRAVITY-DRIP IRRIGATION SYSTEM**" by OIGANJI EZEKIEL, meets the regulation governing the award of the degree of Doctor of Philosophy of Agricultural Engineering of Ahmadu Bello University, Zaria, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

To God who lightens my path, the source of my inspiration and upholder of my destiny, who preserved my life on the 9th September, 2015 when armed robbers attacked my family; and to every one who contributed greatly to my well-being.

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ABSTRACT

Among other ways of effective water management strategies is the use of drip irrigation system and adoption of deficit irrigation schedulling strategy which is not common in the study area. Effective water management is a key to improving agricultural water management, enhancing crop production and improved sustainability of irrigated agriculture. In the past, outcome of any water management strategy could only be known after field experiment, in recent times, means of evaluating the implications of irrigation schedules without field experiment is fast gaining grounds with the use of models. However, there is need for proper evaluation of developed irrigation schedulling options with the use of models for optimal water management and crop response, before recommendation can be made to relevant bodies. This research work presents scenarios studies for different developed irrigation schedulling options for a drip irrigated maize crop at the Institute for Agricultural Research (I.A.R) irrigation farm Samaru-Nigeria during 2012/2013 and 2013/2014 cropping season using a computer-based model. The experiment consisted of eight (8) treatments replicated three times and laid in a randomized complete block design. The water application was regulated at selected crop growth stages. The test crop was SAMMAZ 14 early maturity maize variety. AquaCrop, a decision support model was calibrated and validated with data obtained from the field, and later used to simulate impact of developed schedulling strategies on yields, soil water balance and water productivity of a drip irrigated Maize. It was further, used to generate scenario of different irrigation schedulling outcome which were interpreted. A drip irrigation setup with 72 laterals each 5m long and 16 mm diameter with inline emitters was used in the experiment. The results of the hydraulic characteristics were: The average variation of the emitter flow rate was found to be 19.7% the emission uniformity calculated was 92%, while the distribution uniformity was 91.9% which signified an even distribution of water through the system. The average discharge coefficient of variation was 6.34 % and the average coefficient of variation uniformity was calculated as 93.6 %. The overall application efficiency of the system was 92.2% and the overall average dripper discharge was found to be 0.557 l/hr. Grain and biomass yields, harvest index, seasonal evapotranspiration and crop water productivity were determined. The grain and biomass yields ranged from 1.56 to 3.52 t/ha and 5.63 to 11.53 t/ha, respectively, while the seasonal evapotranspiration varied from 280 to 483 mm across seasons. The general trend of the results suggests that skipping regular irrigations may be advantageous if such is done at grain-filling stage, though most of the time this stage is intercepted by rain. Performance evaluation was carried out, The CRM shows that the model has a tendency to over -predict grain and biomass yield at harvest by 3 and 4 % and under- predict seasonal evapotranspiration by 2%, over-predict grain water productivity by 3% and biomass water productivity by 24%. The modelling efficiencies for grain water productivity and biomass water productivity were 50 and 90%. The scenario studies shows that the peak grain and biomass yield value of 3273 and 10492kg/ha was recorded when 20mm WAD with 3-day irrigation interval was applied across all the growth stages; the irrigation water productivity with respect to grain yield and biomass yield were 0.83 kg/m^3 and 2.65 kg/m^3, which implies that about 830 g of maize grain and 2.65 kg of dry matter was produced from every cubic meters of water. Increasing the interval from 3 - 6 days

led to grain yield reduction of 14.3, 30.8 and 48%, respectively, while the biomass yield reduction were 15.4, 31.3 and 45%, respectively. Imposing deficit at three growth stages led to grain and biomass yield reduction ranging from 14.3 - 30.8%. There was percentage grain yield increase value of 0.21, 1.84, and 1.22% for the following plant densities, 55,556 74,074 and 66,667, while percentage reduction value of 0.95% was recorded when 44,444 plants/ha was adopted.

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ACRONYMS AND ABBREVIATIONS

A	Total area of treatment
AE	Application Efficiency
ASAE	American Society of Agricultural Engineers
B	Biomass
BWP	Biomass water productivity
BWPp	Biomass water productivity predicted
BWPm	Biomass water productivity measured
BY	Biomass yield
Bym	Biomass yield measured
Byp	Biomass yield predicted
Cc	Canopy Cover
CCx	Maximum canopy cover
CCo	Canopy cover per seedling
CDC	Canopy decline coefficient
CGC	Canopy growth coefficient
CRM	Coefficient of residual mass
CV	Coefficient of Variation
CV_q	Discharge Coefficient of Variation
CV_u	Discharge Coefficient of Uniformity
DAP	Days after planting
DRET	Daily Reference Evapotranspiration

DU	Discharge Uniformity
E	Evaporation
E_a	Irrigation Application Efficiency
EF	Modelling Efficiency
ET	Evapotranspiration (Seasonal evapotranspiration)
ETa	Actual crop evapotranspiration
ET_o	Reference Evapotranspiration
EU	Emission Uniformity
F	Flowering stage
FAO	Food and Agricultural Organization
FC	Field Capacity
G	Grain-filling stage
Girr	Gross Irrigation
GMC	Gravimetric Moisture Content
GWP	Grain water productivity
GWPp	Grain water productivity predicted
GWPm	Grain water productivity measured
GY	Grain yield
Gyp	Grain yield predicted
Gym	grain yield measured
HI	Harvest Index
I	Seasonal irrigation depth
IAR	Institute for Agricultural Research

IntL	Precipitation intercepted by the crop canopy
IWP	Irrigation water productivity
K_s	Average stored Water in the root zone
Ky	Crop yield response factor
Kcbx	Maximum basal crop coefficient
Ksat	Saturated hydraulic Conductivity
LD	Length of Lateral lines
l/hr	Liter per hour
ml/hr	Mililiter per hour
Nd	Number of drip lines
N_{irr}	Net Irrigation
P	Mean of input
Pcd	Plant crown diameter
P_{eff}	Effective rainfall
P_{tot}	Total rainfall
Pe	Prediction Error
PWP	Permanent wilting Point
Q	Single emitter discharge
Q_{av}	Emitter Flow Variation
R	Amount of Rainfall
R^2	Coefficient of determination
Ra	Extra terrestrial radiation for daily periods
RD	Rain depth

rd	Inter-row distance
RMSE	Root Mean Squared Error
R_f	Amount of runoff
SB_E	Spacing between emitters
Sc	Sensitivity Coefficient
SIWA	Seasonal irrigation water applied
SWUp	Seasonal water use predicted
SWUm	Seasonal water use measured
T	Transpiration
TAW	Total available water
Tmax	Daily maximum temperature
T_{mean}	Daily mean temperature
Tmin	Daily minimum temperature
TSWA	Total seasonal water applied
Tr	Crop transpiration
t/ha	Tonnes per hectare
v	volume of water collected
V	Vegetative stage
V_{gr}	Volume of Gross Irrigation
WAR	Wetted Area
W	Mean of output
WAD	Water application depth
WP	Water productivity
Y	Final yield

CHAPTER ONE

INTRODUCTION

1.1 Background of Study

Management of irrigation water has become needful for sustainability of agriculture in Nigeria. Some farmers in Nigeria irrigate until their fields are inundated; they seldom know the depth of water to apply per irrigation, which leads to flooding and rise in water table. This call for a paradigm shift in the way irrigation is practiced in Nigeria from maximizing yield per unit area to sustainability of irrigation as a whole; which entails adoption of effective irrigation water management strategies that could help to maximize yield per unit of water applied, minimizing energy requirement and maximizing the return for irrigation. The call to improve the efficiency and productivity of water use for crop production has never been more urgent than now because of the emerging threat to sustainability of agriculture (Kendall, 2011; Igbadun *et al.,* 2012).

Some of the effective water management strategies are the use of drip irrigation system and adoption of deficit irrigation schedulling. Drip irrigation system is one of the fastest expanding technologies in modern irrigated agriculture with great potential for achieving high effectiveness of water-use. It allows judicious use of water and fertilizer during irrigation of a wide range of crops (Segal *et al.,* 2000; Mofoke, 2006; Oyebode *et al*., 2011). Deficit irrigation schedulling has been recognized as a viable practice that could lead to increased crop yield, reduced negative environmental impact and improved sustainability of irrigated agriculture (Igbadun, 2008; FAO, 2012). Regulated deficit irrigation schedulling practice is the technique of reducing the amount of water applied per irrigation at some stages of the crop growth with the aim of saving water and in some cases energy (Prichad *et al*., 2004; Zhang *et al*., 2004).

Growth-stage deficit irrigation schedulling involves applying water less than the crop water requirement at some growth stages, considered less critical to moisture stress while applying it to meet full crop water requirement at other growth stages (Hamid *et al.,* 2009; Himanshu *et al.*, 2012).

Evaluation of irrigation schedulling methods can be carried out directly by conducting field trials. However, this approach is always expensive, time consuming, subject to uncontrolled environmental condition and practically difficult for researchers to analyze long-term effects and large impact scenarios beyond experimental sites and years. An easier option is to use crop simulation models for the exercise (Igbadun, 2008). Crop simulation models are computer software describing the dynamics of the growth of a crop in relation to the environment (Kumar and Ahlamat, 2004; Oguntunde, 2004; Abedinpour *et al*., 2012).

Maize is the third most important cereals in the world after rice and wheat, useful both for human and animal consumption (FAO, 2000). In 2008, the world production of maize was 822.7 million tonnes; while 53.4 million tonnes was estimated in Africa and 7.5 million tonnes in Nigeria (FAO, 2010). Among all herbaceous crops, none occupies a larger land area in Nigeria than maize. It is used as raw material for industrial products, forage, silage and grains, besides being a staple food in many countries including Nigeria (Babaji *et al*., 2007, Hussein *et al*; 2011, Mani *et al.,* 1998, Mani *et al.,* 2006a; Mani *et al.,* 2006b; Shaib *et al.,* 1997).

1.2 Statement of the Problem

The estimated average annual growth rate of maize production in Nigeria was 5.46% about twice the projected value of 3.2% needed to meet demands; despite the increase

in production, the demand for maize is higher even than the target set for self sufficiency (Ado *et al.*, 2007). Maize is one of the crops cultivated under irrigation in the Northern Guinea Savannah. However, the zone is characterized by variable and erratic precipitation, which is largely responsible for the low water productivity in the study area. Consequent upon this fact, improving the water use efficiency for maize production with the use of drip irrigation is therefore of paramount importance (Karlberg and Penning de Vries, 2004; Hussein *et al*; 2011).

The complexity of emitters in drip systems, makes it difficult to maintain precision during its production, as a result of changes in temperature, mould damage and non-uniform mixing of raw materials. These are some of the factors affecting emitter homogeneity. Similarly, field evaluation of the hydraulic characteristics of the system under local conditions of the Guinea Savannah ecological zone has not been fully explored (Oyebode *et al.*, 2011).

Research results documented on deficit irrigation schedulling are very few in the sub-Saharan African countries and for Samaru-Nigeria in particular. Igbadun (2012) for instance, reported field experiments on the impacts of methods of administering growth-stage deficit irrigation on yield and soil water balance of a maize crop in Samaru. Other investigators (Halilu, 2014; Ismail, 2014) worked on water use for vegetable crops of water melon and tomatoes in Samaru and Kadawa, Nigeria. Thus, knowledge gaps remain as to the growth stage deficit irrigation tolerance limit for maize crop under different soil types, climatic conditions, different methods of administering deficit irrigation and the corresponding impacts on yield, soil water balance and water productivity. This suggests that more research work that could be applied beyond years, site and climatic conditions is needed; which can only be possible through the use of a

model, such as the Aqua Crop model. The model is not new, but yet to be explored by irrigators and researchers in the study area.

1.3 Justification

Optimal irrigation quantities and corresponding impact on yield varied along crop growth stages is essential for sustainable production and water savings (Molden *et al.*, 2001; Dabaeke and Aboudrare, 2004). However, before recommendation can be made on appropriate irrigation schedulling strategies for optimal water management to farmers, there must be knowledge on how different irrigation schedulling approaches affect crops and their environment. If a field study is to be done to answer this question, it will take several years and a high cost with several uncertainties (Igbadun, 2008).

One cheap and efficient way to conduct an evaluation of the impacts of irrigation schedulling practice on a long-term basis is the use of a computer-based simulation model, such as AquaCrop amongst others, which has not been previously evaluated for simulating maize growth and yield in the study area. The outcome of such evaluations will constitute a body of knowledge that can be used to advise and help farmers plan for expected returns. It will also help projects managers, consultants, irrigation engineers and agronomists to increase crop water productivity and optimal water management decision (Kirnak and Demirtas, 2006).

This research work presents the use of Aquacrop crop simulation model developed by FAO (Steduto *et al.*, 2009; Raes *et al.*, 2009) to explore scenarios that will help farmers plan for future water allocation, improve overall knowledge and ability to effectively simulate the interaction of yield and water under stressed condition as it affect soil water balance, water productivity extending the results beyond the site, years and climatic condition.

1.4 Aim and Objectives of the Study

The aim of this study was to develop deficit irrigation schedulling strategies for a maize crop under gravity-drip irrigation system.

The specific objectives are to:

i. Evaluate performance indices of the gravity drip irrigation system;
ii. Determine yield and water use response of the maize crop to deficit irrigation schedules;
iii. Calibrate and validate the AquaCrop model for deficit irrigated Maize; and.
iv. Determine the effect of deficit irrigation schedulling scenarios on yield and water productivity of the maize crop.

CHAPTER TWO

LITERATURE REVIEW

2.1 Drip Irrigation Hydraulics

Drip irrigation is a method of watering plants frequently and with a volume of water approaching the consumptive use of plants, thereby minimizing such conventional losses such as deep percolation, runoff and soil water evaporation (Mofoke *et al.*, 2006). More plants can be irrigated per unit of water with less labour using drip irrigation system achieving water savings of 50-80 per cent, crop production per unit of water consumed by plant evapotranspiration increased from 10 to 50 per cent (Ramalan *et al*., 2010; Angela 2012).

Drip irrigation is accomplished by using small diameter plastic lateral lines with devices called emitters or drippers at selected spacing to deliver water to the soil surface near the base of the crops. The system applies water slowly to keep the soil moisture within the desired range for plant growth. The source of irrigation water has to be elevated above the ground surface to create the necessary pressure head to enable water release at all emitter points. In most cases, a drip irrigation system consists of raised water container, mainline, sub-mainline, drip laterals, filters, pressure gauges, flow meter and fittings (elbow, tee, nipple, socket, end cover, gate valve, ball valve, amongst others) (Mofoke, 2006).

Consequently, many farmers have turned to drip irrigation and have enjoyed improved profitability by increasing crop yield and quality while at the same time reducing costs from water, energy, labour, chemical inputs and runoff. Many landscapers have also enjoyed significant water and capital investment savings using drip irrigation, while simultaneously improving plant vigour by delivering water and nutrients directly to the

plant roots and avoiding unnecessary wetting of plant leaves. The main disadvantages of drip method are their comparatively high initial cost, proneness to clogging, tendency to build up salinity and where improperly designed too partial and spotty distribution of soil moisture (Ramalan *et al*., 2010).

It is nearly impossible and practically infeasible for any irrigation system to supply exactly the same amount of water to all plants within a field, which may be due to hydraulic variation results from pressure head difference (Mofoke, 2006).

The hydraulic characteristics of a drip system involve how to supply each plant with the calculated water requirement at the same rate. The uniform application of water along the lateral line is essential so that each part of the irrigated area receives the same amount of water. However, as water flows from one end to the other, there will be head loss which results in uneven distribution of discharge from the outlets over the lateral lines (Ramalan *et al*., 2010).

In drip irrigation system, water flows under low pressure to a network of closely spaced outlets which discharge water slowly at virtually zero pressure with the purpose of supplying water to limited soil volume in which active root uptake can take place (Victor *et al.,* 2008). The design of a trickle system depends on determining the total flow and the energy losses of each of the laterals, the mains, and the sub mains, all of which distribute irrigation water (Ahmed, 2006). The most widely accepted hydraulic performance parameters used in evaluating drip irrigation systems are: emitter flow rate, emitter flow rate variation, emission uniformity and distribution uniformity (Mofoke, 2006).

2.1.1 Measures of Discharge Uniformity (DU)

Distribution uniformity is an application uniformity term commonly used in evaluating farm irrigation systems. The first requirement for an efficient operation of an irrigation system is the uniform water application, as measured by the discharge uniformity (DU). DU is computed by Eq (2.1) as given by Merriam *et al.* (1980):

$$DU = \frac{\overline{x_{tq}}}{\bar{x}} \times 100\% \quad (2.1)$$

Where:

$\bar{x}$ = Average depth of water received

$\overline{x_{tq}}$ = Average low- quarter depth of water received

2.1.2 Emitter flow variation

Emitter flow variation measures the deviation between the maximum and minimum emitter flow rates (Camp *et al*., 1997), and is given by Eq (2.2):

$$q_{av} = \frac{qmax - qmin}{qmax} \times 100\% \quad (2.2)$$

where:

qmax = Maximum emitter flow along lateral line, l/hr

qmin = Minimum emitter flow along the lateral, l/hr.

2.1.3 Emission Uniformity

Emission Uniformity is a measure of a dripper's ability to water uniformly over the surface, Michael (1978) recommended that EU values of 94% or more are desirable and in no case should the designed EU be below 90%. Thus, EU can be estimated using Eq (2.3) as cited by Michael (1998):

$$EU = 100 \left| \frac{q_{LQ}}{q_{mean}} \right| \quad (2.3)$$

where:

EU = Emission uniformity (%)

q_{LQ} = Average of the lowest quarter of the observed value (ml)

q_{mean} = Average of discharge values (ml)

2.1.4 Discharge Coefficient of Variation

Discharge coefficient of Variation is a measure of application uniformity (Wu, 1997; Camp *et al.*, 1997; Keller *et al*., 2001; Mofoke, 2006) which is calculated by Eqn (2.4):

$$CV_q = \frac{sd}{q_a} \quad (2.4)$$

where:

CV_q = Discharge coefficient of variation

Sd = Estimated standard deviation of the catch rates

q_a = Average catch rate

Keller *et al.,* (2001) recommended that the application uniformity of affordable micro-irrigation systems for small plots be expressed in terms of the coefficient of variation uniformity (CvU) expressed by Eq (2.5). They reported that CvU values should be in the range of 79 to 89% for affordable drip irrigation systems and proposed the following general standard for assessing low-cost drip irrigation systems serving small plots: Above 88% is excellent, 88 to 80% is good and 80 to 68% is acceptable.

$$CvU = 100\ (1.0-(CVq)), \quad (2.5)$$

in which the terms are as previously defined.

2.1.5 Application Efficiency

Water application efficiency is an irrigation concept that is very important in system selection, design and irrigation management. The ability of an irrigation system to apply water uniformly and efficiently to the irrigated area is a major factor influencing the agronomic and economic viability of a farm enterprise (Nega, 2009). The overall system application efficiency of drip irrigation (AE) was estimated as detailed by Vermeir and Jobling (1980) and expressed by Eqn (2.6) as :

$$AE = K_s.EU \quad (2.6)$$

where:

AE = Application Efficiency (%)
K_s = Average water stored in the root zone which expresses the storage efficiency of the soil taking into account the pressure variation in the drip system; for loam soil K_s= 1 or 100%, and other term as previously defined, and other term as previously defined.

2.2 Determination of Irrigation Water Requirement

Irrigation water depth was applied with respect to daily reference evapotranspiration, computed from climatic data as presented in section 2.6. Irrigation water application Efficiency for drip irrigation ranges from 80-95% (Mofoke, 2006), in this study 90% was used. Gross irrigation water requirement in depth of water is determined using Eq. (2.7) (Solomon, 2000):

$$G_{irr} = \frac{N_{irr}}{E_a} \quad (2.7)$$

where:

G_{irr} = Gross irrigation (mm/day),

E_a = Irrigation application efficiency (%)

Nirr = Net Irrigation (mm/day)

Thus, volume of net irrigation water requirement is calculated (Solomon, 2000):

$$V_{net\ irr} = N_{irr} \cdot A. WAR \quad (2.8)$$

where:

$V_{net\ irr}$ = Volume of net irrigation requirement at different irrigation levels (l/day)

N_{irr} = Net Irrigation at different deficit irrigation levels(mm/day)

A= Total area of Treatment plot (m^2)

WAR = wetted area ratio (%) percent of total soil which was wetted by the drip is equal to 66.7%

Volume of gross irrigation water requirement (Solomon, 2000):

$$V_{gr} = \frac{\text{Nirr .A.WAR}}{E_a} \quad , \quad (2.9)$$

in which, V_{gr}= Volume of gross irrigation requirement (l/day), at different deficit irrigation levels, and other terms as previously defined.

The water application rate, AR, is given by (Solomon, 2000):

$$\text{AR} == \frac{\text{Qave .LD.Nd}}{SB_E} \quad (2.10)$$

where:

Qave = Average emitter discharge(l/hr)

LD = Length of lateral lines (m),

Nd = Number of drip lines

SB_E= Spacing between emitters (m)

The irrigation running time, IRT, is given by (Solomon, 2000):

$$\text{IRT} = \frac{V_{gr}}{AR} \quad (2.11)$$

in which, all the terms are as previously defined.

2.3 Deficit Irrigation Schedulling

Deficit irrigation schedulling is the practice of irrigating crops below the full water requirement, which thus, leads to yield reduction (Kirda and Kanber, 1999; Igbadun *et al..*, 2012). In economic terms, deficit irrigation increases irrigation efficiency, reduce cost of irrigation and opportunity cost of water, while in ecological terms it prevents rising water tables in areas where the water levels are near the surface and minimizes leaching of agrochemicals to ground water. Deficit irrigation has several features depending on how, when, where and why it is administered. It is used to supplement rainfall during drought spells to stabilize production and where water is applied below evapotranspiration (ET) throughout the growing season (Angela, 2012).

Deficit irrigation practices differ from traditional water supplying practices. The manager needs to know the level of transpiration deficiency allowable without significant reduction in crop yields. The main objective of deficit irrigation is to increase the WUE of a crop by eliminating irrigations that have little impact on yield. The resulting yield reduction may be small compared with the benefits gained through diverting the saved water to irrigate other crops for which water would normally be insufficient under traditional irrigation practices (Kirda and Kanber, 1999)

Deficit irrigation is an optimization strategy in which water is applied during drought-sensitive growth stages of a crop. It is a well known fact that certain growth stages of crops are more sensitive to water deficits than others and consequently, water restriction is limited to drought- tolerant phenological stages such as the vegetative stages and the late ripening period. Knowledge of the marginal productivity of water allocated to each crop at different stages of its growth is thus required to arrive at an optimal sets of decision (Angela, 2012).

Doorenbos and Kassam (1979) reported that water deficits in crops and the resulting water stress have effects on crop evapotranspiration and yield. However, when the moisture stress is not severe, the adverse effect on crop yield is minimal and there can be an appreciable increase in crop water use efficiency especially when there is reduction in water losses due to evaporation, deep percolation and surface runoff.

Regulated deficit irrigation practice is the technique of withholding or skipping irrigation, or reducing the amount of water applied per irrigation at some stages of the crop growth with the aim of saving water, labour, and in some cases energy (Igbadun, et al., 2006). Deficit irrigation is conducted on crops according to their characteristics and water requirement. It causes changes in intrinsic plant physiology, biochemical processes, regulates the distribution of photosynthetic product, improves reproductive growth and leads to some degree of moisture stress on the crop and reduction in crop yield (Igbadun, *et al.*, 2006).

High-yielding varieties are more sensitive to water stress than low-yielding varieties; for example, deficit irrigation had a more adverse effect on the yields of new maize varieties than on those of traditional varieties (FAO, 1979). Crops varieties that are most suitable for deficit irrigation are those with a short growing season and are tolerant of drought (Stewart and Musick, 1982).

2.4 Growth- Stage Deficit Irrigation

Growth-stage deficit irrigation schedulling involves applying water less than crop water requirement at some growth stages considered less critical to moisture stress, while at other growth stages water may be applied to meet full crop water requirement; which is a deviation from conventional deficit irrigation as reported by Ayana (2011) and Pandey *et al.(*2000).

Growth-stage deficit irrigation can be administered in two ways: by skipping regular irrigation event at selected growth stages, but apply water to meet crop water demand at each irrigation event and the other method is to irrigate at regular interval throughout the crop growing season, but apply water less than crop water requirement at selected growth stages of the crop (Igbadun, 2012).

Both methods when compared with the conventional method have the capacity to minimize the amount of water administered in the field, where fixed frequency and water application depths are observed throughout the season as commonly practiced by farmers (Ayana, 2011). Growth-stage deficit concept offer some additional advantages since irrigation frequency is reduced, less man-hours, reduction in energy and cost which was adopted in this research (Igbadun *et al.*, 2005, 2006).

Researchers have shown that crop yield response varies with the growth stage in which an irrigation deficit is suffered (Angela, 2012). An irrigation deficit suffered at one stage in the growth cycle of the crop may have little or no significant effect on crop yield, while a deficit suffered at a more critical stage such as flowering and grain formation stage may dramatically affect yield because they are more sensitive to water shortage (Angela, 2012). Angela (2012), obtained water savings of 25- 75 per cent by applying deficit irrigation at various growth stages (establishment, vegetative, flowering and grain-filling stage) of a wheat crop on the North China plain without significant yield loss.

2.5 Growth Stages of Maize

The use of extra early varieties is an effective way of escaping havoc caused by drought. These varieties are appropriate for the Sudan savannah zone since they mature within 75-85 days (Ado *et al.*,1999). According to FAO (2013), the growth stages for maize are

as follows: the initial stage which ranges from 15-30 days; development stage, 30- 45 days, mid-season stage, 30-45 days, while the late season stage, 10-30 days.

Igbadun (2012) used three growth stages for deficit irrigation study on maize crop on the study location. These were: Vegetative (15-42); Flowering – tasseling to silking (43-63) and grain filling to physiological maturity stages (64-95); which were based on the observation of the crop growth and development of *sammaz* 14 on the field. According to FAO (2013), for maximum productivity maize requires 500-800mm of water depending on the climate, variety and agronomic practices employed.

2.6 Crop Evapotranspiration

Evapotranspiration measurement methods can be broadly classified as field and empirical methods. The principal methods of measuring actual evapotranspiration as described by Michael (1978) are lysimeter experiment, field experimental plots, soil moisture depletion and water balance method. The most commonly used empirical methods in estimating potential evapotranspiration are the Blany-Criddle method, Thornthwaite method, Penman's method, modified Penman's method, Penman-Monteith method, Christiansen method, Hargreaves method, Jansen- Haise method, and pan evaporation methods (Michael 1978).

The evapotranspiration from a reference surface not short of water is called the reference crop evapotranspiration denoted by ETo. Penman-Monteith method is generally used to estimate ETo. However, because of the absence of some parameters, Hargreaves equation was adopted for the estimation of the reference evapotranspiration in this research herein expressed as (Allen *et al.*, 1998); expressed in Eqn (2.12):

$$ET_O = 0.0023(T_{mean}+17.8)(T_{max}-T_{Min})^{0.5}R_a \quad (2.12)$$

where:

T_{mean} = daily mean temperature (^{0}C)

T_{max} = daily maximum temperature (^{0}C)

T_{min} = daily minimum temperature (^{0}C)

R_a = extra terrestrial radiation ($MJm^{-2}day^{-1}$) as detailed by Allen *et al.* (1998).

2.6.1 Crop water use

Crop water use, also known as evapotranspiration (ET), is the water used by a crop for growth and cooling purposes. This water is extracted from the soil root zone by the root system, which represents evapotranspiration and is no longer available as stored water in the soil. Consequently, the term "ET" is used interchangeably with crop water use. The evapotranspiration process is composed of two separate processes: transpiration (T) and evaporation (E). Transpiration is the water transpired or "lost" to the atmosphere from small openings on the leaf surfaces, called stomata. Evaporation is the water evaporated or "lost" from the wet soil and plant surfaces. Significant evaporation can take place only when the soil's top layer or when the plant canopy is wet. Once the soil surface is dried up, evaporation decreases sharply. Thus, significant evaporation occurs after rain or irrigation. Furthermore, as the growing season progresses and canopy cover increases, evaporation from the wet soil surface gradually decreases. When the crop reaches full cover, approximately 95 per cent of the ET is due to transpiration and evaporation from the crop canopy where most of the solar radiation is intercepted. Crop water use (ET) is influenced by prevailing weather conditions, available water in the soil, crop species and growth stage. Evapotranspiration can be derived from a range of measurement systems including lysimeter, gravimetric method, Neutron meter, soil water sensing device and even

satellite-based remote sensing (Nega, 2009).

The actual crop evapotranspiration outlined by Michael (1978) is expressed in Eqn (2.13):

$$ET_a = \sum_{i=1}^{n} \left[\frac{M1-M2}{100}\right] D_i \times Bi \qquad (2.13)$$

where:

M_1 = gravimetric moisture content (g/g) at first sampling in the ith layer;

M_2 = gravimetric moisture content (g/g) at the second sampling in the ith layer;

D_i = depth of ith layer (mm)

n = number of layers within the soil profile

B_i = apparent specific gravity of the soil layer

2.6.2 Crop Yield and Water Use

The relationship between crop yield and water use is very unique. When climatic and agronomic conditions are adequate, crop yield completely depends on the amount of water available for use by the crops. According to Doorenbos and Kassam, (1979) when economic conditions do not restrict crop production, and in a constraint- free condition, crop yield is at maximum when full water requirements are met. When water supply does not meet crop water requirement, actual evapotranspiration (ET_a) will fall below maximum evapotranspiration (ET_m) resulting to a water deficit in plant which may develop to a point where crop growth and yield are adversely affected. The effect of the magnitude and the timing of occurrence of water deficit on crop growth and yield is therefore of major importance in the schedulling available but limited water supply for

the growing period of the crop and in determining the priority of water supply amongst different crops during the growing season.

Doorenbos and kassam (1979) concluded that in order to quantify the effect of water stress, it is necessary to derive a relationship between the relative yield decrease and relative evapotranspiration deficits as shown in Eq. (2.13a)

$$(\mathbf{1 - y_a|y_m}) = \mathbf{k_y}(\mathbf{1 - ET_a|ET_m}) \quad (2.13a)$$

Where:

y_a = Actual yield (t/ha)

y_m = Maximum yield (t/ha)

ET_a = Actual evapotranspiration (mm)

ET_m = Maximum evapotranspiration (mm)

The relationship between yield and seasonal evapotranspiration can be characterized by the evapotranspiration production function. The relationship between crop yield and evapotranspiration is usually linear in the deficit irrigation range; because all the applied water is used as evapotranspiration and the water production is equal to the evapotranspiration production function (Al-Jamal *et al.,* 2000).

However, a non-linear Evapotranspiration function relationship indicates that not all water was used by the crop, because some went to deep drainage. The water production function becomes curvilinear as more of the applied water goes to deep drainage (Al-Jamal *et al.,* 2000).

Generally, a curvilinear water production function is expressed as a second order polynomial evapotranspiration production function, which can be useful to determine the capacity of irrigation systems and irrigation amount and timing, as well as to compare relative water use efficiencies. Daily and seasonal evapotranspiration varies

according to the climate, years, varieties of crops and irrigation management (Al-Jamal *et al.,* 2000).

2.6.3 Soil Water Balance

The water balance is an accounting of the inputs and outputs of water which can be determined by calculating the input, output and storage changes of water at an agricultural land. It can be by is expressed as (Allen *et al.,* 1998; Abedinpour *et al.,* 2012) in Eqn (2.14):

$$I + R = ET + Rf + intL + DP \pm \Delta S \quad (2.14)$$

Where:
Δs = difference between soil moisture content at the beginning and end of the season (mm)
ET = seasonal evapotranspiration (mm)

I = seasonal irrigation depth (mm)

R = amount of rainfall (mm)

Rf = amount of runoff (mm), which was zero in this experiment because water was confined within the basin

IntL = precipitation intercepted by the crop canopy (mm)

DP = seasonal deep percolation depth (mm)

2.6.4 Effective Rainfall

According to Sheng –Feng *et al.,* (2001) the empirical formula to estimate effective rainfall as developed by FAO (2012), which may be used for design purposes where 80% probability of the exceedance is required is given as Eqns (2.15) and (2.16), respectively.

$$P_{eff} = 0.6\ P_{tot} - 10 \quad ; \quad P_{tot} < 70mm \quad (2.15)$$

$$P_{eff} = 0.8\ P_{tot} - 24 \ ; \quad P_{tot} > 70mm \quad (2.16)$$

Where

P_{eff} = effective rainfall (mm)

P_{tot} = total rainfall (mm)

2.7 Crop Water Productivity

The productivity of the seasonal water applied which is defined as the mass of produced (kg) per volume of water applied (m^3) for biomass and grain yield were expressed as Eqn (2.17 and 2.18):

$$BWP = \frac{BY}{ET} \quad (2.17)$$

$$GWP = \frac{Y}{ET} \quad (2.18)$$

Where:

BWP = Biomass water productivity (kg/m^3)
GWP = Grain water productivity (kg/m^3)
BY = Biomass yield (t/ha)
Y = Grain yield (t/ha), and other term as previously defined.

2.8 Economic Evaluation

This is usually done by a cost- benefit analysis, Cost –benefit analysis involves weighing the expected costs against the total expected benefits of one or more actions in order to choose the most profitable options; it measures economic efficiency as a ratio of benefits to costs, evaluating alternative actions, measuring stream of benefits and costs over time resulting from a project (Nega, 2009).

The cost-benefit ratio is the best method for calculating the profitability of an investment which is consumed in one year or less. This method is most effective for investments that are consumed within one year, such as seeds, fertilizers and pesticides (Itil and Rainer, 2006). The accuracy of the outcome of a cost-benefits analysis is

dependent on how accurately costs and benefits have been estimated. The impact of a project might be zero for one area but not in another area (Nega, 2009).

2.9 The AquaCrop Model

There are several models to implement management strategies for limited available water, most of these models are complicated, and require advanced skills for their calibration, operation as well as large number of parameters. Simulation models that quantify the effects of water on yield at farm level can be valuable tools in water and irrigation management. In the case of maize, many simulation models have been tested: for example, the Cropsyst model, which is based on both water and solar radiation driven modules (Azam *et al*., 1994; Steduto, 2003; Tanner and Sinclair, 1983; Steduto and Albrizio, 2005; Steduto *et al*.,2007), WOFOST, which simulates crop growth using a carbon driven approach (Stockle *et al*., 2003), others are Ceres (Jones and Kiniry, 1986), CERES-Maize (Jones and Kiniry, 1986), Hybrid-Maize (Yang *et al*., 2004) and EPIC model (Heng *et al*., 2009; Cavero *et al*., 2000).

These models differ among themselves, and are able to simulate plant production with higher or lower degree of accuracy. Efforts to achieve a new model that is less complex with accuracy, simplicity and versality with fewer numbers of inputs have been made. An outcome of such efforts is the development of AquaCrop model, which focuses on yield response to water (Steduto *et al*., 2009).

The FAO crop model, AquaCrop, simulates attainable yields of major herbaceous crops as a function of water consumption under rain fed, supplemental, deficit and full irrigation conditions (Yang *et al*., 2004; Steduto *et al*., 2009; Lopez-Cedron, *et al*., 2008; Heng *et al*., 2009).

AquaCrop evolves from the previous Doorenbos and Kassam (1979) approach with the use of crop yield response factor (Ky) by separating ET into soil evaporation (E) and crop transpiration (Tr) and the final yield (Y) into biomass (B) and harvest index (HI). The separation of ET into E and Tr avoids the confounding effect of the non-productive consumptive use of water (E). The separation of Y into B and HI allows the distinction of the basic functional relations between the environment and B from those between environment and HI. AquaCrop is described by Steduto *et al.* (2009), while the structural details and algorithms are reported by Raes *et al*. (2009). The changes described led to Eqn. (2.19) as the core of the AquaCrop growth engine:

$$B = WP \cdot \Sigma Tr, \qquad (2.19)$$

Where

WP = water productivity (kg/m^3)
Tr = Transpiration (mm)
B = Biomass (t/ha)

For most crops, only part of the biomass produced is partitioned to the harvested organs to give yield (Y), and the ratio of yield to biomass is known as harvest index (HI), hence:

$$Y = HI.\ B \qquad (2.19a)$$

The underlying processes culminating in B and in HI are largely distinct from each other. Therefore, separation of Y into B and HI makes it possible to consider effects of environmental conditions and stresses on B and HI separately. This has fundamental implications for the robustness of the model, which is further enhanced by quantification of the harvest index day-by-day over the yield formation period. Improved knowledge of plant responses to water stress on short time scales, enhances computation capacity, and more accurate procedures to determine daily soil water

status. Thus, it is possible to simulate soil water status in daily time steps. This has allowed the important change from a static approach to a dynamic growth model.

Schematic representations of the functional relationships between the different model components depicted in the flow evolution of AquaCrop are shown in Figs 2.1 and 2.2

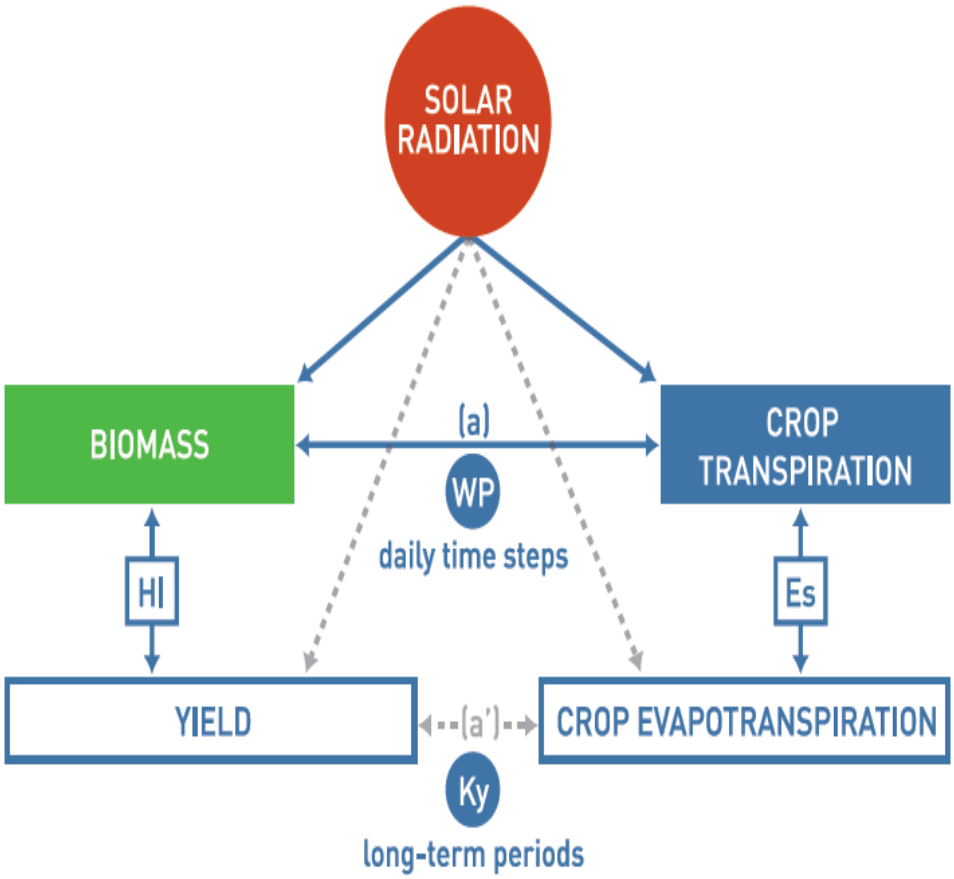


Figure 2.1 The separation of soil evaporation (E) from crop transpiration (Tr) and the attainment of yield (Y) from Biomass (B) and harvest index (HI)

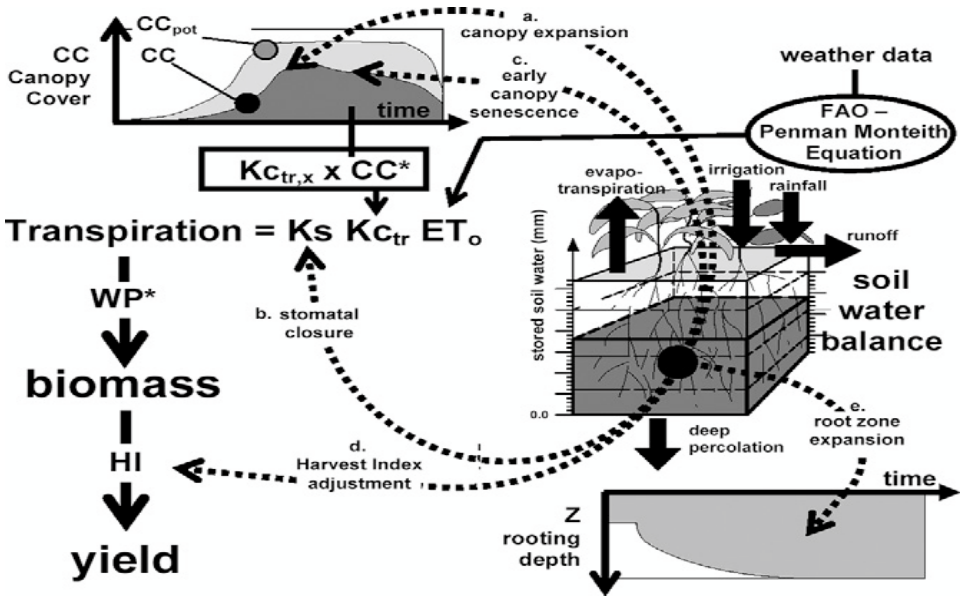


Fig 2.2 Calculation scheme of AquaCrop with indication (dotted arrows)

The growth engine of AquaCrop model is water-driven, in that transpiration is calculated first and transformed into biomass using conservative crop-specific parameters (Geerts *et al.,* 2009). The biomass water productivity is normalized for atmospheric evaporative demand and air carbon dioxide (CO_2) concentration. The normalization is to make AquaCrop applicable to diverse locations and seasons. Simulations are performed on thermal time, that is, growth degree days, where the model determines when sowing/planting starts, and also on calendar time, in daily time steps, where the model does not determine when sowing starts. The model uses canopy ground cover instead of leaf area index (LAI) as the basis to calculate transpiration and separate soil evaporation from transpiration. Crop yield is calculated as the product of above-ground dry biomass and harvest index (HI); starting at flowering, HI increases linearly with time after a lag phase, until near physiological maturity. Crop responses to water deficits are simulated with four modifiers that are functions of fractional available soil water modulated by evaporative demand, based on the differential sensitivity to water stress of four plant

processes: canopy expansion, stomata control of transpiration, canopy senescence and HI. The HI can be modified negatively or positively, depending on water stress level, timing and stress duration.

2.9.1 Sub-Models of AquaCrop

AquaCrop has four sub-model components:

1) Soil (water balance)
2) Crop: development, growth and yield
3) Atmosphere (temperature, rainfall, Evapotranspiration, and Carbon dioxide concentration)
4) Management (major agronomic practices such as planting dates, fertilizer application and irrigation).

2.9.2 AquaCrop Input Parameters

AquaCrop keeps track of the soil water balance over time, by simulating the incoming and outgoing water fluxes with well-described subroutines. The soil can be subdivided vertically up to five layers of variable depth, each layer accommodating different soil physical characteristics: the soil water content at saturation; the upper limit of water content under gravity (field capacity); the lower limit of water content where a crop can reach the permanent wilting point; and the hydraulic conductivity at saturation. From these characteristics AquaCrop derives other parameters governing soil evaporation, internal drainage and deep percolation, surface runoff, and capillary rise (Raes *et al.,* 2012).

When calculating the soil-water balance, the amount of water stored in the root zone can be expressed as an equivalent water depth or as root zone depletion. At field capacity root zone depletion is zero, and at permanent wilting point, the total available water.

AquaCrop accurately describes surface runoff, infiltration, capillary rise, soil evaporation, crop transpiration and movement of water and salt in the soil profile throughout the simulation period (Raes *et al.,* 2012).

The crop component of the model includes the following subcomponents: phenology, canopy cover, rooting depth, crop transpiration, soil evaporation, biomass production, and harvestable yield. AquaCrop considers five major components and associated dynamic responses which are used to simulate crop growth and yield development: phenology, aerial canopy, rooting depth, biomass production and harvestable yield.
The model has two options for crop growth and development processes: calendar based; in which the user has to specify planting/sowing data and thermal based on Growing Degree Days (GDD). The model determines when sowing starts (Raes *et al.,* 2012).

There are five weather input variables required to run the AquaCrop model. These are: daily maximum and minimum air temperatures (T), daily rainfall, daily reference evapotranspiration (ET_o) and the mean annual CO_2 concentration. AquaCrop has default values for several crop parameters that it uses for simulating different crops including Maize. However, some of these parameters are not universal and thus, have to be adjusted for local conditions, cultivars and management practices (Raes *et al.,* 2012).
Field management aspects are: (i) fertility of the soil for growing the crop, whether native or by fertilization; (ii) mulching of the soil to reduce soil evaporation; and (iii) use of soil bunds (small dykes) to pond water to control surface runoff and enhance infiltration. Effects of fertility on crop growth and productivity are not directly simulated. Instead, AquaCrop provides default adjustments of the pivotal crop

parameters for several limiting fertility categories, ranging from near optimal to poor (Raes *et al.,* 2012).

Simulation of irrigation management is one of the strengths of AquaCrop with the following options: rain fed-agriculture, sprinkler irrigation, drip irrigation, surface irrigation by basin, surface irrigation by border and surface irrigation by furrow. Defining the schedule by specifying the time, depth and quality of the irrigation water of each application, or allow the model automatically generate the schedule based on fixed time intervals, fixed depth per application, or fixed percentage of allowable water depletion.

Crop input parameters used in the AquaCrop model were either obtained or calculated. Crop-specific but non-location-specific parameters for major agricultural crops including maize have been determined and validated in many locations by Steduto *et al*.(2009) and are provided as default values in the model. However, some of these parameters are referred to as "*conservative"* because they do not change with geographical location, management practices and time. They were determined using data from favourable and non-limiting conditions but remain applicable for stress conditions via their modulation by stress response factors (Hsiao *et al.,* 2009; Raes *et al.,* 2009; Steduto *et al.,* 2009).

The upper and lower thresholds and the shape of the response curve are the parameters for each type of stress that define the sensitivity and severity of a depleted soil profile as shown in Fig. 2.3. The upper threshold determines when the stress begins, while the lower threshold is the point at which the physiological processes completely cease. The shape factor used in AquaCrop model describes the amplitude of the stresses which affect the crop yield. A shape factor of zero indicates highest sensitivity of crop to water stress and more than zero, an indication of less sensitivity to water stress. The water

stress coefficient was divided into expansion stress, stomata closure stress and senescence stress coefficients. These coefficients were calibrated using the experimental data to obtain a better match between the AquaCrop simulated and observed data. Some other parameters were cultivar specific or less conservative and thus have to be provided by the user and termed user-specific (Abedinpour *et al.*, 2012).

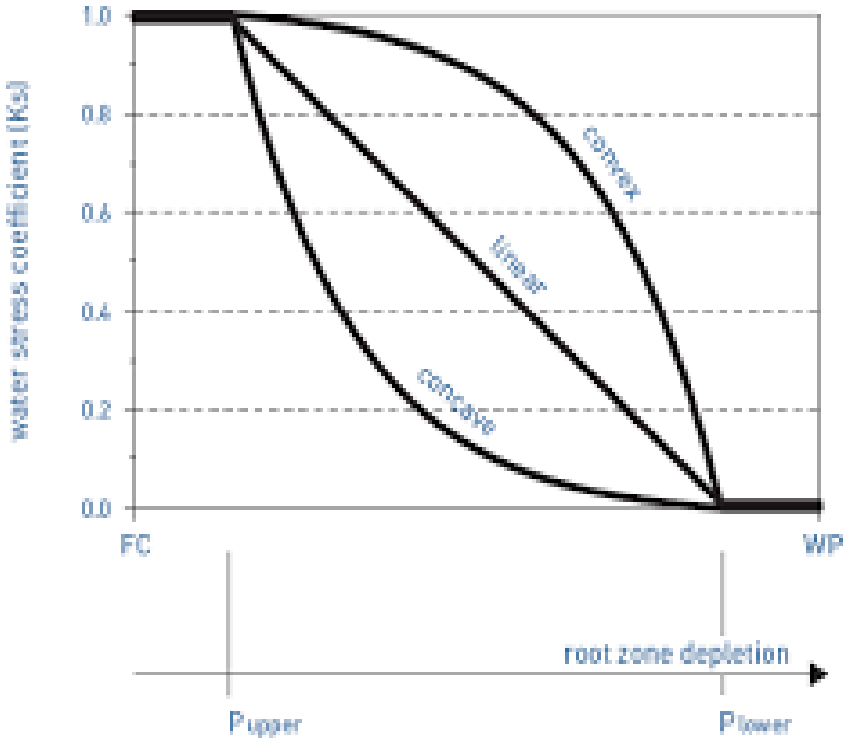


Fig 2.3: Variations of water stress coefficient for various water depletions

2.9.3 Outputs of AquaCrop Model

The main outputs of *AquaCrop* model are the yield, water use, soil water balance component (E and Tr) and yield water productivity of a crop grown at a specific location, with that climate, soil, and with a certain water supply (Steduto *et al.*, 2009).When the input information is precise, its performance is accurate, as shown in the validation tests conducted in

many locations (Todorovic *et al.*, 2009; Heng *et al.*, 2009; Farahani *et al.*, 2009; Mainuddin *et al.*, 2010).

The ability of AquaCrop to simulate yields for different crops has been extensively tested by several researchers around the globe in diverse environments and all have reported positive results, such as: barley(Araya *et al.*, 2010a), teff (Araya *et al.*, 2010b), cotton (Baumhardt *et al*., 2009; Hussein *et al.*, 2011), quinoa (Geerts *et al.*, 2009), maize (Heng *et al.*, 2009; Hsiao *et al*., 2009; Zinyengere *et al.*,2011), potato (Vanuytrecht *et al.*, 2011) , wheat (Andarzian *et al.*, 2011) and canola (Zeleke *et al.*, 2011).

The information provided by crop simulation models such as AquaCrop may be used in a myriad of ways and by many different types of users. Yield predictions may be useful for farmers, extension specialists, field consultants, engineers, water planners, economists, policy analysts, and scientists (Geerts *et al.*, 2009; Heng *et al.*, 2009; Hsiao *et al.*, 2009; Raes *et al.*, 2009; Steduto *et al.*, 2009).

2.10 Validation and Calibration of Models

Model calibration consists of changing model input parameter values to produce simulated values that are within a certain range of measured data. It involves systematic adjustment of the parameters of a model such that the model can describe more closely the system behaviour for site-specific application, hence reducing the parameter uncertainty. During the process, the structure of the model remain the same and only the model parameters are adjusted until some values are obtained which brings the model simulated outputs close to the real system data (Igbadun, 2012).

These values obtained are usually retained as the values for those parameters of the model for that site-specific application. In crop simulation models, calibration is necessary to estimate the model parameter values for different crops, cultivars and ecosystems.

Correct simulation of canopy cover is a key factor for AquaCrop calibration, as it affects the transpiration rate and consequently biomass production. Parameters affecting CC are: canopy growth coefficient (CGC), referring to the daily percentage increase in CC during growth; canopy decline coefficient (CDC), referring to the daily percentage decline in CC during late season and the coefficients for triggering water stress affecting leaf expansion and early canopy senescence. Canopy cover is estimated using Eq (2.20) as reported by Hussein *et al* (2011):

$$CC\% = \frac{Pcd}{rd} \text{ X } 100 \qquad (2.20)$$

where:

Cc = canopy cover (%)

Pcd= plant crown diameter (mm)

rd = inter-row distance (mm)

Model validation involves running a model using input parameters measured or determined during the calibration process. It is a process of comparing model simulated results to real system data not previously used in the calibration or in any parameter estimation process (Igbadun, 2012). The purpose of validation is to determine if the model is sufficiently accurate for its application as defined by the objective (Igbadun, 2012). Calibration and performance evaluation of AquaCrop model for several crops are presented by Farahani *et al.*,(2009), Garcia-

Vila *et al.,* (2009), Geerts et al. (2009), Heng et al. (2009), and Hsiao *et al.,* (2009).

2.10.1 Sensitivity Analysis

Sensitivity analysis is a technique for evaluating the impression of a model (Heng *et al*., 2009). Sensitivity Analysis is carried out to determine how the simulated results from a model are influenced by several parameters that can be used to fit the model to the field data. Before applying a model, it is necessary to have some familiarity with its behaviour and sensitivity to input parameters. According to Abbas (2007) sensitivity analysis helps to recognize the parameters that have significant impact on model output. Selection of percentage change in the inputs is some what arbitrary and depends on sensitivity of model and limits of parameters of the model. The interval of variation of the inputs was chosen as ±5% of its mean value**.** It is done by varying input parameters one at a time, while holding other parameters at fixed values. The model is run with selected data and the results considered as "base". All comparison will now be made with respect to the "base" simulation using the following relationship (McCuen, 1973):

$$\text{Sc} = \frac{\frac{\Delta w}{w}}{\frac{\Delta p}{p}} \qquad (2.21)$$

where:
Sc = sensitivity coefficient
Δw = output difference before and after changing the input value
w = the mean of output;
Δp = input difference
p = mean of input.
The parameter with the highest absolute value of Sc is taken as the most sensitive.

2.10.2 Performance Evaluation of a Model

Since no single measure can determine how well a simulation model performs, a combination of statistical indices are generally used to evaluate the model (Anjum *et al.,* 2014). The agreement between the measured and the simulated values can be assessed using the following statistical indices: Root Mean Squared error (RMSE), Coefficient of Variation (CV), Modelling Efficiency (EF) and Coefficient of Residual Mass.

The RMSE gives the weighted variations in errors (residual) between the modelled and observed values and is calculated as follows (Nash and Sutcliff, 1970):

$$\text{RMSE} = \sqrt{\frac{1}{n} \sum (M_i - S_i)^2} \qquad (2.22)$$

in which S_i is simulated , M_i , measured value and n, the number of measurements

The coefficient of Variation is expressed as (Willmout and Matsuura, 2005):

$$\text{CV} = 100^* \sqrt{\frac{1}{n} \frac{\sum (M_i - S_i)^2}{S_i}} \qquad (2.23)$$

in which all the terms are as previously defined.

Modelling efficiency is a measure of the degree of fit between simulated and measured data, similar to the coefficient of determination (R^2), and varies from negative infinity for total lack of fit to 1 for an exact fit. The expression is given in Eq.(2.24) (Willmott,1982):

$$\text{EF} = \frac{\left[\sum(S_i - S_m)^2 - \sum(M_i - S_i)^2\right]}{\sum(S_i - S_m)^2} \quad (2.24)$$

in which S_m is maximum simulated value and other terms are as previously defined.

The coefficient of residual mass is an indicator of the tendency of the model to either over-or under-predict measured values, a positive value indicates a tendency of under-prediction, while a negative value indicates a tendency of over-prediction (Igbadun, 2012; Kahimba *et al.*, 2009).

$$\text{CRM} = \frac{\sum S_i - \sum M_i}{\sum S_i} \quad (2.25)$$

in which all the terms are as previously defined.

The model performance was further evaluated using prediction error. The expression is given in Eq (2.26) (Nash and Sutcliff, 1970):

$$\text{Pe} = \frac{\text{Si} - \text{Mi}}{Mi} \times 100, \quad (2.26)$$

in which all the terms are as previously defined.

CHAPTER THREE

MATERIALS AND METHODS

3.1 The Study Area

The field experiments used in calibrating and validating the AquaCrop model were carried out at the Institute for Agricultural Research (I.A.R) Irrigation farm, Ahmadu Bello University, Zaria, which lies on 11°11'N and 7°38'E, and at an altitude of 686 m above mean sea level, within the Northern Guinea Savannah ecological zone (Odunze, 1998). The weather data for the crop growing seasons are presented in Tables 3.1 and 3.2; while the characteristics of the soils of the study location are shown in Table 3.3.

Table 3.1 Weather data for the 2013 crop growing season

Months	Humidity (%)	Max. temp (°C)	Min. temp (°C)	Sunshine (Hours)	Wind speed (Km/d)	ETo[a] (mm/d)	Total Rainfall (mm)
January	19.37	32.48	17.74	8.01	142.66	6.82	-
February	13.52	35.50	18.79	7.49	131.44	8.56	-
March	26.37	39.29	22.77	7.63	118.24	9.14	-
April	38.85	37.47	24.77	7.09	143.03	7.89	14.76

Table 3.2 Weather data for the 2014 crop growing season

Months	Humidity (%)	Max. temp (°C)	Min. temp (°C)	Sunshine (Hours)	Wind speed (Km/d)	ETo[a] (mm/d)	Total Rainfall (mm)
January	18.65	33.4	17.2	8.78	145.16	7.95	-
February	15.39	34.29	19.29	8.18	141.98	9.07	0.4
March	26.68	38.03	22.55	7.43	128.35	9.41	-
April	54.27	36.90	24.37	7.19	115.17	7.14	15.74
May	67.32	33.35	24.23	6.33	117.28	5.12	14.13

Table 3.3 Physical properties of soils at various depths at the Irrigation Research Farm, IAR, Samaru.

Depth(cm)	FC (%Vol)	PWP (% Vol)	Bulk density (g/cm3)	Hydraulic Conductivity (mm/hr)	Clay (%)	Silt (%)	Sand (%)	Texture class[a]
0-15	24.8	13.6	1.58	70	22	28	50	Clay Loam
15-30	26.3	15.9	1.58	100	26	22	54	Clay Loam
30-45	27.4	17.1	1.57	100	28	18	54	Clay Loam
45-60	25.9	15.9	1.58	125	26	18	56	Sandy clay loam
60-80	29.5	18.2	1.55	125	30	22	48	Sandy clay loam

[a] Based on USDA textural classification

Climatic data used as input during the simulation were: default atmospheric CO_2 concentration for a period from 1990 to 2013, rainfall depth, average reference ETo for 10 years (1999-2009) computed with Eqn. (2.12) for the study location and maximum and minimum temperatures shown in Figs. 3.1, 3.2, 3.3 and 3.4.

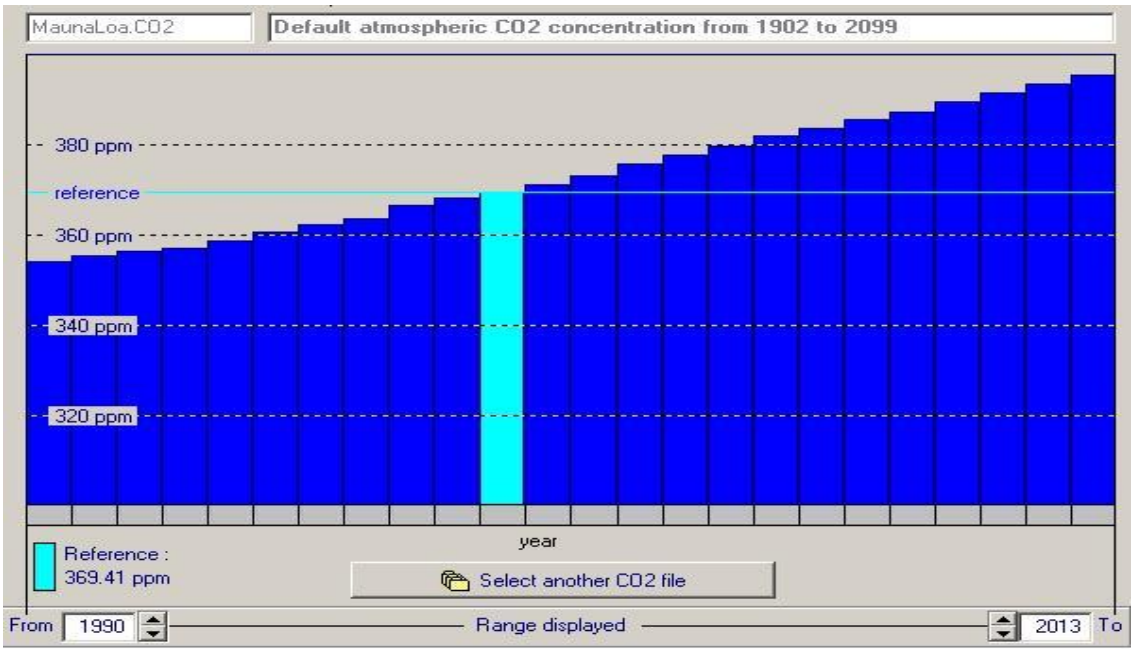


Fig 3.1: Default Atmospheric CO_2 Concentration from 1990 to 2013 from the AquaCrop Model

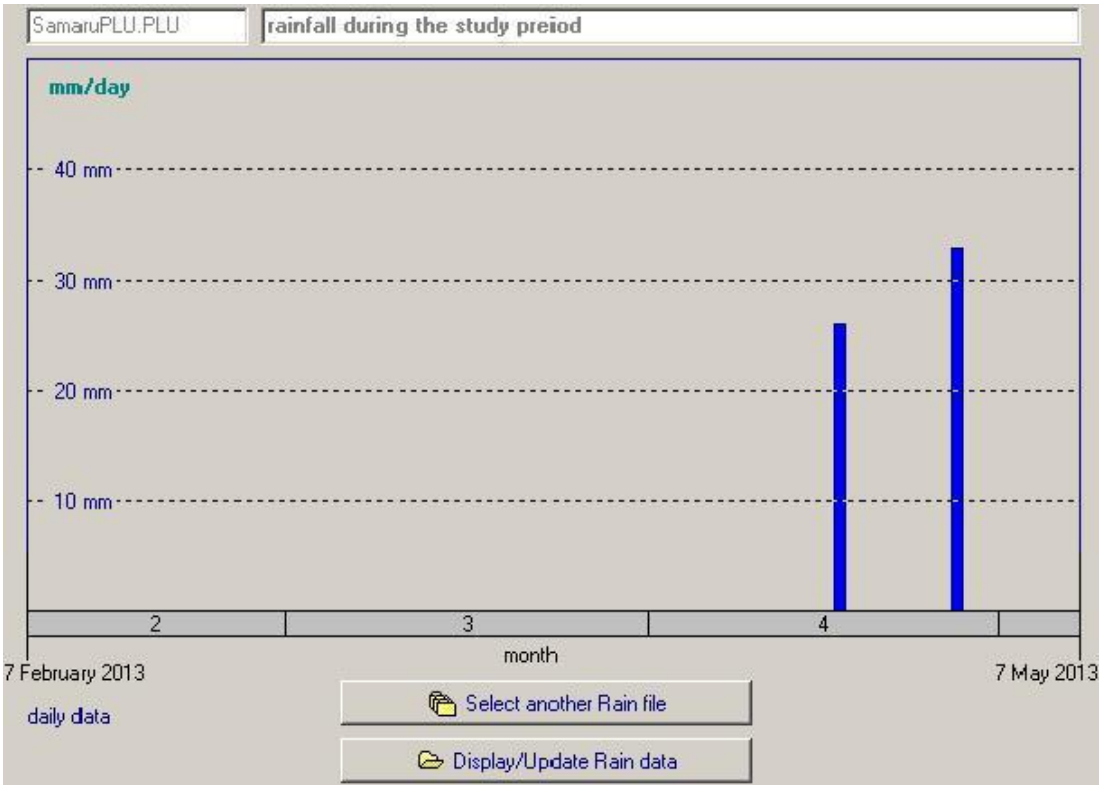


Fig 3.2:Rainfall amount during 2013 cropping season

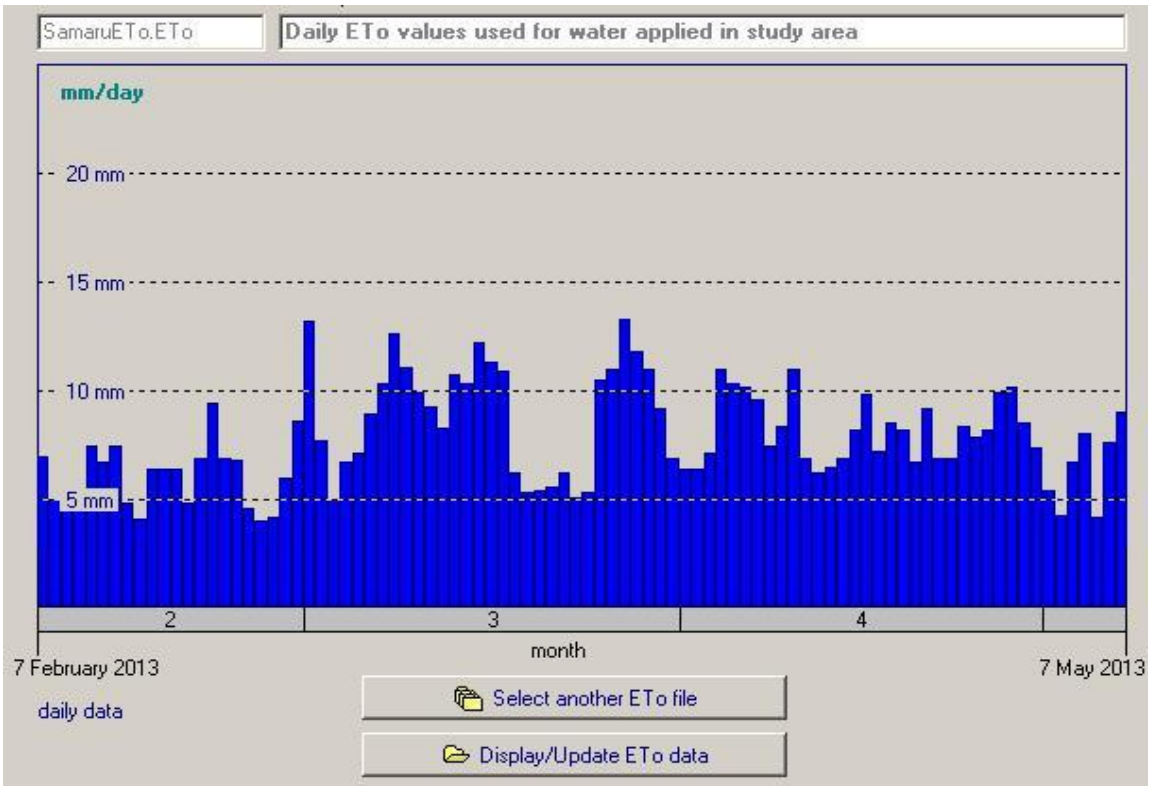


Fig 3.3: Average ETo values used for depth of water applied

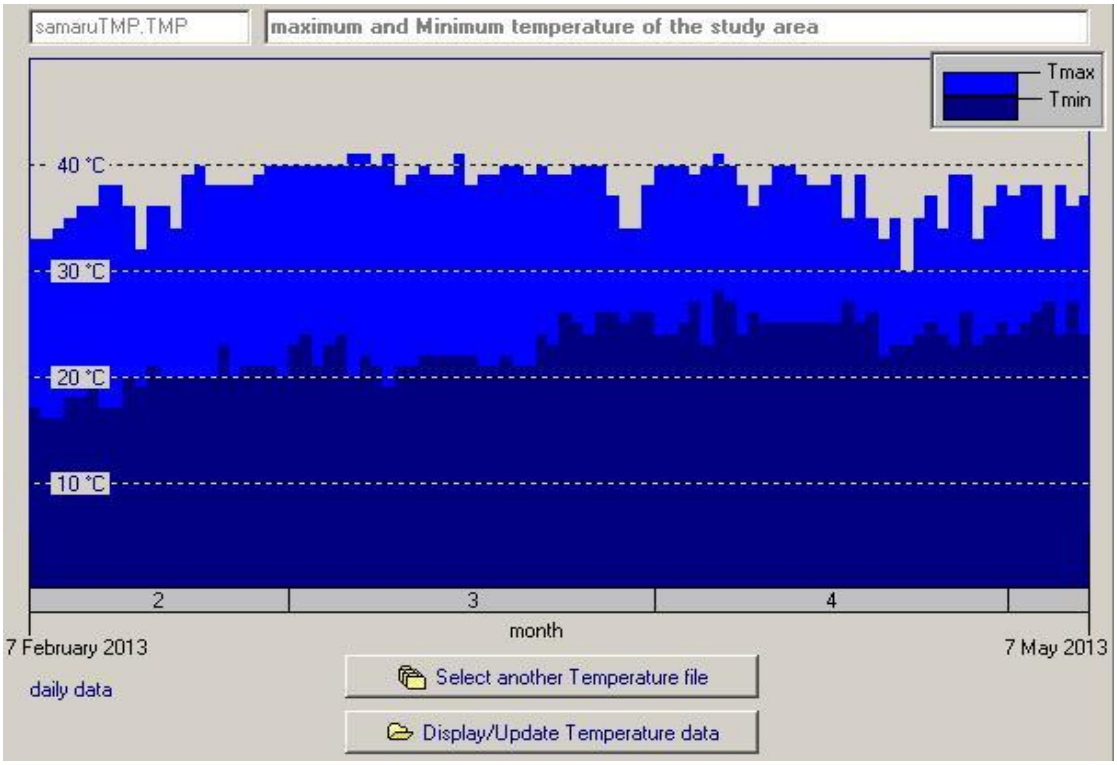


Fig 3.4: Daily Minimum and Maximum temperatures during 2013 cropping season

3.2 Experimental Treatment Description

Two field experiments were carried out concurrently during the 2012/2013 irrigation season for the purpose of generating data for calibrating and validating the AquaCrop Model. The field trial was further repeated during the 2013/2014 irrigation season to obtain data to validate the model performance across seasons. Each field experiment consisted of eight (8) treatments replicated three times and laid in a randomized complete block design, across the general slope of the field in order to ensure as much homogenous soil conditions as possible within the blocks. The treatments were based on water application regulated at selected crop growth stages. The description of the experimental treatments is presented in Tables 3.4 and 3.5.

Table 3.4 Description of Experimental Treatments for Field A in 2012/2013 season

Treatment Label.	Treatment Description
$V_{100}\ F_{100}G_{100A}$	Water applied was 100% of DRET in all the growth stages.
$V_{75}\ F_{100}\ G_{100A}$	Water applied was 75% of DRET at Vegetative (V) Stage and 100% of DRET for Flowering(F) and Grain filling (G) Stages.
$V_{50}\ F_{100}\ G_{100A}$	Water applied was 50% of DRET at Vegetative (V) Stage and 100% of DRET for Flowering(F) and Grain filling (G) Stages.
$V_{100}\ F_{75}\ G_{100A}$	Water applied was 75% of DRET at Flowering (F) Stage and 100% of DRET at Vegetative (V) and Grain filling (G) Stages
$V_{100}\ F_{50}\ G_{100A}$	Water applied was 50% of DRET at Flowering (F) Stage and 100% of DRET at Vegetative (V) and Grain filling (G) Stages
$V_{100}\ F_{100}\ G_{75A}$	Water applied was 75% of DRET at Grain filling (G) Stage 100% of DRET at Vegetative (V) and Stages Flowering (F)
$V_{100}\ F_{100}\ G_{50A}$	Water applied was 50% of DRET at Grain filling (G) Stage 100% of DRET at Vegetative (V) and Stages Flowering (F
$V_{50}\ F_{50}\ G_{50A}$	Water applied was 50% of DRET in all the growth stages

DRET= Daily Reference Evapotranspiration

Table 3.5 Description of Experimental Treatments for Field B in 2012/2013 season

Treatment Label.	Treatment Description
$V_{100}\ F_{100}G_{100B}$	Water applied was 100% of DRET in all the growth stages.
$V_{80}\ F_{100}\ G_{100B}$	Water applied was 80% of DRET at Vegetative (V) Stage and 100% of DRET for Flowering(F) and Grain filling (G) Stages.
$V_{60}\ F_{100}\ G_{100B}$	Water applied was 60% of DRET at Vegetative (V) Stage and 100% of DRET for Flowering(F) and Grain filling (G) Stages.
$V_{100}\ F_{60}\ G_{100B}$	Water applied was 80% of DRET at Flowering (F) Stage and 100% of DRET at Vegetative (V) and Grain filling (G) Stages
$V_{100}\ F_{60}\ G_{100B}$	Water applied was 60% of DRET at Flowering (F) Stage and 100% of DRET at Vegetative (V) and Grain filling (G) Stages
$V_{100}\ F_{100}\ G_{80B}$	Water applied was 80% of DRET at Grain filling (G) Stage 100% of DRET at Vegetative (V) and Stages Flowering (F)
$V_{100}\ F_{100}\ G_{60B}$	Water applied was 60% of DRET at Grain filling (G) Stage 100% of DRET at Vegetative (V) and Stages Flowering (F
$V_{60}\ F_{60}\ G_{60B}$	Water applied was 60% of DRET in all the growth stages

DRET= Daily Reference Evapotranspiration

3.3 Experimental Layout and Agronomic Practices

The experimental field in each season was 0.2 ha as shown in Plate 3.1 and Fig 3.5. The field was divided into plot sizes of 5 m by 1.8 m each. The plots consisted of three drip lines with 30 cm emitter spacing, each 0.6 m apart. SAMMAZ 14 maize variety crop was planted on the 7th February, 2013 in plot A and 18th February, 2013 in plot B during the 2012/2013 cropping season. In both seasons, the planting was done along the drip lines, a plant spacing of 30 cm between plants and 60 cm between rows was used giving a plant population of 55,556 plants/ha, which is a deviation from the

conventional spacing of 25cm by 75cm because the emitter spacing of the drip used in the experiment was 30cm .



Plate 3.1: Experimental Layout of the field

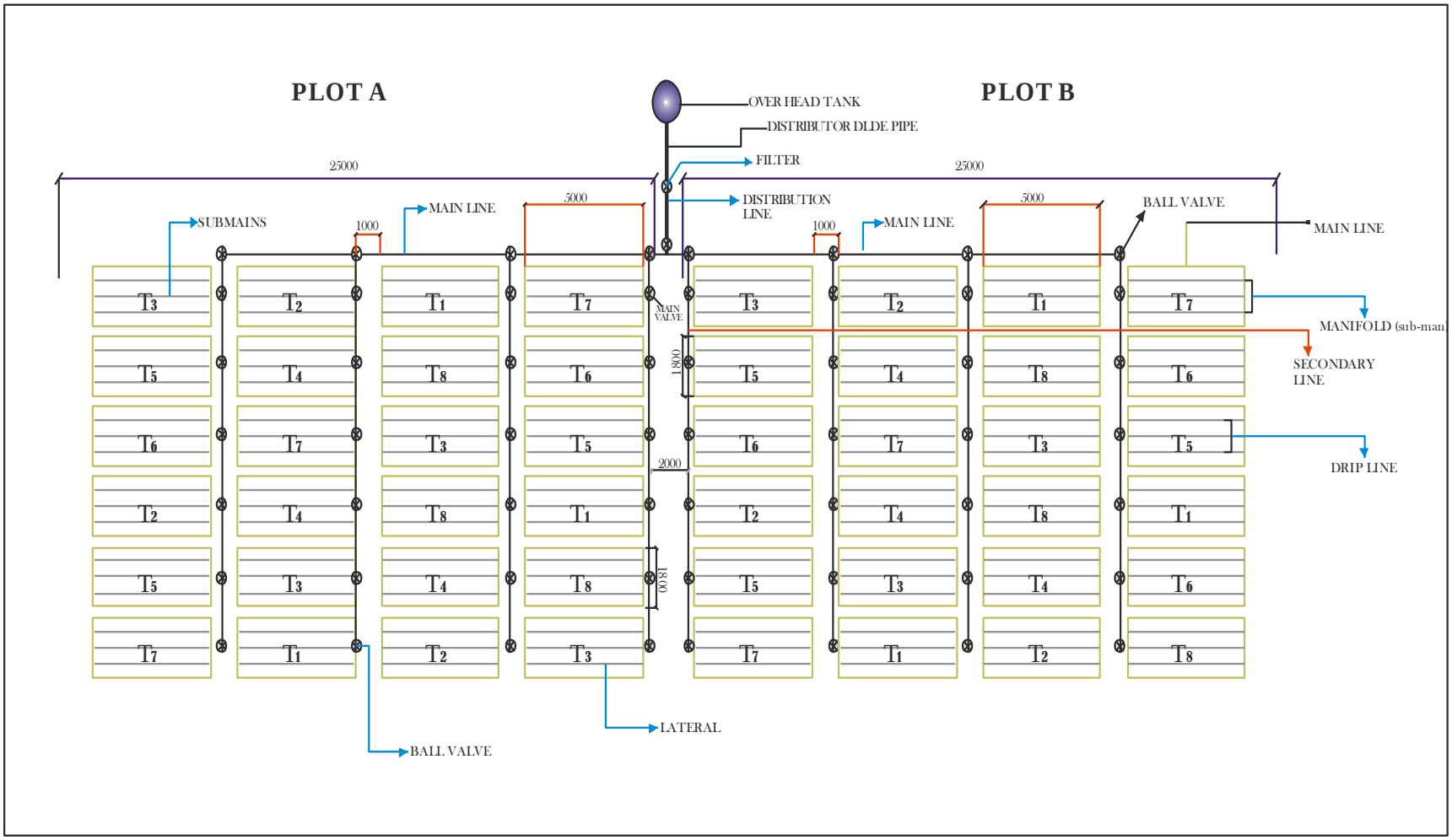


Fig 3.5 Field layout (*all dimensions in mm*)

In 2012/2013 season, manual weeding with the use of hoe was carried out three times for both fields at three, six and nine weeks after planting. In 2013/2014 season, however, weeding was carried out thrice at two, five and nine weeks after planting since weed proliferation on the experimental field was more. Compound fertilizer (NPK 15:15:15) was applied at the rate of 60 kgN/ha at three weeks after planting, applied as basal dose. Urea fertilizer was used for top dressing at 6 weeks after planting at a rate of 60 kgN/ha as recommended by the Institute for Agricultural Research, Samaru, Zaria; thus the total N applied was 120 kg/ha. The fertilizers were applied after weeding on each occasion. There was no incidence of pests or diseases during the 2012/2013 cropping season. In 2013/2014 cropping season however, there was attack of ***aphids*** during the 5^{th} week, which was managed with the application of karate at 0.8l/ha using 40 ml in 15 litres knapsack sprayer as recommended by Avav and Ayuba (2006). Date of sowing and date of emergence were recorded. Emergence date was considered when 90% of seedlings had emerged. Flowering and duration of flowering, maximum canopy cover, senescence and maturity observations were also made.

3.4 Irrigation Water Source and Drip Irrigation Hydraulics

A *Gee Pee* tank 2 m^3 capacity placed on a metal frame stand 2.5 m high was used as the irrigation water source, while a portable 50 mm petrol pump (Robin Model) was used to lift water from a sump where water is being pumped from the dam, located at 65 m away from the sump to the Gee Pee tank. A 2.5 m long and 25 mm diameter distributor low density polyethylene pipe was connected at the bottom of the raised tank. A primary filter was installed at the inlet of the distribution pipe. The distribution pipe (25 mm) from the tank was connected to 3.5 m long mainline with a Tee connection.

The experimental field was divided into two plots (A and B). Four sub-mainlines each 13.5 m long and 25 mm diameter were connected to the mainline by dividing the mainline into four equal parts. Along each sub-mainline, six secondary sub mainlines (25 mm) each 1.8 m long were connected at 0.6 m spacing between them. Then, three laterals with inline emitters 16 mm diameter with emitter spacing of 30 cm apart, each and 5m long were connected at 60 cm between laterals to the secondary sub mainline; hence a total of 72 laterals were used on each field.

3.5 Emitter Discharge

The hydraulic performance of the drip system used in this study were obtained using a can catch test. The individual emitter flow rate in litres per hour (l/hr) was measured from randomly assigned treatments plots in the experimental plot. Separate field tests were carried out one hour for each 17 selected treatment plots. Two drip lines per treatment at different locations were tested against their discharge rate. The data taken during the field test include: discharge rate, location and their respective soil wetting performances. This was later used to calculate discharge uniformity, emitter flow variation, emission uniformity, and discharge coefficient of variation as given by Eqns. (2.1), (2.2), (2.3) and (2.4), respectively.

Empirically, the discharge for a specified head and single emitter was calculated as:

$$q = \frac{V}{\Delta t} \quad (3.1)$$

where:

q = single emitter discharge (l/hr)

V= volume of water collected from emitter (l)

Δt = Change in time (hr)

3.5.1 Soil Wetting Diameter

Soil wetting diameters of the emitters were determined along with the field test carried out on determining the emitter flow rate as shown in Plate 3.2. After one hour of irrigation, the wetted diameter of the soil wetted by each sampled dripper was measured using a ruler.



Plate 3.2: Drippers wetting diameter after 20 minutes

3.5.2 Water Application

Water applied was based on the daily reference evapotranspiration computed from 10 years of climatic data (1999-2009) for the area for the cropping using Eq (2.12). The time allowed for water to be discharged into each plot was based on the depth of water to be applied. Application rate and running time were calculated with the use of Eqs. (2.10) and (2.11). The computed values were rounded up to the nearest whole number throughout the seasons. The plots were irrigated every three and four days alternately of the daily reference evapotranspiration. The irrigation schedule for both seasons is as shown in Tables 3.6 - 3.17.

During the 2013/ 2014 cropping season there was an occurrence of rainfall on 17th April 2014, 71days after planting. The actual irrigation which would have been carried out was withheld since the effective rainfall depth was 10 mm, though the depth of the water that would have been applied through irrigation was supposed to be 20 mm, as a result of this, Treatments V_{100} F_{100} G_{50} and V_{50} F_{50} G_{50} received full water application depth through rainfall; but for other treatments water depth application was reduced by about 50% with the exception of treatment V_{100} F_{100} G_{75} which was reduced by 34%. The following growth-stages ranges were adopted in this research: Vegetative (15-42DAP); Flowering – tasseling to silking (43-63 DAP) and grain filling to physiological maturity stages (64-95 DAP) based on the study by Igbadun (2012).

Table 3.6a Irrigation water Applied during Establishment stage 2012/2013 season

Growth stage	Establishment (0-14DAP) FIELD A					
Days after Planting	0	4	7	11	14	
Date of Irrigation	7-Feb	11-Feb	14-Feb	18-Feb	21-Feb	water applied (mm)
V_{100} F_{100} G_{100}A	20	20	20	20	30	110
V_{75} F_{100} G_{100}A	20	20	20	20	30	110
V_{50} F_{100} G_{100}A	20	20	20	20	30	110
V_{100} F_{75} G_{100}A	20	20	20	20	30	110
$V_{100}F_{50}$ G_{100}A	20	20	20	20	30	110
V_{100} F_{100} G_{75}A	20	20	20	20	30	110
V_{100} F_{100} G_{50}A	20	20	20	20	30	110
V_{50} F_{50} G_{50}A	20	20	20	20	30	110

Table 3.6b Irrigation water Applied during Vegetative Stage 2012/2013 season

Growth stage	Vegetative (15-42DAP) FIELD A								
Days after Planting	17	21	24	28	31	35	38	42	water applied
Date of Irrigation	24Feb	28Feb	4Mar	7Mar	11Mar	14Mar	18Mar	21Mar	(mm)
V_{100} F_{100} G_{100}A	20	40	40	40	30	40	20	20	250
V_{75} F_{100} G_{100}A	15	30	30	30	23	30	15	15	188
V_{50} F_{100} G_{100}A	10	20	20	20	15	20	10	10	125
V_{100} F_{75} G_{100}A	20	40	40	40	30	40	20	20	250
$V_{100}F_{50}$ G_{100}A	20	40	40	40	30	40	20	20	250
V_{100} F_{100} G_{75}A	20	40	40	40	30	40	20	20	250
V_{100} F_{100} G_{50}A	20	40	40	40	30	40	20	20	250
V_{50} F_{50} G_{50}A	10	20	20	20	15	20	10	10	125

Table 3.6c Irrigation water Applied during Flowering Stage 2012/2013 season

Growth stage	Flowering (43-63)DAP FIELD A						
Days after Planting	45	48	52	55	59	62	
Date of Irrigation	25Mar	28Mar	1Apr	4Apr	8Apr	11Apr	water applied (mm)
V_{100} F_{100} G_{100}A	30	50	20	40	30	30	200
V_{75} F_{100} G_{100}A	30	50	20	40	30	30	200
V_{50} F_{100} G_{100}A	30	50	20	40	30	30	200
V_{100} F_{75} G_{100}A	23	38	15	30	23	23	150
$V_{100}F_{50}$ G_{100}A	15	25	10	20	15	15	100
V_{100} F_{100} G_{75}A	30	50	20	40	30	30	200
V_{100} F_{100} G_{50}A	30	50	20	40	30	30	200
V_{50} F_{50} G_{50}A	15	25	10	20	15	15	100

Table 3.6d Irrigation water Applied during Grain-filling Stage 2012/2013 season

Growth stage	Grain-Filling (64-95) DAP FIELD A						
Days after Planting	66	69*	73	77	80*		Total water applied for field A (mm)
Date of Irrigation	15Apr	18Apr	22Apr	25Apr	29Apr	water applied	
V_{100} F_{100} $G_{100}A$	30	26	20	30	33	139	699
V_{75} F_{100} $G_{100}A$	30	26	20	30	33	139	637
V_{50} F_{100} $G_{100}A$	30	26	20	30	33	139	574
V_{100} F_{75} $G_{100}A$	30	26	20	30	33	139	649
$V_{100}F_{50}$ $G_{100}A$	30	26	20	30	33	139	599
V_{100} F_{100} $G_{75}A$	23	26	15	23	33	119	679
V_{100} F_{100} $G_{50}A$	15	26	10	15	33	99	659
V_{50} F_{50} $G_{50}A$	15	26	10	15	33	99	434

*= rainfall depth

Table 3.6e Irrigation water Applied during Establishment Stage 2012/2013 season

Growth stages	Establishment (0-14DAP) FIELD B					
Days after Planting	0	4	7	11	14	Water Applied (mm)
Date of Irrigation	18Feb	21Feb	24Feb	28Feb	4Mar	
V_{100} F_{100} $G_{100}B$	20	30	20	40	40	150
V_{80} F_{100} $G_{100}B$	20	30	20	40	40	150
V_{60} F_{100} $G_{100}B$	20	30	20	40	40	150
V_{100} F_{80} $G_{100}B$	20	30	20	40	40	150
$V_{100}F_{60}$ $G_{100}B$	20	30	20	40	40	150
V_{100} F_{100} $G_{80}B$	20	30	20	40	40	150
V_{100} F_{100} $G_{60}B$	20	30	20	40	40	150
V_{60} F_{60} $G_{60}B$	20	30	20	40	40	150

Table 3.6f Irrigation water Applied during vegetative Stage 2012/2013 season

Growth stages	Vegetative (15-42DAP) FIELD B								
Days after Planting	17	21	25	28	32	35	39	41	water Applied (mm)
Date of Irrigation	7Mar	11Mar	14Mar	18Mar	21Mar	25Mar	28Mar	1Apr	
V_{100} F_{100} $G_{100}B$	40	30	40	20	20	30	50	20	250
V_{80} F_{100} $G_{100}B$	32	24	32	16	16	24	40	16	200
V_{60} F_{100} $G_{100}B$	24	18	24	12	12	18	30	12	150
V_{100} F_{80} $G_{100}B$	40	30	40	20	20	30	50	20	250
$V_{100}F_{60}$ $G_{100}B$	40	30	40	20	20	18	30	12	210
V_{100} F_{100} $G_{80}B$	40	30	40	20	20	30	50	20	250
V_{100} F_{100} $G_{60}B$	40	30	40	20	20	30	50	20	250
V_{60} F_{60} $G_{60}B$	24	18	24	12	12	18	30	12	150

Table 3.6g Irrigation water Applied during flowering Stage 2012/2013 season

Growth stages	Flowering (43-63) DAP FIELD B						
Days after Planting	45	48	52	56	60*	63	Water Applied (mm)
Date of Irrigation	4Apr	8Apr	11Apr	15Apr	18Apr	22Apr	
V_{100} F_{100} G_{100}B	40	30	30	30	26	20	176
V_{80} F_{100} G_{100}B	30	30	40	30	26	30	186
V_{60} F_{100} G_{100}B	30	30	40	30	26	30	186
V_{100} F_{80} G_{100}B	32	24	24	24	26	16	146
$V_{100}F_{60}$ G_{100}B	24	18	18	18	26	12	116
V_{100} F_{100} G_{80}B	40	30	30	30	26	20	176
V_{100} F_{100} G_{60}B	40	30	30	30	26	20	176
V_{60} F_{60} G_{60}B	24	18	18	18	26	12	116

*= rainfall depth

Table 3.6h Irrigation water Applied during Grain-filling Stage 2012/2013 season

Growth stages	Grain-Filling (64-95)DAP FIELD B					
Days after Planting	67	70*	73	76	Water Applied (mm)	Total Water Applied for field B (mm)
Date of Irrigation	25Apr	29Apr	2May	6May		
V_{100} F_{100} G_{100}B	30	33	20	20	103	679
V_{80} F_{100} G_{100}B	30	33	30	20	113	649
V_{60} F_{100} G_{100}B	30	33	30	20	113	599
V_{100} F_{80} G_{100}B	30	33	30	20	113	659
$V_{100}F_{60}$ G_{100}B	30	33	20	20	103	579
V_{100} F_{100} G_{80}B	24	33	16	16	89	665
V_{100} F_{100} G_{60}B	18	33	12	12	75	651
V_{60} F_{60} G_{60}B	18	33	12	12	75	491

*= rainfall dept

Table 3.6i Irrigation water Applied during Establishment Stage 2013/2014 season

Growth stages	Establishment (0-14DAP)				
Days after planting	1	5	8	12	Total Water Applied
Date of Irrigation	6-Feb	10-Feb	13-Feb	17-Feb	(mm)
V_{100} F_{100} G_{100}	40	25	35	25	125
V_{75} F_{100} G_{100}	40	25	35	25	125
V_{50} F_{100} G_{100}	40	25	35	25	125
V_{100} F_{75} G_{100}	40	25	35	25	125
$V_{100}F_{50}$ G_{100}	40	25	35	25	125
V_{100} F_{100} G_{75}	40	25	35	25	125
V_{100} F_{100} G_{50}	40	25	35	25	125
V_{50} F_{50} G_{50}	40	25	35	25	125

Table 3.6j Irrigation water Applied during Vegetative Stage 2013/2014 season

Growth stages	Vegetative (15-42DAP)								
Days after Planting	15	19	22	26	29	33	36	40	
Date of Irrigation	20-Feb	24-Feb	27-Feb	3-Mar	6-Mar	10-Mar	13-Mar	17-Mar	*TWA (mm)
V_{100} F_{100} G_{100}	35	30	30	30	35	30	40	30	260
V_{75} F_{100} G_{100}	26	23	23	23	26	23	30	23	195
V_{50} F_{100} G_{100}	18	15	15	15	18	15	20	15	130
V_{100} F_{75} G_{100}	20	40	40	40	30	40	20	20	250
$V_{100}F_{50}$ G_{100}	35	30	30	30	35	30	40	30	260
V_{100} F_{100} G_{75}	35	30	30	30	35	30	40	30	260
V_{100} F_{100} G_{50}	35	30	30	30	35	30	40	30	260
V_{50} F_{50} G_{50}	18	15	15	15	18	15	20	15	130

*TWA = Total water Applied

Table 3.6k Irrigation water Applied during Vegetative Stage 2013/2014 season

Growth stages	Flowering (43-63)DAP						
Days after Planting	43	47	50	54	57	61	Total water applied(mm)
Date of Irrigation	20-Mar	24-Mar	27-Mar	31-Mar	3-Apr	7-Apr	
V_{100} F_{100} G_{100}	40	30	35	20	30	10	165
V_{75} F_{100} G_{100}	40	30	35	20	30	10	165
V_{50} F_{100} G_{100}	40	30	35	20	30	10	165
V_{100} F_{75} G_{100}	30	23	26	15	23	8	124
$V_{100}F_{50}$ G_{100}	20	15	18	10	15	5	83
V_{100} F_{100} G_{75}	40	30	35	20	30	10	165
V_{100} F_{100} G_{50}	40	30	35	20	30	10	165
V_{50} F_{50} G_{50}	20	15	18	10	15	5	83

Table 3.6m Irrigation water Applied during Grain-filling Stage 2013/2014 season

Growth stages	Grain-Filling (64-95)DAP						
Days after Planting	64	68	71*	75	78	total applied	Total water applied
Date of Irrigation	10-Apr	14-Apr	17-Apr	21-Apr	24-Apr		
V_{100} F_{100} G_{100}	30	35	10	20	30	125	675
V_{75} F_{100} G_{100}	30	26	10	20	30	129	614
V_{50} F_{100} G_{100}	30	26	10	20	30	129	549
V_{100} F_{75} G_{100}	30	26	10	20	30	129	628
$V_{100}F_{50}$ G_{100}	30	26	10	20	30	129	597
V_{100} F_{100} G_{75}	23	26	10	15	23	96	646
V_{100} F_{100} G_{50}	15	18	10	10	15	68	618
V_{50} F_{50} G_{50}	15	18	10	10	15	94	432

*Rainfall depth

3. 6 Computation of Soil moisture Content

Soil moisture contents of the experimental plots were monitored throughout the crop growing season using calibrated gypsum blocks in both seasons, During the 2012/2013 cropping season three (3) gypsum blocks were installed in each experimental plot at 25, 45 and 70 cm soil profile depths to monitor soil moisture changes at 0-30, 30-60, 60-90 cm depths, while during 2013/2014 cropping season four (4) gypsum blocks were installed in each experimental plot at 12, 25, 45 and 70cm soil profile depths to monitor soil moisture changes at closer intervals at 0-15,0-30, 30-60, 60-90 cm depths; in order to capture the soil moisture content at the upper section of the soil profile. Soil moisture resistances were measured using Delmhorst soil moisture tester KS-D1 4862 model a day after every irrigation and just before the next irrigation. The resistance measured were related to gravimetric soil moisture content using gypsum-moisture content calibration curve developed for the sets of gypsum blocks used with R^2 value of 0.87. The calibration curve was obtained from field data as expressed in Eqn (3.2):

$$GMC = 44.75 * R^{-0.24} \quad (3.2)$$

in which, GMC is the gravimetric moisture content (% dry weight basis) and R , the electrical resistance in ohm (Ω)

The actual crop evapotranspiration was calculated from the measured soil moisture content data using gypsum blocks as outlined by Michael (1978). Equation (2.13) was used to estimate the actual crop evapotranspiration (ETa).

3.7 Canopy Cover Determination

Canopy development was measured in the field at each crop growth stages during the 2013/2014 cropping season; the plant crown diameter was estimated using a measuring tape to measure the foliage of the maize crop. However, the canopy cover was estimated using Equation (2.19).

3.8 Above ground Biomass and Final Harvesting

Samples of the above ground biomass during the vegetative, flowering and grain filling stages were harvested from $0.33m^2$ area and dried for a week to document biomass production (Andarzian *et al.,* 2011). The crop attained physiological maturity at 88 and 89 days after planting in 2012/2013 seasons for field A and B, while during 2013/2014 season, physiological maturity was reached 86 days after planting; irrigation was withdrawn thereafter to allow the crop to dry in both seasons. Accordingly, harvesting was done by cutting the above ground dry matter. Each plot had three rows with an area of 1.2m x 5m which constituted the net plot for final yield assessment. They were carefully labelled and conveyed to the laboratory for curing for three weeks until the biomass was fully dried. The dry matter was then weighed, the maize cobs threshed and weighed.

3.9 Statistical Analysis

The grain and biomass yield, seasonal crop water use, biomass and grain yield irrigation water productivity were subjected to statistical analysis of variance and the significance among treatment means was evaluated with Duncan's Multiple Range Test to check significant differences between the treatments (SPSS, 2003).

3.10 Running AquaCrop Model

The input data used for the running of the model include: weather, soil, crop and irrigation schedulling (timing of irrigation and amount of water applied). The weather data were obtained from the meteorological station in the Institute for Agricultural Research Farm close to the research field, for the two seasons. The irrigation schedulling input data were in accordance with Tables 3.6(a-m). Maize crop simulation parameters used for calibrating AquaCrop Software are presented in Table 3.7.

Table 3.7 Crop input parameters for AquaCrop Model

Description	Value	Source
Base temperature	8 ^{o}C	Hsiao *et al.*, 2009
Cut-off temperature	35 ^{o}C	Hsiao *et al.*, 2009
Canopy cover per seedling at 90% emergence (CCo)	6.5 cm^2	Hsiao *et al.*, 2009
Canopy growth coefficient (CGC)	19.6 %	Dirk *et al*., 2010
Plant density	55,556 plants/ha	a
Maximum canopy Cover (CCx)	60%	Function of plant density
Canopy decline Coefficient (CDC) at senescence	12.5 %	Dirk *et al*., 2010
Water productivity normalized for ETo and $C0_2$ (g/m^2)	31.7	a
Water productivity normalized for ETo and $C0_2$ during yield formation	85%	Dirk *et al*., 2010
Leaf growth threshold p-upper	0.10	Hsiao *et al.*, 2009
Leaf growth threshold p-lower	0.45	Hsiao *et al.*, 2009
Leaf growth stress coefficient curve shape	2.9	Hsiao *et al.*, 2009
Stomata conductance thresh p-upper	0.45	Hsiao *et al.*, 2009
Stomata stress coefficient curve shape	6.0	Hsiao *et al.*, 2009
Senescence stress coefficient p-upper	0.45	Hsiao *et al.*, 2009
Senescence stress coefficient curve shape	1.5	Hsiao *et al.*, 2009
Reference harvest index	32%	a
Coefficient, inhibition of leaf growth on HI	7	Dirk *et al*., 2010
Coefficient, inhibition of stomata on HI	3.0	Dirk *et al*., 2010
Maximum basal crop coefficient (K_{cb})	1.05	Allen *et al.*, 1998
Effective rooting depth	0.6m	Keller and Bliesner, 1990
Time from sowing to emergence	8 days	a
Time from sowing to maximum canopy cover	47days	a
Time from sowing to start Senescence	65 days	a
Time from sowing to maturity	90 days	a
Time from sowing to flowering	52 days	a
Length of the flowering stage	10days	a
Time to maximum rooting depth	60 days	a

a= data obtained from the field

The hydraulic properties of the soil used as input were those of the experimental site as presented in Table 3.8.

Table 3.8: Hydraulic properties of the soil used as input to the AquaCrop Model

Characteristics of soil	Thickness (m)	PWP (vol%)	FC (vol%)	Saturation (Vol %)	TAW (mm/m)	Ksat (mm/day)
Clay loam	0.15	13.6	24.8	40.3	112	70
Clay loam	0.15	15.9	26.3	40.4	104	100
Clay loam	0.15	17.1	27.4	40.6	103	100
Sandy clay loam	0.15	15.9	25.9	40.2	100	125
Sandy Clay loam	0.15	18.2	29.5	41.4	113	125

3.10.1 Calibration Procedure

AquaCrop model was calibrated with 2013 field data. During the calibration process, conservative parameters were adapted from the report of Hsiao *et al* (2009). These parameters included: canopy cover growth and canopy decline coefficient; crop coefficient for transpiration at full canopy; water productivity (WP); soil water depletion thresholds for inhibition of leaf growth, stomata conductance and acceleration of canopy senescence. These parameters are presumed to be applicable to a wide range of conditions and not specific for a given crop cultivar. The process of calibration was repeated several times to list out a set of parameters that produced results in line with the measured data (Abedinpour *et al*., 2012).

The days to emergence, maximum canopy, maturity and senescence as observed from the field were 8, 47, 65 and 90 days, respectively. The calibrated maximum canopy cover was 60%, values of canopy growth coefficient (CGC) and canopy decline coefficient (CDC) for the experiment were 19.6% and 22.5%, respectively. The following was recorded from the model output: controlled days to flowering, duration of flowering, length to building of yield, 52, 10 and 34 days, respectively. The effective rooting depth was set at 0.6 m, while the Kcb_x value obtained was 1.05 which is in line

with the crop coefficients for the midseason as giving by FAO-56 (Allen *et al.*, 1998).The value of WP adopted was 31.7 g m^{-2} which was in the range (31-34 g m^{-2}) suggested for the AquaCrop for C_4 crops (crops that produces the 4-carbon compound oxalocethanoic acid as the first stage of photosynthesis). The harvest index obtained was 32% and the soil set as clay loam with initial soil condition as wet dry.

Factors pertaining to expansion stress were calibrated to have the upper threshold, lower threshold and shape factors to be 0.10, 0.45 and 2.9, respectively. Also, the stomata closure stress; upper threshold and shape factor were 0.45 and 6.0, respectively, while the lower threshold was set at the permanent wilting point.

Moreover, the early senescence stress, upper threshold and shape factor were 0.45 and 1.5, respectively, while the lower threshold was set at the permanent wilting point. These calibrated coefficients were related to the crop water stress function in the AquaCrop model, which was used to simulate the yield from the different experimental plots.

During the calibration process, the calculated biomass and grain yield were compared with the measured data using water productivity and the crop coefficient. At the same time simulated irrigation water productivity was compared with the observed data in the field experiment for field B during the 2012/2013 cropping season. The process was repeated several times to list out a set of parameters that produced results in line with the measured data. The final values of the adjusted parameters at which the model simulated outputs had the highest correlation with the field-measured data were adopted as input data for the model as shown in Table 4.12.

Calibration was accomplished by using the observed values from the field experiment during the 2012/2013 (field B) as model input and then using the model to predict the

output. Subsequently the output values were compared with observed field data.

The model output during the calibration process that was compared with the field-measured data include: biomass yield at harvest, grain yield, seasonal evapotranspiration and water productivity. The difference between the predicted and the experimental data was adjusted by using a trial and error approach until the closest match between the simulated and the observed value were obtained. The final values of the adjusted parameters at which the model simulated outputs had the highest correlation with the field-measured data were adopted as input data for the model as shown in Table 3.7.

3.10.2 Sensitivity Analysis

A sensitivity analysis was performed to determine how the simulated results from AquaCrop were influenced by several parameters that were used to fit the model to the field data. The parameter values in Table 4.12 were used as base to investigate the effect of changing the parameters on biomass and grain yield. The input for sensitivity analysis for this research were: agronomic, soil, meteorology and irrigation management data; first, AquaCrop model was run with these data and the results were considered as "base" .The sensitivity analysis was conducted for two scenarios; fully irrigated treatment (100% ETo for all growth stages and deficit irrigated treatments (50% ETo) using 2014 field data.

The following parameters were altered during the analysis: maximum canopy, canopy decline coefficient (CDC), plant population, reference harvest index, water productivity Time to Emergence, canopy senescence and flowering, root deepening and Kcbx. The impacts of changing a parameter were explored for the following AquaCrop outputs: Grain and Biomass yield for the entire season.

The range of suggested sensitive changes was presented by Hsiao and Kxu, 2009 and sensitivity classification of input parameters with sensitivity factors were classified as follows:

$S_c > 1.5$ = high sensitivity
$0.3 < S_c < 1.5$ = average sensitivity
$0 < S_c < 0.3$ = low sensitivity
$S_c = 0$ = without Sensitivity

3.10.3 Validation of the AquaCrop Model

Model validation was carried out by comparing independent field data from Field B during 2012/2013 cropping season and field data (across seasons) for 2013/2014 cropping seasons, with the outputs computed by the model. Grain yield, biomass yield, Seasonal crop water use and irrigation water productivity for biomass and yield, were considered as the evaluation parameters for the AquaCrop model. The crop parameters obtained from the calibration of the model were used in the validation of the model.

3.10.4 Performance Evaluation of AquaCrop Model

A combination of statistical indices was used to evaluate the model, the correlation between the observed and simulated values were determined using the following: Root Mean squared error (RMSE), Coefficient of variation (CV), Modelling Efficiency (EF), Coefficient of Residual Mass and percentage deviation (PE) as depicted by Eqns. (2.22), (2.23), (2.24), (2.25) and (2.26), respectively.

3.11 Scenario Study on deficit Irrigation Schedulling on yield and water productivity of maize

After the model was found to satisfactorily simulate yield and water productivity in its predictions, it was used for scenario analyses to evaluate the water management practices for drip irrigated maize in the study area. The purpose of the scenario study was to explain the implication of deficit irrigation scheduling on yield, soil water balance and crop water productivity.

Planting date was set at 3rd March and the crop physiologically matured 90 days after planting. The weather data of the year 2000 to 2005 irrigation season was used as weather input data in the model simulation. The daily reference ETo was computed from 10years (1999-2009) of climatic data for the study area based on the Hargreaves model, the computed values were rounded to tens. The soil input data used in the calibration of the model was adopted as shown in Table 3.1, other input data are as shown in Table 3.2, and the experimental crop was a maize variety called SAMMAZ 14 widely embraced by farmers in the study area.

AquaCrop was used to simulate crop and soil water balance response for different irrigation scenarios. Five groups of irrigation scenarios were investigated as follows:

1) Increasing irrigation interval from 3 to 4, 5, 6 days at water application depth of 15, 20, 25 and 30mm to establish the optimal irrigation interval for fixed water application depth (WAD) and optimal WAD for fixed irrigation interval.
2) A fixed irrigation interval of 3days, with water application depths of 15, 20 and 25mm were applied varied along growth stages of the crop to recommend an optimum irrigation.
3) The impact of deficit at one, two and three growth stage, with water application depths of 20mm for 3 to 4 and 5days and investigated to ascertain

the impact on crop and water productivity.

4) Different planting patterns compatible with farmers' practice were investigated to check the effect of plant density on yield and water utilization of the maize crop. The spacing between drip tapes was varied from 45 -75cm, the corresponding plant densities were 74,074 plants/ha (30cm x 45cm), 44,444 plant/ha (30cm x 60cm), 53,333plant/ha (30cm x 75cm), 66,667 plants/ha (25cm x 60cm) and 55556 plants/ha (30cm x 60cm). The WAD was 20mm per irrigation for every 3days.

3.12 Evaluation of Economic Performance

The economic variables were evaluated based on 1 hectare size of farmland. In this regard, production costs consisting of both fixed and variable costs per hectare per treatment were determined.

The fixed cost include: cost of the drip irrigation system (low-density polyethylene pipe for main, sub-mains, and laterals, control valve, drippers, and other accessories), overhead water tank container, angle iron stand for the tank and pump.

The fixed cost (depreciation of farm tools and equipment) was calculated using the straight-line method (Cetin *et al*., 2004; Ojha and Michael, 2006). In calculating the costs of production involved in this study, life cycle costing method was used. Life cycle costing is done by taking into account all the potential fixed costs such as different types of basic hardware, land preparation, energy, maintenance, and maintenance cost, which can be calculated using capital recovery factor (CRF) (Nega, 2009). Capital recovery factor is the uniform series of annual values for depreciation and interest rates over the analysis period that is equivalent to the single present worth value (Thompsom *et al*., 1980). The interest rate (r) and the expected life of the item (n) are the main

variables involved in the calculation of capital recovery factor. This factor is calculated by:

$$\text{CRF} = \frac{i(1+i)^n}{(1+i)^n-1} \quad (3.3)$$

Where, i= annual interest rate expressed in decimal, n=number of years in the life cycle, CRF = capital recovery factor

The salvage values were obtained by using a straight-line depreciation method to determine the values which are not fully depreciated at the end of the analysis period.

Salvage value assumes a fixed rate till the salvage value is reached expressed as (Thompsom *et al*., 1980; Mailumo, 2005):

S = life cycle x present worth value (3.4)

The annual amortization value (AV) is then calculated by (Thompsom *et al*., 1980):

AV = (PW) (CRF) (3.4a)

Where:

PW = present worth value

CRF = capital recovery factor

The present worth value (PW) is calculated (Thompsom *et al*., 1980) by:

$$\text{PW} = s\ (1+i)^{-n} \quad (3.4b)$$

Where:

S = replacement cost

i= interest rate

n= number of years the cost will be incurred in the future

The annual operating cost includes labour (installation, irrigation, planting, weeding, cultivation, fertilizer application, spraying, and harvesting), land preparation, seeds, fertilizers, chemicals (insecticides and pesticides) and water pumping (diesel and oil). The annual operation, maintenance, and repair cost were obtained by direct application of the appropriate percentage values to the initial cost of each component. The tank and metal stand used operation and maintenance cost was fixed at zero, while that of the pump and drip kits were fixed at 5 and 7% of the initial cost of each (Thompsom *et al*., 1980).The cost of irrigation water was calculated based on the pumping cost per irrigation per treatment.

The cost of labour in this study for all activities was based on the Institute for Agricultural Research standard rate of N250 Per person per 8hours per day (hr/day). The revenue generated from each treatment was estimated on the basis of marketable grain yield from 1 hectare farm land for one cropping season.

The revenue generated for each treatment was calculated using the current wholesale price (1 tonne = N80, 000) for maize, while the prevailing interest rate for Agricultural loans in Nigeria was pegged at 8% (www.articlesng.com/federal-government) Subsequently, the net return for maize at different irrigation levels were calculated, considering total cost (fixed + operating) and gross return (Imtiyaz *et al*., 2000a).

The total revenue generated was calculated based on the assumption that maize will be cultivated twice in a year during the dry season for a period of 5 years. The total production cost was subtracted from the revenue generated from the maize sale to obtain the profit made in each treatment. The benefit –cost ratio (B/C) was then calculated by dividing the total gross revenue by the total production cost; the annual B/C ratio for a period of 5years was further evaluated

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Drip Irrigation Hydraulics performance Evaluation

Results of the following hydraulic characteristics of the drip irrigation system setup were obtained: emitter flow rate, emission uniformity, discharge coefficient of variation, application efficiency, discharge uniformity and coefficient of uniformity are as shown in Table 4.1. The highest lateral length of 28.4 m had discharge of 0.6 l/hr, while the lowest lateral length of 5.4 m had a discharge of 0.5l/hr. The average variation of the emitter flow rate was found to be 19.7 % which indicates that the arrangement of the drip lines were satisfactory in terms of uniformity of flow from individual emitters. The result conforms to Michael (1978) and Jensen (1983) who stated that in drip irrigation setup the average variation in discharge rate of individual emitters in the whole field should not exceed 20%.

The average emission uniformity was obtained as 92% while the Distribution uniformity was 92%, which is an indication of uniform distribution of water in the system. High uniformity implies that all the areas of the field received adequate water and thus will prevent build-up of salt concentration. The average discharge coefficient of variation was 6.34 % and the average coefficient of variation uniformity was calculated as 93.6%. These results were consistent with the recommendations of Merriam and Keller (1978) who stated that a drip irrigation system with uniformity parameters, emission uniformity and distribution uniformity of 85% or more and discharge variation of the whole system less than 20% is considered to be satisfactory. The overall average water application efficiency of the system was 92.2% as presented in Table 4.1.

Table 4.1 Hydraulic Characteristics of different plots as affected by Lateral Length

S/No	lateral length (m)	EU%	qvar %	Cv %	DU %	CvU%	AE%	Discharge (l/hr)
1	5.4	94.1	15.9	4.9	93.8	95.1	94.1	0.50
2	10.8	91.5	20.5	6.7	91.4	93.3	91.5	0.39
3	11.9	95.9	11.4	3.2	95.9	96.8	95.9	0.42
4	10.9	91.1	20.0	6.9	91.2	93.1	91.1	0.52
5	15.0	90.4	21.2	7.1	91.0	92.9	90.4	0.52
6	14.9	94.1	14.3	4.4	94.4	95.6	94.1	0.50
7	15.4	89.1	30.1	9.4	88.1	90.6	89.1	0.42
8	19.5	93.3	16.9	5.1	93.5	94.9	93.3	0.51
9	26.9	93.6	16.5	5.3	93.3	94.7	93.6	0.65
10	28.4	95.3	12.0	3.8	95.2	96.2	95.3	0.68
11	26.6	95.4	12.2	3.6	95.4	96.4	95.4	0.61
12	27.3	96.0	11.0	3.3	95.8	96.7	96.0	0.54
13	7.7	88.6	32.9	8.7	88.9	91.3	88.6	0.68
14	10.0	86.9	32.3	11.7	85.2	88.3	86.9	0.61
15	12.3	86.8	28.8	11.0	86.1	89.0	86.8	0.65
16	21.9	88.8	22.1	7.8	90.0	92.2	88.8	0.66
17	17.3	93.5	17.2	4.9	93.7	95.1	93.5	0.62
	Average	***92.02***	***19.72***	***6.34***	***91.94***	***93.66***	***92.02***	***0.56***

Table 4.1a Recommended Ranges of manufacturers' coefficients of variation

Emitter type	***Cv range***	***Classification***
Point source	*<0.05*	*Good*
	0.05-0.1	*Average*
	0.1-0.15	*Marginal*
	>0.15	*Unacceptable*
Line source	*<0.1*	*Good*
	0.1 to 0.12	*Average*
	>0.2	*Marginal or Unacceptable*

Source: ASAE (1985)

The overall performance was compared with the ASAE (1985), ASAE (2002) standards for classifying manufacturer's coefficient of variation and design Emission Uniformity (EU) ranges. The measured mean coefficient of variation of 6.34 % falls within the range of point source emitters classified as 'average' as shown in Table 4.1a. The measured mean Emission Uniformity value of 92% is within the recommended acceptable limit for arid areas as shown in Table 4.1b

Table 4.1b Recommended ranges of design Emission Uniformity (EU)

Emitter Type	Topography	EU range for arid Areas (%)
Point source on permanent Crop	Uniform	90-95
	Steep or Undulating	85-90
Point source on permanent or semi permanent crops	Uniform	85-90
	Steep or Undulating	80-90
Line source on annual row crops	Uniform	80-90
	Steep or Undulating	70-80

Source: ASAE (2002)

4.1.1 Emitter Flow Rate

Table 4.1 shows the dripper flow rate as affected by operating pressure and lateral distance of the dripper from Gee Pee tank at different plots tested using catch can test. The overall average dripper discharge was found to be 0.557 l/hr, while the average maximum and minimum discharge rates were 0.612 and 0.489 l/hr, respectively, which was lower than the manufacturer's estimate of 1 l/hr. This may be as a result of the head loss observed in the field.

4.1.2 Soil Wetting Capacities of Drippers

The maximum and minimum wetting diameters of the soil obtained after one hour of irrigation as shown in Table 4.2 were 26.0 and 22.2 cm, respectively, with an average value of 24.3 cm. The field test revealed that on the average with emitter flow rate of 0.557 l/hr, the wetting front can extend to 24.3 cm in the horizontal direction which implies that with one inline dripper, 30 cm between two drippers, it is possible to irrigate two maize stands if planted 25 cm apart.

Table 4.2 Soil wetting performances as affected by different lateral distances

lateral length (m)	Average wetted diameter(cm)	Max(cm)	Min(cm)	Standard deviation
5.4	22.1	23.8	20.2	1.2
10.8	19.6	21.5	18.3	0.9
11.9	20.9	21.8	20.0	0.6
10.9	22.8	24.3	19.3	1.1
15.0	21.5	22.9	19.9	0.9
14.9	22.1	23.3	20.1	1.0
15.4	19.6	23.0	17.6	1.6
19.5	26.6	28.2	24.7	1.0
26.9	27.7	29.1	25.9	1.0
28.4	26.5	28.1	24.2	1.3
26.6	27.1	29.3	24.6	1.6
27.3	22.1	23.8	20.2	1.2
7.7	26.5	28.1	24.2	1.3
10.0	26.4	28.2	23.6	1.2
12.3	27.1	29.3	24.6	1.6
21.9	27.7	29.1	25.9	1.0
17.3	26.5	28.2	24.6	1.0
Average	***24.28***	***26.00***	***22.23***	***1.15***

4.2 Grain and Biomass Yield

Table 4.3 shows the grain and biomass yields for the 2013/2014 cropping season. The grain yield varied from 1.56 to 3.4 t/ha while the biomass yield ranged from 5.6 to 11.1 t/ha, for field A. For field B, the grain yield varied from 2.08 to 3.52 t/ha and biomass yield ranged from 6.75 to 11.5 t/ha, for the 2012/2013 cropping season as shown in Table 4.4. Furthermore, the grain yield varied from 1.77 to 3.43 t/ha, while the biomass yield ranged from and 7.21 to 11.4 t/ha, respectively, for 2013/2014 cropping season as shown in Table 4.3. However, there was no significant difference between the yields for the two seasons at 95% probability level, respectively.

When the application depths were varied at the vegetative stage for field A, 75% (V_{75} $F_{100}G_{100A}$) and 50% (V_{100} $F_{50}G_{100A}$) with respect to ETo, it was observed that the grain and biomass yields were 12.7 % , 30.4 % and 13.7 % and 31.2 % less than when 100 % water was applied to all the crop growth stages (V_{100} $F_{100}G_{100A}$) accordingly. Also, when the depth of water applied was varied at 75 % (V_{100} F_{75} G_{100A}) and 50% (V_{100} $F_{50}G_{100A}$) at the flowering stage, the reduction in grain and biomass yield were 8.8 % , 26.8 % and 9.4 % , 36.7 %, respectively, with respect to the control. When the depth of application was varied at the grain filling stage at 75 % (V_{100} $F_{100}G_{75A}$) and 50 % (V_{100} $F_{100}G_{50A}$) the corresponding grain and biomass yield reduction were 0.9, 4.7 % and 2, 5.9 %.

Table 4.3 Grain yield, Biomass yield and Harvest index of the Maize crop for 2012/2013 and 2013/2014 cropping season

	2012/13					2013/2014				
Treatments	**GY (t/ha)**	**ΔGY (%)**	**BY (t/ha)**	**ΔBY (%)**	**HI (%)**	**GY (t/ha)**	**ΔGY (%)**	**BY (t/ha)**	**ΔBY (%)**	**HI (%)**
V_{100} $F_{100}G_{100A}$	3.39a	0.0	11.12a	0.0	31	3.43a	0.0	11.38a	0.0	31
V_{75} F_{100} G_{100A}	2.96bc	12.7	9.6bc	13.7	30	3.12bc	9.0	10.74bc	5.6	32
V_{50} F_{100} G_{100A}	2.36de	30.4	7.65de	31.2	30	2.80bc	18.4	10.00bc	12.1	32
V_{100} F_{75} G_{100A}	3.09bc	8.8	10.07bc	9.4	31	3.50bc	2.0	11.17ab	1.8	31
$V_{100}F_{50}$ G_{100A}	2.48dc	26.8	7.04dc	36.7	27	2.96bc	13.7	10.37bc	8.9	32
V_{100} F_{100} G_{75A}	3.36ab	0.9	10.9ab	2.0	29	3.35ab	2.3	10.17ab	10.6	32
V_{100} F_{100} G_{50A}	3.23bc	4.7	10.46bc	5.9	31	3.22bc	6.1	11.21ab	1.5	31
V_{50} F_{50} G_{50A}	1.56e	54.0	5.63e	49.4	31	1.77c	48.4	7.21c	36.6	31

Treatment means followed by the same letter(s) in any column are not significantly different at 5% level of significance. GY = Grain yield; BY = Biomass Yield; HI = Harvest Index (%)

The highest yield reduction value of 54% and 49.4% for grain and biomass yield was observed when 50% depth of water was applied throughout the crop growth season, the next is treatment V_{50} F_{100} G_{100A} with grain yield reduction value of 30.4%.The vegetative and flowering stages seem to be very sensitive to yield reduction for field A, so it is advantageous to impose deficit irrigation during the grain-filling stage.

The highest and lowest grain yield reduction values of 48.4 and 2 % were obtained from treatment $V_{50}F_{50}$ G_{50A} and V_{100} F_{75} $G_{100A,}$ respectively, while the highest and lowest biomass yield reduction value of 36.6 and 1.5 % were obtained from treatments $V_{50}F_{50}$ G_{50A} and $V_{100}F_{100}$ G_{50A} , respectively. However, treatments V_{100} F_{100} G_{75A} , V_{100} F_{75} G_{100A} and V_{100} F_{100} G_{75A} were statistically not significantly different from the control at 95% probability level. This is an indicative of the fact that it will be advantageous when deficit irrigation is imposed on grain-filling stage for the crop variety used.

Table 4.4 shows grain and biomass yield, when deficit irrigation schedule was imposed on treatments during crop growth stages for field B. When 20% deficit (V_{80} F_{100} G_{100B}) and 40% deficit (V_{60} F_{100} G_{100B}) of daily ETo applied at Vegetative stage, the grain and biomass yield reductions were 9.9 and 19.6 % and 10 and 21%, respectively. When water application depth was varied at the flowering stage at 80% (V_{100} $F_{80}G_{100B}$) and 60% (V_{100} $F_{60}G_{100B}$), the grain and biomass yield reduction were found to be 8 and 24%, respectively. Furthermore, when 20% deficit (V_{100} $F_{100}G_{80B}$) and 40% deficit (V_{100} $F_{100}G_{60B}$) was imposed at grain filling stage, the grain and biomass yield reductions were obtained as 6.8, 9.4% and 7.7, 10.4%, respectively. The highest yield reductions value of 41% for grain and biomass yield was observed when 40% of water deficit was imposed for all the growth stages (V_{60} F_{60} G_{60B}) for field B. The flowering stage was found to be affected much at 40% deficit ($V_{100}F_{60}$ G_{100B}) with 24% reduction for grain and biomass yields.

This indicates that imposing deficit irrigation on the maize crop may be advantageous if such is done at grain-filling and maturity stage, mindful of the fact that there was onset of rainfall 60 and 70 DAP (grain filling to maturity) which may have reduced the impact of deficit irrigation schedulling, however, if imposed at vegetative and flowering stage, it will drastically affect the grain and biomass yield, which is

consistent with the findings of Igbadun (2012) as rain was observed at the late season of the crop.

Table 4.4 Grain yield, Biomass yield and Harvest index of the Maize crop for field B 2012/2013 cropping season

Treatments	GY (t/ha)	ΔGY (%)	BY (t/ha)	ΔBY (%)	HI (%)
$V_{100}F_{100}G_{100B}$	3.52a	0.0	11.53a	0.0	31
$V_{80}F_{100}G_{100B}$	3.17cd	9.9	10.37cd	10.1	30.5
$V_{60}F_{100}G_{100B}$	2.83cd	19.6	9.16cd	20.6	31
$V_{100}F_{80}G_{100B}$	3.24b	8.0	10.51b	8.8	30.8
$V_{100}F_{60}G_{100B}$	2.69d	23.6	8.72d	24.4	30.8
$V_{100}F_{100}G_{80B}$	3.28a	6.8	10.64a	7.7	31
$V_{100}F_{100}G_{60B}$	3.19c	9.4	10.33c	10.4	30.8
$V_{60}F_{60}G_{60B}$	2.08e	40.9	6.75e	41.5	31

Treatment means followed by the same letter(s) in any column are not significantly different at 5% level of significance. GY = Grain yield; BY = Biomass Yield; HI = Harvest Index (%) ,Δ= percentage reduction

The grain and biomass yield ranges obtained in this study were in consonance with the report of Sefer *et al*. (2011), who obtained range of grain yield ranging from 1.93- 10.4 t/ha under clay loam soil with the use of drip irrigation system in the Eastern Mediterranean climatic conditions of Turkey; Lyocks *et al.*,(2013) who found that grain yield ranged from 2.05- 3.98 t/ha within Samaru region. Garba and Namo (2013) reported grain yield of 3.88 and 3.49 t/ha within two savanna agro-ecologies of Saminaka (lowland)and Vom (mountainous) in Nigeria. Differences in grain and biomass yield reported, may be due to the following: crop variety, extent of irrigation deficit, irrigation method, climate and other agronomic practices.

4.3 Soil Water Balance

Table 4.5 shows the soil water balance for 2012/2013 and 2013/2014 season, during the 2012/2013 season, the seasonal irrigation water applied (SIWA) ranged from 375 to 640 mm, while the total seasonal water applied (TSWA) which is a total of effective rainfall depth and irrigation water applied ranged from 434 to 699 mm for 2012/2013 cropping season. The highest crop water use value of 483 mm was obtained when 100% water depth was applied throughout the crop growth stages, while the lowest crop water use value of 320 mm was obtained when 50% deficit was imposed throughout the crop growth stages.

Table 4.5 Seasonal soil water balance of the field in 2012 and 2013 season

	2012/2013 cropping season				2013/2014 cropping season			
Treatments	RD (mm)	SIWA (mm)	TSWA (mm)	SET (mm)	RD (mm)	SIWA (mm)	TSWA (mm)	SET (mm)
$V_{100}\,F_{100}G_{100A}$	59	640	699	483a	39	636	675	453a
$V_{75}\,F_{100}\,G_{100A}$	59	578	637	441d	39	575	614	412bc
$V_{50}\,F_{100}\,G_{100A}$	59	515	574	417e	39	510	549	368d
$V_{100}\,F_{75}\,G_{100A}$	59	592	651	453c	39	589	628	421bc
$V_{100}F_{50}\,G_{100A}$	59	540	599	428e	39	558	597	399c
$V_{100}\,F_{100}\,G_{75A}$	59	621	680	470b	39	607	646	433ab
$V_{100}\,F_{100}\,G_{50A}$	59	600	659	464bc	39	579	618	414bc
$V_{50}\,F_{50}\,G_{50A}$	59	375	434	320f	39	393	432	289e

Treatment means followed by the same letter(s) in any column are not significantly different at 5% level of significance

The seasonal irrigation water applied (SIWA) ranged from 393 to 636 mm, while the total seasonal water applied (TSWA) ranged from 432 to 675 mm. The highest crop water use value of 453 mm was obtained when 100% depth of water was applied throughout the crop growth stages, while the lowest crop water use value of 289 mm was obtained when 50% deficit was applied throughout the crop growth stages.

During 2013/2014 season the crop water use for treatments $V_{100}\,F_{100}G_{100A}$ and $V_{100}\,F_{100}G_{75A}$ were not significantly different, though the crop water use reduction when

compared to the conventional irrigation schedule was 4%. When 25 and 50% deficit were imposed on the vegetative stage the crop water use reductions were 9 and 19%. Also, when 25 and 50% deficits were imposed on the flowering stage the reduction in crop water use were 7 and 12%. Furthermore, when 50% was imposed on the grain-filling stage and throughout the growth stages, the resultant crop water use reductions were found to be 9 and 36%, when compared to the conventional irrigation schedule for 2013/2014. These ranged of crop water use reported herein, were consistent with the findings of Viswanatha *et al* (2002) and Mahdi *et al* (2011) who similarly worked on drip irrigated maize.

Table 4.6 shows the soil water balance for 2012/2013 cropping season. The seasonal irrigation water applied ranged from 432 to 640 mm, while the total water applied ranged from 491 to 699 mm for field B. The effective rain depth throughout the season was 59 mm as shown in Table 4.6. The highest crop water use of 458 mm was obtained when 100% depth of water was applied throughout the crop growth stages, while the lowest crop water use of 329 mm was obtained when 50% deficit was applied throughout the crop growth stages. Applying 20% deficit during the grain-filling stage, the crop water use obtained was not significantly different from the control (V_{100} $F_{100}G_{100B}$**)** at 95% probability level**.** Also, when 20 and 40% deficit was imposed on the grain-filling stage, the crop water use was not significantly different at 95% probability level as shown in Table 4.6.

Table 4.6 Seasonal water balance of field B in 2012/2013 cropping season

Treatments	RD (mm)	SIWA (mm)	TSWA (mm)	SET(mm)
$V_{100}F_{100}G_{100B}$	59	640	699	458a
$V_{80}F_{100}G_{100B}$	59	590	649	435c
$V_{60}F_{100}G_{100B}$	59	540	599	401d
$V_{100}F_{80}G_{100B}$	59	600	659	442ab
$V_{100}F_{60}G_{100B}$	59	520	579	388e
$V_{100}F_{100}G_{80B}$	59	606	665	446a
$V_{100}F_{100}G_{60B}$	59	592	651	436b
$V_{60}F_{60}G_{60B}$	59	432	491	329f

Treatment means followed by the same letter(s) in any column are not significantly different at 5% level of significance

The water applied in treatments $V_{50}F_{50}G_{50A}$ (2012/2013 and 2013/2014 seasons) and treatment $V_{60}F_{60}G_{60B}$ were not within the range of 500-800 mm given by Doorenbos and Kassam (1979) for a maize crop which further explains the differences in yield compared to others.

4.4 Irrigation Water productivity

Tables 4.7 and 4.8 show the productivity of seasonal water applied to the field during the two seasons with respect to grain and biomass yields. The water productivity with respect to grain and biomass yield varied from 0.47 to 0.53 kg/m^3 and 1.53 to 1.73 kg/m^3, respectively, during the 2012/2013 cropping season. The water productivity with respect to grain yield and biomass yield varied from 0.41 to 0.63 kg/m^3 and 1.76 to 1.98 kg/m^3, respectively, during the 2013/2014 cropping season.

4.7 Irrigation water productivity for grain and biomass yields (kg/m^3) of maize crop 2013/2014 cropping season.

	2013/2014 cropping season		2012/2013 cropping season	
Treatments	**IWP (biomass yield)**	**IWP (grain yield)**	**IWP (biomass yield)**	**IWP (grain yield)**
$V_{100}F_{100}G_{100A}$	1.98a	0.63a	1.73a	0.53a
$V_{75}F_{100}G_{100A}$	1.75c	0.51b	1.51b	0.46ab
$V_{50}F_{100}G_{100A}$	1.82ab	0.51b	1.33c	0.41c
$V_{100}F_{75}G_{100A}$	1.86ab	0.56ab	1.55b	0.47ab
$V_{100}F_{50}G_{100A}$	1.74c	0.50c	1.51b	0.46b
$V_{100}F_{100}G_{75A}$	1.88ab	0.58ab	1.60ab	0.49ab
$V_{100}F_{100}G_{50A}$	1.81b	0.54b	1.59ab	0.49ab
$V_{50}F_{50}G_{50A}$	1.76c	0.41c	1.53b	0.47b

Treatment means followed by the same letter(s) in any column are not significantly different at 5% level of significance

Furthermore, Table 4.8 shows the productivity of seasonal water applied to field B. The water productivity with respect to grain and biomass yield values ranged from 0.42 to 0.50 kg/m^3 and 1.37 to 1.65 kg/m^3. There was no significant difference between fields at 95% probability level.

4.8 Irrigation water productivity for grain and biomass yields (kg/m^3) of maize crop for field B in 2012/2013 cropping season

Treatments	**IWP (biomass yield)**	**IWP (grain yield)**
$V_{100}F_{100}G_{100B}$	1.65a	0.5a
$V_{80}F_{100}G_{100B}$	1.60ab	0.49ab
$V_{60}F_{100}G_{100B}$	1.53b	0.47b
$V_{100}F_{80}G_{100B}$	1.59ab	0.49ab
$V_{100}F_{60}G_{100B}$	1.51b	0.46b
$V_{100}F_{100}G_{80B}$	1.60ab	0.49ab
$V_{100}F_{100}G_{60B}$	1.59ab	0.49ab
$V_{60}F_{60}G_{60B}$	1.37c	0.42c

Treatment means followed by the same letter(s) in any column are not significantly different at 5% level of significance

These results imply that about 0.42 to 0.63 kg of maize was produced from every cubic depth of water, while 1.37 to 1.98 kg of dry matter was produced from every cubic meter of irrigation water.

4.5 Crop yield – Seasonal ET Relationship

The graphical relationship between the maize grain, biomass yield and seasonal evapotranspiration are shown in Fig 4.1. The graph was plotted with a pooled data for 2012/2013 and 2013/2014 cropping season. The relationship between the yields and seasonal evapotranspiration was linear implying that both grain and biomass yields were increasing linearly with increase in evapotranspiration within the lower and upper bound of the data.

The linear equations for the biomass (BY), grain yield (GY in t/ha) and seasonal evapotranspiration (SET in mm) for field were obtained as:

$$BY = 0.025*SET - 0.83; \quad R^2 = 0.60 \tag{4.1}$$

$$GY = 0.009*SET - 0.80; \quad R^2 = 0.74 \tag{4.2}$$

The implication of these expressions are that about 0.25 t/ha-mm of biomass will be obtained from every 10 mm increment of seasonal evapotranspiration after the initial threshold of 33.2 mm depth of water use ; while 0.9t/ha-mm grain yield will be obtained from every 10mm increment of seasonal evapotranspiration after the threshold of 8.9mm depth of water used.

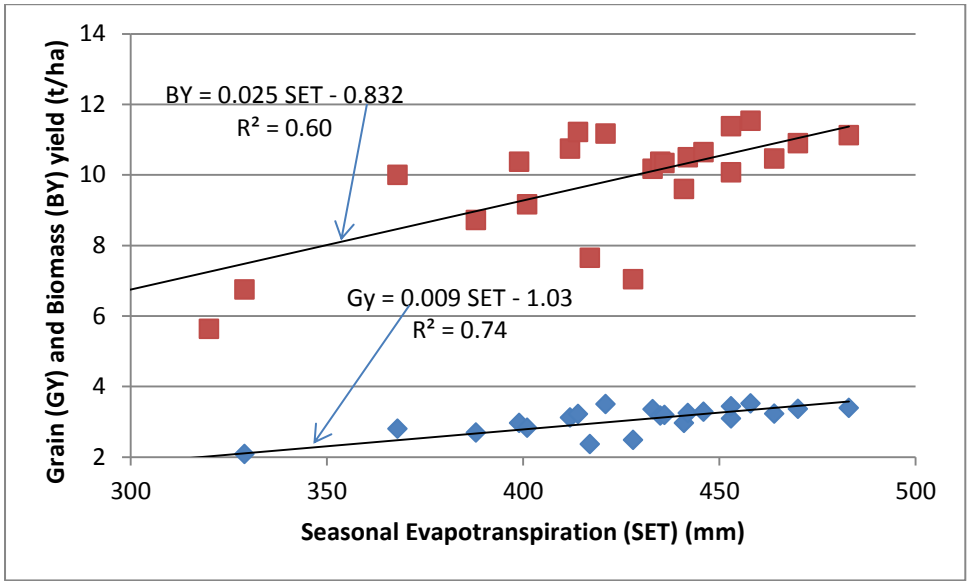


Figure 4.1: Grain and biomass yields relationship with seasonal evapotranspiration pooled from 2012/2013 and 2013/2014 cropping season

4.6 Relative Yield Decrease, Seasonal Crop water use deficit and yield response factor

Figures 4.2 and 4.3 shows the relationship between relative grain yield, biomass yield decrease and relative evapotranspiration deficit, with pooled data from 2012/2013 and 2013/2014 cropping seasons. The yield response factor (Ky), explains the severity of the moisture stress, magnitude of the proportionality of the rate of grain and biomass yield decrease to evapotranspiration deficit, obtained in this study were 1.23 and 1.09, while the coefficients of determination (R^2) were 0.83 and 0.85 as shown in Figs. 4.2 and 4.3.

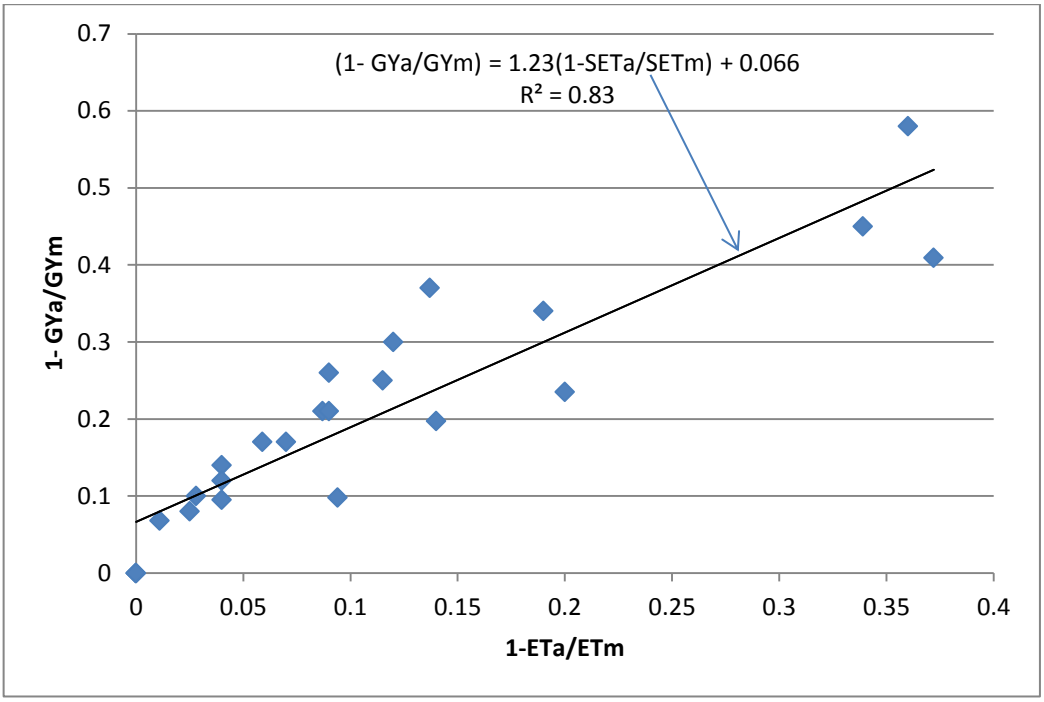


Fig 4.2: Relationship between relative grain yield decrease and relative evapotranspiration deficit pooled data for 2012/2013 and 2013/2014 cropping seasons

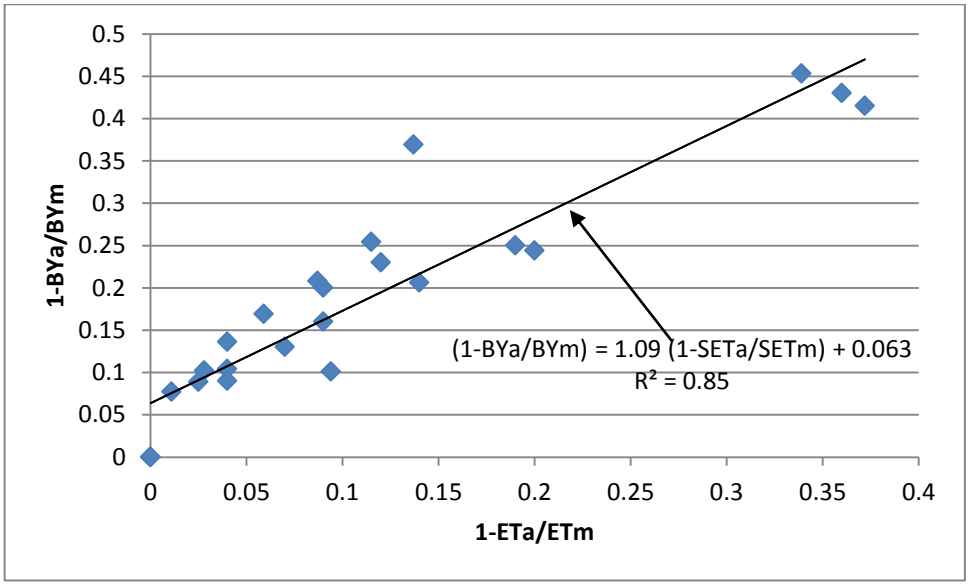


Fig 4.3: Relationship between relative biomass yield decrease and relative evapotranspiration deficit pooled data for 2012/2013 and 2013/2014 cropping seasons

$$1- GYa/GYm = 1.23 (1-SETa/SETm) + 0.066 \quad (4.3)$$

$$1- BYa/BYm = 1.09 (1-SETa/SETm) + 0.063 \quad (4.4)$$

Equations 4.3 and 4.4 give the regression equation for relative grain and biomass yield. The intercepts on the y-axis can be approximated as zero, which imply that the equations are approximately the same as Eqn (2.13a). This relationship indicates that, if the seasonal evapotranspiration was 10 % less than the total ET required for maximum yield, then the actual grain yield will be 12.3 % less than the maximum yield, while the actual biomass yield will be 10.9 % less than the maximum 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. Doorenbos and Kassam (1979) also reported a Ky value of 1.25 which was higher than what was obtained in the study herein.

4.7 AquaCrop Model Calibrations

Figure 4.4 shows a relationship between the simulated and field measured grain yield during the model calibration.

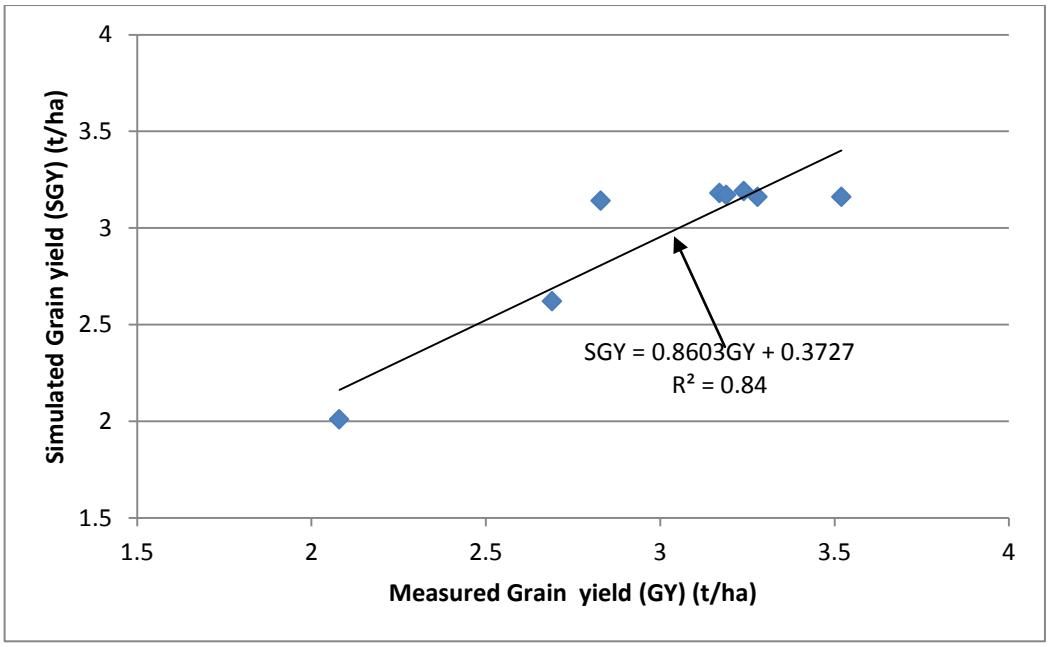


Fig 4.4: Simulated versus field measured grain yield (t/ha)

Figure 4.4 shows the simulated (SGY) and field measured grain yield (GY). The simulated grain yield ranged from 2.01 to 3.19 t/ha as shown in Appendix C6. The maximum and minimum prediction errors (P_e) in grain yield prediction were recorded in treatments V_{60} F_{100} G_{100B} and V_{80} F_{100} G_{100B} amounting to 10.95 % and 0.32 %, respectively. The maximum and minimum prediction errors (P_e) recorded in this research were lower, when compared with values of 16 and 0.84%, respectively, reported by Abedinpour *et al.*, (2012) for maize planted in a semi-arid environment. The simulated versus observed yields gave an R^2 value of 0.84 which indicated a good performance of the simulation process. Evaluation of the differences between measured and predicted values of the grain yield for field B was carried out using student t-test, (t_{tab} = 2.36, while t_{cal} = 2.21) at 95% probability level. The result indicates that the

differences were not significant at 95% probability. Stricevic *et al.* (2011) reported R^2 values greater than 0.84 when simulating yield of maize. Abedinpour *et al.*, (2012) reported R^2 value of 0.90 for maize crop simulation. Thus, the simulated grain yields obtained in this work are consistent with those obtained from similar works by other researchers.

Figure 4.5 shows the relationship between field-measured and simulated biomass (SBY). The differences between the measured and predicted values of the biomass yield for field B were analysed using student t-test (t_{tab} = 2.36, while t_{cal} = 0.05) at 95% probability level. This indicates that the differences were not significant at 95% probability level.

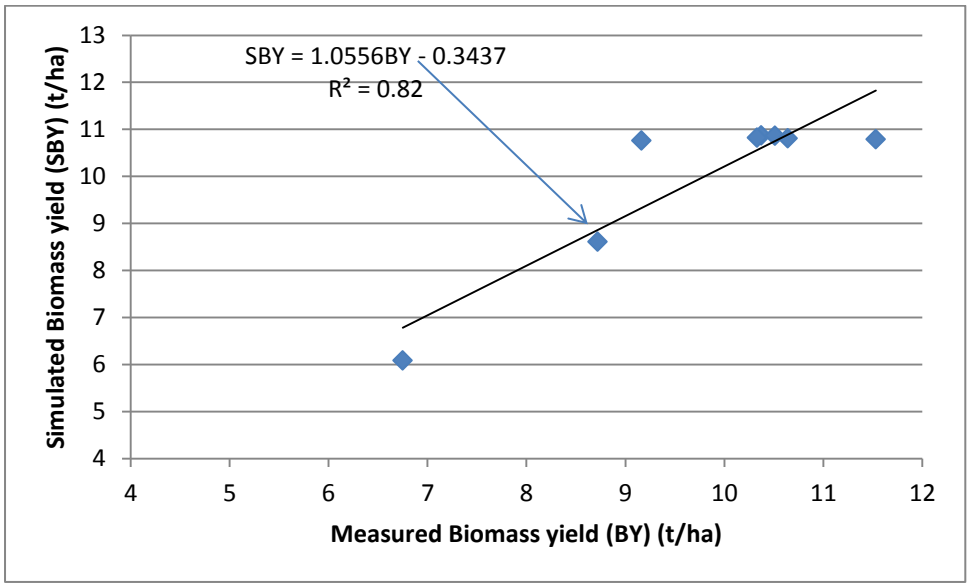


Fig 4.5 Simulated versus field measured biomass yield (t/ha)

The maximum and minimum error in biomass yield prediction for treatments V_{60} F_{100} $G_{100\ B}$ and V_{100} $F_{60}G_{60B}$ amounted to 13.8 and 0.95%, respectively. The prediction errors (P_e) for biomass yield obtained in this research are lower when compared with values of 30.6 and 1.82 %, respectively reported by Abedinpour *et al* (2012) for maize planted in a semi-arid environment.

The relationship between field measured and simulated seasonal evapotranspiration data (SETs) is shown in Fig. 4.6. The differences between the measured and predicted values of the seasonal evapotranspiration using student were analysed using student t-test (t_{tab} = 2.36, t_{cal} = 0.88) at 95% probability level. The observed and predicted seasonal evapotranspiration gave an R^2 of 0.93 which indicated a good performance of the simulation process

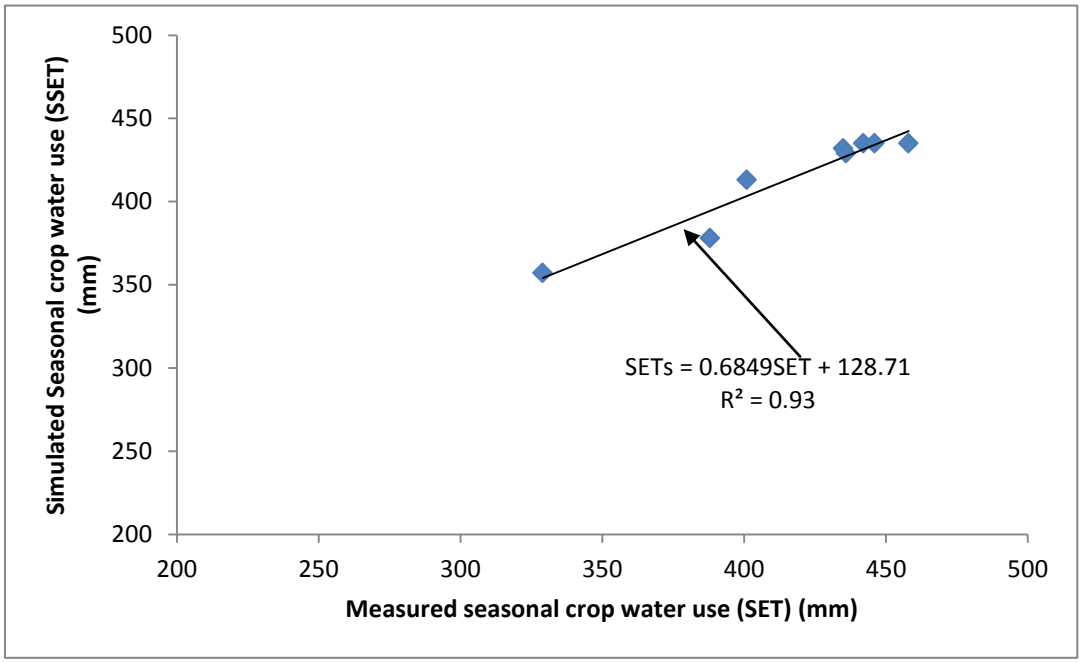


Fig 4.6: Simulated versus field measured crop water use

The statistical comparison of the model-simulated and field- measured data for the final calibration test is presented in Table 4.9.

Table 4.9 Statistics of the comparison between grain yield, biomass yield at harvest and Seasonal Evapotranspiration for field B 2012/2013 cropping season

Statistical performance Indices	Grain yield	Biomass yield	Crop water use
EF	0.82	0.73	0.86
RMSE*	0.32	0.31	0.32
CV (%)	10.7	3.17	0.08
CRM	0.02	-0.02	0.03

*unit of RMSE for biomass yield and grain yield is t/ha, crop water use is mm

The coefficient of variation (CV) between the simulated and measured data were quite low and the modelling efficiency 0.82, 0.73 and 0.86 for the grain and biomass yields and seasonal evapotranspiration, which were good for model performance. The AquaCrop Model can be considered an appropriate tool for simulation for maize in the study area. The CRM shows that the model has a tendency to under - predict grain and over – predict biomass yield at harvest by 2%, its also under - predicted seasonal evapotranspiration by 3%, which is an indication that the model can predict seasonal evapotranspiration.

The simulated and field measured crop water productivity with respect to grain and biomass yield of maize for field B during 2012/2013 cropping season is presented in Table 4.10. The Table shows indicators of the quantity of crop yield produced per cubic meter of water applied used in evapotranspiration. They reflect the water utilization efficiencies, the rate at which the water supplied is converted to harvestable produce.

Table 4.10 Comparison of crop water productivity during model calibration

Treatments	Field B 2012/2013 cropping season			
	GWP (kg/m^3)		BWP (kg/m^3)	
	Sim.	Mea.	Sim	Mea.
$V_{100}F_{100}G_{100B}$	2.68	2.52	0.75	0.77
$V_{80}F_{100}G_{100B}$	2.51	2.38	0.75	0.73
$V_{60}F_{100}G_{100B}$	2.39	2.28	0.74	0.71
$V_{100}F_{80}G_{100B}$	2.40	2.38	0.75	0.73
$V_{100}F_{60}G_{100B}$	2.38	2.25	0.76	0.69
$V_{100}F_{100}G_{80B}$	2.48	2.39	0.75	0.74
$V_{100}F_{100}G_{60B}$	2.50	2.37	0.75	0.73
$V_{60}F_{60}G_{60B}$	2.42	2.05	0.74	0.63

GWP = Grain water productivity, BWP = Biomass water productivity

Table 4.11 shows the statistics of the comparison between the simulated and the measured water productivity. The modelling efficiencies for grain water productivity and biomass water productivity were 73 and 92%. The CRM shows that the model has a tendency to over-predict grain water productivity by 6% and biomass water productivity by 5%. The close relationship between the simulated and measured data was considered as a good performance of the model ability to predict grain and biomass water productivity.

Table 4.11 performance indices of water productivity for field B 2012/2013 cropping season

Statistical performance Indices	Grain water Productivity	Biomass water Productivity
EF	0.73	0.92
RMSE*	0.30	0.34
CV (%)	13.02	47.7
CRM	-0.06	-0.05

*unit of RMSE for biomass yield and grain yield is kg/m^3

4.8 Model Validation

4.8.1 Simulated Grain and Biomass Yield

Table 4.13 shows simulated and measured dry matter and grain yields at harvest. The data from field A was used for validation of the model for 2012/2013, while 2013/2014 cropping season field data was used for the validation of the model across seasons and fields. The observed and predicted values of grain and biomass yield for validation of the AquaCrop model are presented in Table 4.14.

The simulated grain yield for 2012/2013 and 2013/2014 cropping season are for field A are presented in Table 4.12. It was observed that the maximum and minimum error of grain yield prediction during model validation with 2012/2013 data was for treatments $V_{50}F_{100}$ G_{100A} and $V_{100}F_{100}$ G_{50A} amounting to 29.6 and 0.9%, respectively. Further, the maximum and minimum error for biomass was observed to be in treatments $V_{50}F_{100}$ G_{100A} and $V_{100}F_{100}$ G_{50A} with 19.6% and 0.3%, respectively.

Table 4.12 Simulated and measured dry matter and grain yields at harvest

	2012/2013 cropping season field A						2013/2014 cropping season					
	Grain yield (t/ha)			Biomass yield (t/ha)			Grain yield (t/ha)			Biomass yield (t/ha)		
	Sim.	Mea	Pe	Sim	Mea.	Pe	Sim.	Mea	Pe	Sim	Mea	Pe
$V_{100}F_{100}G_{100A}$	3.36	3.39	0.9	10.85	11.12	2.4	3.23	3.43	5.8	10.42	11.38	8.4
$V_{75}F_{100}G_{100A}$	3.13	2.96	5.7	9.94	9.6	3.5	3.29	3.12	5.4	10.61	10.74	1.2
$V_{50}F_{100}G_{100A}$	3.06	2.36	29.7	9.15	7.65	19.6	3.21	2.8	14.6	10.37	10	3.7
$V_{100}F_{75}G_{100A}$	3.06	3.09	2.3	10.99	10.9	0.8	3.34	3.17	5.4	10.71	11.67	8.2
$V_{100}F_{50}G_{100A}$	2.37	2.48	4.4	7.85	7.04	11.5	3.03	2.96	2.4	9.59	10.37	7.5
$V_{100}F_{100}G_{75A}$	3.40	3.36	1.2	10.95	10.9	0.5	3.24	3.35	3.3	10.44	10.17	7.4
$V_{100}F_{100}G_{50A}$	3.20	3.23	0.9	10.32	10.46	0.3	3.24	3.22	0.6	10.46	11.21	6.7
$V_{50}F_{50}G_{50A}$	1.53	1.56	1.9	6.03	5.63	7.1	1.97	1.77	11.3	6.67	7.21	7.5

Prediction Error in per cent (%)

Similarly, the maximum and minimum error of grain yield prediction error during the model validation across the season with 2013/2014 data was obtained for treatments $V_{50}F_{100}$ G_{100A} and $V_{100}F_{100}$ G_{50A} amounting to 14.6% and 0.6%, respectively, while the maximum and minimum error value for biomass was observed to be recorded in treatment $V_{100}F_{100}$ G_{100A} and $V_{75}F_{100}$ G_{100A} amounting to 8.4% and 1.2 %, respectively (Table 4.12) which shows close relationship between the simulated and measured data, indicating that the model's ability to predict grain yield of maize.

Table 4.13 Statistics of the comparison between grain yield and biomass yield at harvest for 2012/2013 and 2013/2014 cropping season

Statistical performance Indices	Grain yield	Biomass yield	Grain yield	Biomass yield
EF	0.81	0.90	0.86	0.74
RMSE*	0.26	0.64	0.33	0.30
CV (%)	9.28	6.97	10.94	2.94
CRM	-0.03	-0.04	-0.03	0.06

*unit of RMSE for biomass yield and grain yield is ton/ha

The statistics of the model validation across fields and seasons is presented in Table 4.13. The CRM shows that the model over-predicted grain yield by 3% and under-predicted yield at harvest by 6 % for 2013/2014 season, and over- predict grain and biomass yield by 3 and 4% , respectively, for 2012/2013 season. The modelling efficiencies (EF) were between 74 and 90% biomass and grain yield. The close relationship between the simulated and the measured data was considered as good performance of the model ability to predict biomass and grain yields.

4.8.2 Simulated Seasonal Evapotranspiration

The simulated and the field measured seasonal evapotranspiration for 2012/2013 and 2013/2014 cropping seasons is presented in Table 4.14.

Table 4.14 Simulated and measured dry matter and grain yields at harvest

Treatment	Crop water use (mm) 2012/2013 field A			Crop water use (mm) 2013/2014		
	Sim.	Mea	Pe (%)	Sim	Mea.	Pe (%)
$V_{100}F_{100}G_{100A}$	492	483	1.9	442	453	2.4
$V_{75}F_{100}G_{100A}$	444	441	0.7	413	412	0.2
$V_{50}F_{100}G_{100A}$	412	417	1.2	408	368	10.9
$V_{100}F_{75}G_{100A}$	492	453	8.6	419	421	0l.5
$V_{100}F_{50}G_{100A}$	402	428	6.1	400	399	0.3
$V_{100}F_{100}G_{75A}$	492	470	4.7	412	433	4.8
$V_{100}F_{100}G_{50A}$	486	464	4.7	412	414	0.5
$V_{50}F_{50}G_{50A}$	309	320	3.4	361	289	24.9
Mean	441	435	3.91	408	398	6.29
Standard Error	65.1	51.2	2.67	22.7	50.7	6.34

The maximum and minimum error of crop water use prediction during the model validation with 2012/2013 data was for the treatments $V_{100}F_{75}$ G_{100A} and $V_{75}F_{100}$ G_{100A} amounting to 8.6% and 0.7%, respectively. The maximum and minimum errors of crop water use prediction during model validation with 2013/2014 data was for treatments $V_{50}F_{50}$ G_{50A} and $V_{75}F_{100}$ G_{100A} amounted to 24.9% and 0.2%, respectively.

Table 4.15 shows the statistics of the comparison between the simulated and the measured data. There was tendency of over-prediction of the seasonal evapotranspiration by 1% in 2013/2014 season and under-prediction of seasonal evapotranspiration by 2% in the 2012/2013 season as indicated by the CRM. The modelling efficiency was low for 2013/2014 cropping season (49%) and quite high for 2012/2013 cropping season (85%) which may be as a result of the low sensitivity of the gypsum blocks used to measure the crop during 2013/2014 cropping season which in turn affected the model performance. The RMSE value for validation of the seasonal evapotranspiration obtained in this

research were 0.19 and 0.21 mm for 2012/2013 and 2013/2014 season, respectively, which is low compared to the RMSE value of 9.76 and 22.74mm, respectively as reported by Igbadun (2012) . However, low RMSE values of 0.19 – 0.21 mm indicate good correlation between simulated and measured seasonal evapotranspiration.

Table 4.15 Statistics of the comparison between seasonal evapotranspiration for 2013/2014 and 2012/2013 cropping season

Statistical performance Indices	Crop water use (2012/2013)	Crop water use (2013/2014)
EF	0.85	0.49
RMSE*	0.19	0.21
CV (%)	8.84	8.27
CRM	0.02	0.01

*unit of RMSE for crop water use is mm

4.8.3 Simulated Biomass and Grain Water Productivity

The water productivity predictions by AquaCrop model is presented in Table 4.16. The statistics of the comparison between the simulated and measured grain and biomass water productivity for 2013/2014 and 2012/2013 cropping season is presented in Table 4.16.

Table 4.16 Validation Result for crop water productivity for 2013 and 2014 cropping season

	2012/2013 cropping season				2013/2014 cropping season			
	GWP (kg/m^3)		BWP (kg/m^3)		GWP (kg/m^3)		BWP (kg/m^3)	
Treatment	Sim.	Mea	Sim.	Mea.	Sim.	Mea.	Sim	Mea
$V_{100}F_{100}G_{100A}$	0.77	0.70	2.19	2.30	0.72	0.76	2.67	2.51
$V_{75}F_{100}G_{100A}$	0.66	0.67	2.14	2.18	0.72	0.76	2.66	2.61
$V_{50}F_{100}G_{100A}$	0.67	0.57	2.19	1.83	0.71	0.76	2.62	2.72
$V_{100}F_{75}G_{100A}$	0.87	0.68	2.21	2.41	0.82	0.83	2.65	2.77
$V_{100}F_{50}G_{100A}$	0.87	0.58	1.79	1.64	0.73	0.74	2.54	2.60
$V_{100}F_{100}G_{75A}$	2.78	0.71	2.22	2.32	0.72	0.77	2.61	2.35
$V_{100}F_{100}G_{50A}$	0.86	0.70	2.16	2.25	0.82	0.80	2.69	2.71
$V_{50}F_{50}G_{50A}$	0.59	0.49	1.52	1.76	0.71	0.61	2.47	2.49

Table 4.17 Statistics of the comparison between Grain and biomass water productivity for 2013/2014 and 2012/2013 cropping season

Statistical performance Indices	Grain water productivity	Biomass water productivity	Grain water productivity	Biomass water productivity
EF	0.41	0.56	0.85	0.62
RMSE*	0.22	0.27	0.65	0.16
CV (%)	8.27	34.16	30.86	26.47
CRM	0.03	0.03	-0.3	-0.24

*unit of RMSE for biomass yield and grain yield is ton/ha, for crop water use is mm.

4.8.4 Above ground biomass

Above ground biomass is derived from the crop transpiration by means of the crop water productivity, normalized for ETo and CO_2. Table 4.18 shows simulated and observed aboveground biomass during vegetative, flowering and grain-filling stage for maize during the 2013/2014 cropping season. Table 4.19 shows the statistics of the comparison between the simulated and measured biomass yield at vegetative, flowering and grain-filling stage.

Table 4.18 Simulated and observed biomass at vegetative, flowering and Grain-filling stage for maize 2013/2014 cropping season

Treatment	2013/2014 cropping season					
	Vegetative Stage (t/ha) (15-42DAP)		Flowering stage (t/ha) (43-60DAP)		Grain-filling stage (t/ha) (60-70DAP)	
	Sim.	Mea	Sim	Mea.	Sim	Mea.
$V_{100}F_{100}G_{100A}$	1.18	1.01	5.53	5.74	7.86	7.60
$V_{75}F_{100}G_{100A}$	0.63	0.54	4.56	4.77	6.96	6.68
$V_{50}F_{100}G_{100A}$	0.45	0.39	4.07	4.29	6.49	6.21
$V_{100}F_{75}G_{100A}$	0.74	0.63	4.80	5.02	7.19	6.91
$V_{100}F_{50}G_{100A}$	0.53	0.45	4.32	4.53	6.72	6.44
$V_{100}F_{100}G_{75A}$	1.02	0.87	5.29	5.49	7.64	7.37
$V_{100}F_{100}G_{50A}$	0.87	0.74	5.05	5.26	7.42	7.14
$V_{50}F_{50}G_{50A}$	0.38	0.33	3.83	4.05	6.25	5.98

Table 4.19 Statistics of the comparison between Vegetative, flowering and Grain-filling stage for 2013/2014 cropping season

Statistical performance Indices	Vegetative stage	Flowering Stage	Grain-filling Stage
EF	0.74	0.85	0.73
RMSE*	0.12	0.21	0.28
CV (%)	4.15	2.31	0.06
CRM	0.07	0.02	0.02

4.8.5 Canopy Cover Simulation

The AquaCrop model simulated CC under different water application depths for the crop growth stages are as shown in Table 4.20. The simulated canopy cover was close to the observed values from vegetative to flowering during the 2013/2014 cropping season, but after flowering stage there was change in the last senesced CC measurement, with predicted CC declining faster when compared with the observed CC. This change could be related to abrupt increased temperature which resulted to the acceleration of the CC recorded 24, 52 and 68 days after planting which corresponds to the vegetative, flowering and grain filling stages. The predicted error between the observed and predicted canopy cover was found to be 12% for treatment V_{75} F_{100} G_{100A} and V_{50} F_{100} G_{100A} during the vegetative stage and 20% for treatments V_{50} F_{100} G_{100A} and V_{100} F_{75} G_{100A} during the grain filling stage. Treatments V_{50} F_{50} G_{50A}, however, recorded the highest Prediction error of 46% for vegetative and flowering stages; during the grain filling stage while treatments $V_{100}F_{100}$ G_{50A} recorded the lowest prediction error as 0% during flowering stage 2013/2014 cropping season.

Table 4.20 Comparison of canopy cover under different water depths with respect to crop growth stages during 2013/2014 cropping season

	Vegetative Stage			Flowering Stage			Grain-Filling stage		
Treatment	sim	Mea.	Pe	sim	Mea.	Pe	sim	Mea.	Pe
$V_{100}F_{100}G_{100A}$	38	35	9	52	65	20	68	88	23
$V_{75}F_{100}G_{100A}$	38	34	12	52	64	19	68	87	22
$V_{50}F_{100}G_{100A}$	38	34	12	52	63	17	68	85	20
$V_{100}F_{75}G_{100A}$	38	33	15	52	63	17	68	85	20
$V_{100}F_{50}G_{100A}$	38	32	19	52	61	15	68	80	15
$V_{100}F_{100}G_{75A}$	38	31	23	52	55	5	68	75	9
$V_{100}F_{100}G_{50A}$	38	30	27	52	52	0	68	70	3
$V_{50}F_{50}G_{50A}$	38	26	46	52	46	13	68	64	6
Mean	38	31.9	20.4	52	59	13.3	68	79	15
Standard Error	0	2.9	12	0	6.9	7.1	0	8.8	7.8

In AquaCrop model, as crop approaches maturity, CC enters a declining phase due to leaf senescence, which starts generally in the oldest leaf located at the shaded bottom of the canopy that contributes little to transpiration; it is functional at the time when canopy transpiration and photosynthesis start declining as maturity is approached, AquaCrop model cannot simulate canopy cover correctly at the end of the crop cycle as reported by Andarzian *et al.,* (2011).

4.9 Sensitivity Analysis

Sensitivity analysis was carried out by varying the input variables by $\pm 5\%$ with respect to base value parameters used during calibration. When the model was set at full irrigation and the base parameter was increased by 5%, it was observed that grain yield was highly sensitive to maximum canopy cover, referenced harvest index and time to canopy senescence, while plant density, time to emergence, time to flowering and canopy decline coefficient indicated a null sensitive. Biomass yield was averagely sensitive to the maximum canopy, crop water productivity, time to senescence and root deepening.

However, when it was set at full irrigation and the base parameter was decreased by 5%, the grain yield was highly sensitive to time to senescence, reference harvest index, while

grain yield indicated a null sensitivity to Kcbx, time to emergence and canopy decline coefficient, biomass yield indicated a null sensitivity to canopy decline coefficient, reference harvest index, time to emergence and Kcbx as presented in Table 4.21.

Table 4.21 Sensitivity classification for fully irrigated maize on Grain and Biomass yield

Input parameter	Sc (+5%) Grain yield	Sc (-5%) Grain yield	Sc (-5%) Biomass yield	Sc (+5%) Biomass yield
Maximum canopy	1.6	1.0	1.0	0.9
Canopy decline coefficient	0.0	0.0	0.0	0.0
Plant density	0.1	0.1	0.1	0.1
Crop water productivity	1.2	0.6	0.6	1.2
Reference Harvest index	1.5	1.5	0.0	0.0
Time to Emergence	0.0	0.0	0.0	0.0
Time to canopy senescence	2.2	3.1	1.0	0.9
Time to flowering	0.0	0.1	0.1	0.0
Rooting deepening	0.8	0.9	0.9	0.8
Kcbx	0.0	0.0	0.0	0.0

$S_c > 1.5$ = high sensitivity, $0.3 < S_c < 1.5$ = average sensitivity, $0 < S_c < 0.3$ = low sensitivity, $S_c = 0$ = without Sensitivity

However, when irrigation was set at 50% ETo for all growth stages and the base parameter was increased and decreased by 5%, it was observed that the AquaCrop model's sensitivity increased with decreasing irrigation depth except for maximum canopy which decreased as shown in Table 4.22. Parameter that displayed a null level of influence over the biomass yield and grain yield when it was set at 50% ETo for all growth stages, was time to emergence.

Table 4.22 Sensitivity classification for 50% ETo irrigated maize on Grain and Biomass yield

Input parameter	Sc (+5%) Grain yield	Sc (-5%) Grain yield	Sc (-5%) Biomass yield	Sc (+5%) Biomass yield
Maximum canopy	0.5	0.4	0.6	0.6
Canopy decline coefficient	0.1	0.3	0.6	0.6
Plant density	0.1	0.3	0.4	0.4
Crop water productivity	1.5	0.5	0.8	0.8
Reference Harvest index	1.5	7.8	0.3	0.3
Time to Emergence	0.0	0.0	0.0	0.0
Time to canopy senescence	2.4	3.0	0.6	0.6
Time to flowering	0.4	1.2	0.1	0.1
Rooting deepening	1.3	0.9	1.8	1.8
Kcbx	0.8	0.2	0.3	0.3

$S_c > 1.5$ = high sensitivity, $0.3 < S_c < 1.5$ = average sensitivity, $0 < S_c < 0.3$ = low sensitivity, $S_c = 0$ = without Sensitivity

When the base value (parameter used for calibration) was increased by 5% , grain yield was highly sensitive to crop water productivity, reference harvest index and time to canopy senescence. Grain yield was also averagely sensitive to root deepening, Kcbx and maximum canopy as shown in Table 4.22. Furthermore, the biomass yield was highly sensitive to only root deepening, averagely sensitive to time to senescence, crop water productivity, plant density, canopy decline coefficient and maximum canopy.

When the parameters were decreased by 5%, the influence of reference of harvest index to grain yield was high, while for biomass, root deepening sensitivity was high as shown in Table 4.22. The results obtained in these sensitivity analysis were consistent with that obtained by Hamidreza *et al*., (2011a) who reported that AquaCrop model's sensitivity increased with decreasing irrigation depth. Atefah (2013) also found that model has little sensitivity to density of cultivation, period of yield formation for potato. Hamidreza *et al* (2011b) reported that the most sensitive agronomic parameters are time to senescence, root deepening, irrigation management, CC, WP and CGC which are not different from what was obtained in the work reported herein.

4.10 Effect of Deficit Irrigation on Benefit-Cost Ratio of Drip Irrigated Maize

Table 4.23 shows the total production cost, economic returns per treatment per hectare in just a season for 5 years. The highest revenue, profit and benefit- cost ratio of ₦ 1,126,400, ₦ 652,870 and 2.4, respectively were recorded for treatment $V_{100}F_{100}G_{100A}$ for 5 years, while the lowest revenue, profit and benefit- cost ratio of ₦ 665,600, ₦ 192,523 and 1.4, respectively, were recorded for treatment $V_{50}F_{50}G_{50A}$ for 5 years as shown in Table 4.23.

When the overall economic performances of the drip irrigated maize at different irrigation level were compared in terms of B/C ratio and total volume of irrigation water used, treatment $V_{100}F_{100}G_{100A}$ resulted in higher per cent of B/C ratio value of 2.4 compared to others. However, in terms of benefit-cost ratio, treatment $V_{100}F_{75}G_{100A}$, $V_{100}F_{100}G75_{A}$ and $V_{100}F_{100}G_{50A}$ resulted to same economic level of performance (B/C= 2.2) as shown in Table 4.23.

The results imply that, if a farmer in the study area irrigate with 50% deficit of water required for maize production through out the crop growth stages for 5 years, the total accumulated cost will be less than the total accumulated revenue for 5 years, which is a worth while adventure because the B/C ratio were above unity.

Table 4.23 Summary of total production cost, returns on drip irrigated maize per treatment for 5years per hectare

Treatment	Irrigation Equipment (₦)[a]	Applied water (mm)	pumping cost (₦)	Farm inputs (₦)	Labour (₦)	Total production cost (₦)	Yield (t/ha)[b]	Revenue (₦)	Profit (₦)	B/C
$\mathbf{V_{100}\,F_{100}G_{100A}}$	383530	679	11000	25000	54000	473530	14.08	1126400	652870	**2.4**
$\mathbf{V_{75}\,F_{100}\,G_{100A}}$	383530	649	10513.8	25000	54000	473044	12.68	1014400	540870	**2.1**
$\mathbf{V_{50}\,F_{100}\,G_{100A}}$	383530	599	9703.8	25000	54000	472234	11.32	905600	432556	**1.9**
$\mathbf{V_{100}\,F_{75}\,G_{100A}}$	383530	659	10675.8	25000	54000	473206	12.96	1036800	564566	**2.2**
$\mathbf{V_{100}F_{50}\,G_{100A}}$	383530	579	9379.8	25000	54000	471909	10.76	860800	387594	**1.8**
$\mathbf{V_{100}\,F_{100}\,G_{75A}}$	383530	665	10773	25000	54000	473303	13.12	1049600	577690	**2.2**
$\mathbf{V_{100}\,F_{100}\,G_{50A}}$	383530	651	10546.2	25000	54000	473076	12.76	1020800	547497	**2.2**
$\mathbf{V_{50}\,F_{50}\,G_{50A}}$	383530	491	7954.2	25000	54000	470484	8.32	665600	192523	**1.4**

[a]Detail cost breakdowns are given in Appendix D, [b] Grain yield for a season per hectare

4.11 Scenario study of deficit irrigation schedulling for a drip irrigated maize crop with AquaCrop model

The water requirement for maximum crop productivity for a maize crop as reported by Doorenbos and Kassam (1979) crop is 500-800 mm; hence, the irrigation schedule scenarios adopted in this research were within the recommended range. The vegetative stage (tassel formation) was taken as 0-42 days after planting; the flowering stage (silking) was taken as 43-63 days after planting, while the grain filling stage to physiological maturity was taken as 64-90 DAP. The lengths of the growth stages adopted in this research were similar to those of Doorenbos and Kassam (1979).

4.11.1 Effect of varying irrigation intervals and fixed water application depth

Figure 4.7 shows the average simulated grain yields for a fixed water application depth (WAD) of 15, 20, 25 and 30 mm per irrigation event and irrigation intervals of 3, 4, 5 and 6 days. The simulated grain yield ranged from a null yield at 6-day intervals to 2714 kg/ha at 3-day intervals for fixed water application depth (WAD) of 15mm, per irrigation event and irrigation intervals of 3, 4, 5 and 6 days. Increase in irrigation interval to 6-day with fixed depth of 15 mm throughout the crop growth stages gave a null yield, increasing the interval from 3 to 4,5 and 6-day led to grain yield reduction of 17.1, 45, 70 and 100 %, respectively, a using WAD of 20mm throughout the crop growth stages as reference. The potential yield of irrigated maize (SAMMAZ 14) for Samaru locality has been put at 4 t/ha (Lyocks *et al.*, 2013), which is within the range of the simulated values.

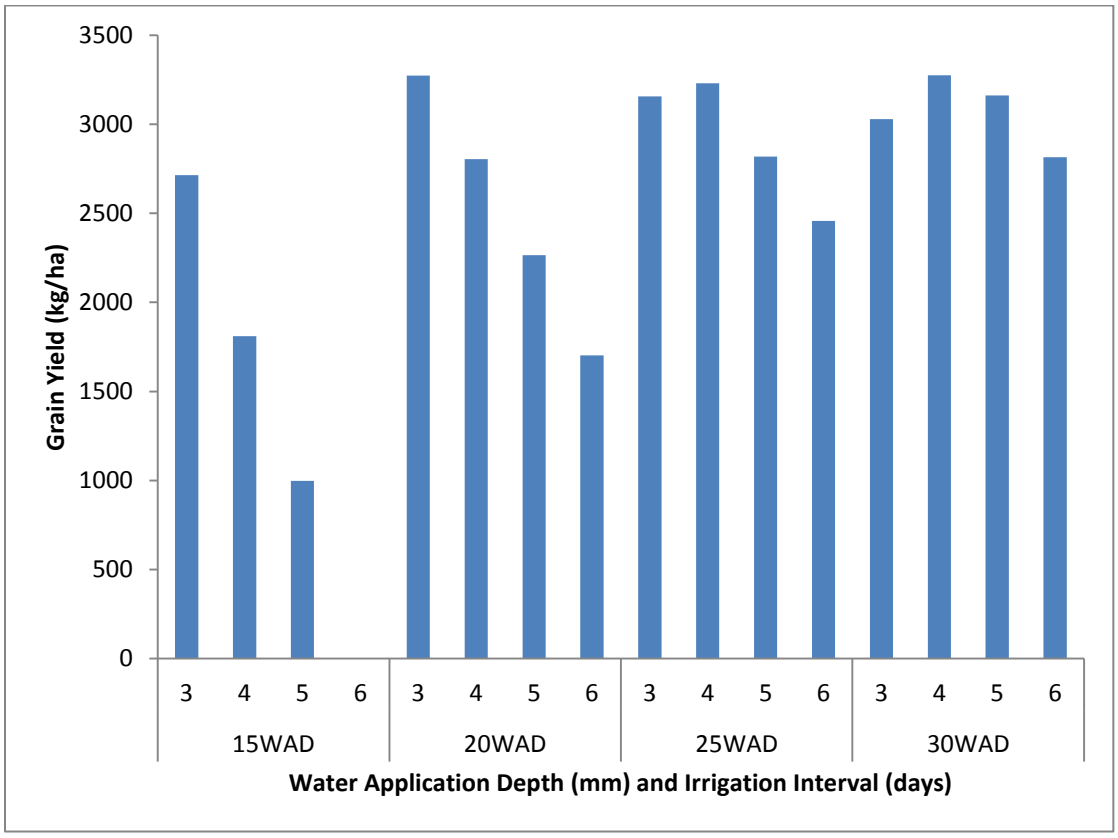


Fig. 4.7 grain yield under different water application depth and irrigation intervals

The simulated biomass yield ranged from 2401kg/ha at 6-day intervals to 8638 kg/ha at 3-day intervals as shown in Figure 4.7. Increase in irrigation interval from 3 to 4 ,5 and 6 days led to biomass yield reduction of 18, 41, 67 and 77 %, respectively, using WAD of 20mm throughout the crop growth stages as reference. Seasonal water applied ranged from 225 – 450 mm (Appendix C6), while the seasonal crop water use ranged from 218 – 429 mm as shown in Figure 4.9. The biomass and grain water productivity ranged from 1.81- 2.44 kg/m^3 and 0-0.77 kg/m^3; null grain water productivity was obtained when 15mm WAD and a 6-day irrigation interval was adopted as shown in Appendix C6.

The average simulated grain yields as a result of a fixed WAD (20mm) and different

irrigation interval (3 - 6days) is shown in Fig. 4.7. The simulated grain yield ranged from 1702 kg/ha at 6days interval to 3273 kg/ha at 3days interval. Increasing the irrigation interval from 3 to 6 days led to a grain yield reduction values of 14.3, 30.8 and 48 %, for 4, 5 and 6 days, respectively. The simulated biomass yield ranged from 5798 kg/ha at 6-day interval to 10492 kg/ha at 3-day intervals as shown in Fig. 4.8. Increasing the irrigation interval from 3 to 6-day led to a biomass yield reduction value of 15. 4, 31.3 and 45%, for 4, 5 and 6 days, respectively, with reference to 20mm WAD with 3-day irrigation intervals. The biomass and grain water productivity ranged from 2.30 -2.65 kg/m^3 and 0.61-0.83 kg/ m^3, when 20 mm WAD application depth was applied from 3-6 days irrigation interval as presented in Appendix C6.

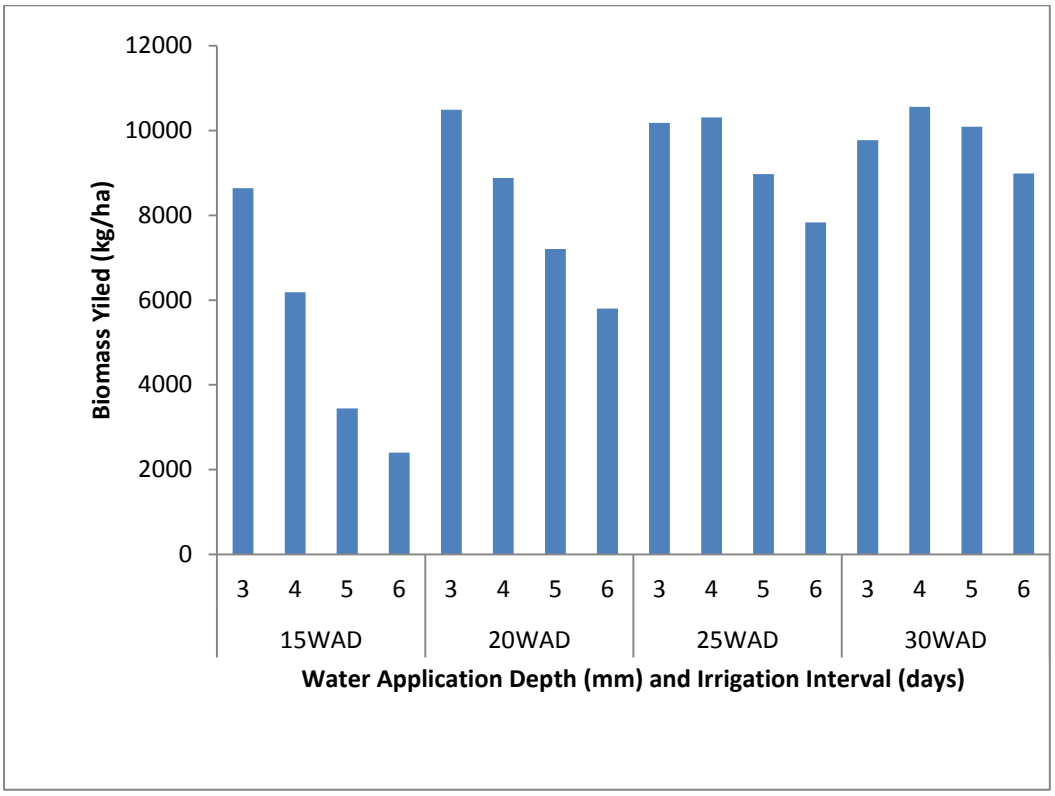


Fig. 4.8 biomass yield under different water application depth and irrigation intervals

The average simulated grain yields as a result of a fixed WAD (25mm) and different irrigation intervals (3 - 6days) is shown in Fig. 4.7. The simulated grain ranged from 2457 kg/ha at 6-day intervals to 3156 kg/ha at 3-day intervals. Increasing the irrigation interval from 3 to 6 days led to a grain yield reduction value of 1.8, 1.4 and 25 %, for 4, 5 and 6 days, respectively.

The simulated biomass yield ranged from 7830kg/ha at 6-day interval to 10180kg/ha at 3days interval as shown in Fig. 4.8. Increasing the irrigation interval from 3 to 6-day led to a biomass yield reduction value of 3, 2, 15 and 25 %, for 3, 4, 5 and 6 days, respectively, with reference to 20mm WAD with 3-day irrigation intervals. The seasonal water applied ranged from 375-750mm, while the crop water use ranged from 289- 450mm; when 25mm was applied for 3days throughout the growth stages, as shown in Fig. 4.9. The biomass and grain water productivity ranged from 2.60 - 2.73 kg/m^3 and 0.82- 0.86 kg/ m^3, when 25mm WAD application depth was applied from 3-6days irrigation interval as presented in Appendix C6.

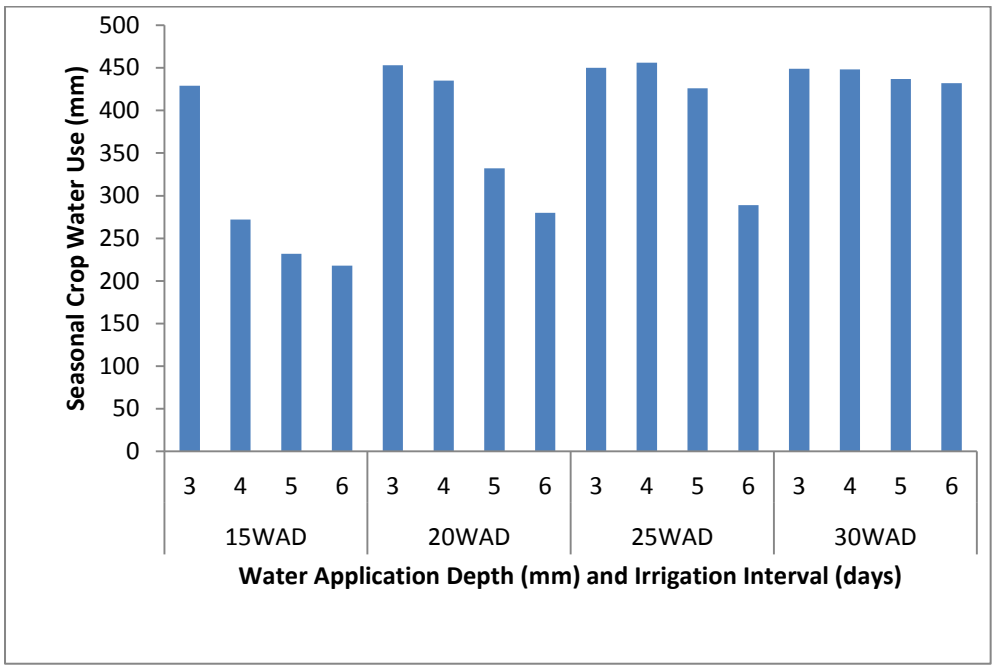


Fig. 4.9 seasonal crop water use under different water application depth and irrigation intervals

The average simulated grain yields as a result of a fixed WAD of 30mm and different irrigation intervals (3- 6 days) are as presented in Fig. 4.7. The simulated grain yield ranged from 2814 kg/ha at 6-day intervals to 3029 kg/ha at 3-day intervals. Increasing the irrigation intervals from 3 to 6 days led to a grain yield reduction values of 8, 3 and 14 %, for 3, 5 and 6 days, respectively. The simulated biomass yield ranged from 8985 kg/ha at 6-day intervals to 10557 kg/ha at 4-day intervals as shown in Fig. 4.8. Increasing the irrigation intervals from 3 to 6 days led to biomass yield reduction values of 7 , 4 , 14 % , for 3, 5 and 6 days, respectively, with reference to 20mm WAD with 3days irrigation interval. The seasonal water applied ranged from 450-870 mm, while the crop water use ranged from 432- 449 mm as shown in Fig. 4.9. The biomass and grain water productivity ranged from 2.64 - 2.83 kg/m^3 and 0.82- 0.88 kg/ m^3 when 30mm WAD application depth was applied from 3- 6 day irrigation intervals as shown in Appendix C6.

Optimum grain and biomass yield value of 3273 and 10492 kg/ha were obtained when 20 and 30mm WAD were applied at 3 and 4days irrigation intervals, respectively. If 20mm WAD at 3days irrigation interval is adopted by farmers in the study area, at the end of the season 60mm depth of water would have been saved, with respect to when 30mm WAD would have been applied. Also, in the study area where the labour charged is on the irrigation activity and not on the depth of water applied, in order to reduce cost, 30mm WAD at 4 days interval should be adopted by farmers, since the number of irrigation activities is less when 20mm WAD was applied. Better water utilization occurred when 30mm WAD at 5days irrigation interval was imposed on the maize crop. However, there was a reduction in yield as presented in Appendix C6. This could have been due to excessive water stress arising from the treatment.

4.11.2 Effect of Irrigation Interval and varied WAD on Yields and Water Balance Responses of Maize

The highest grain yield value of 3266 kg/ha was recorded for treatments V20 F20 G10, while the lowest grain yield value of 1998 kg/ha for treatments V15 F10 G20 as shown in Fig. 4.10. The grain yield reduction ranged from 0.2 -39 %. Treatment V15F10G20 recorded the highest grain yield reduction value of 39%, while treatment V20F20G10 recorded the lowest grain yield reduction value of 0.2%, for scenarios considered. Thus, water deficit at both vegetative and flowering stage for same time should be avoided.

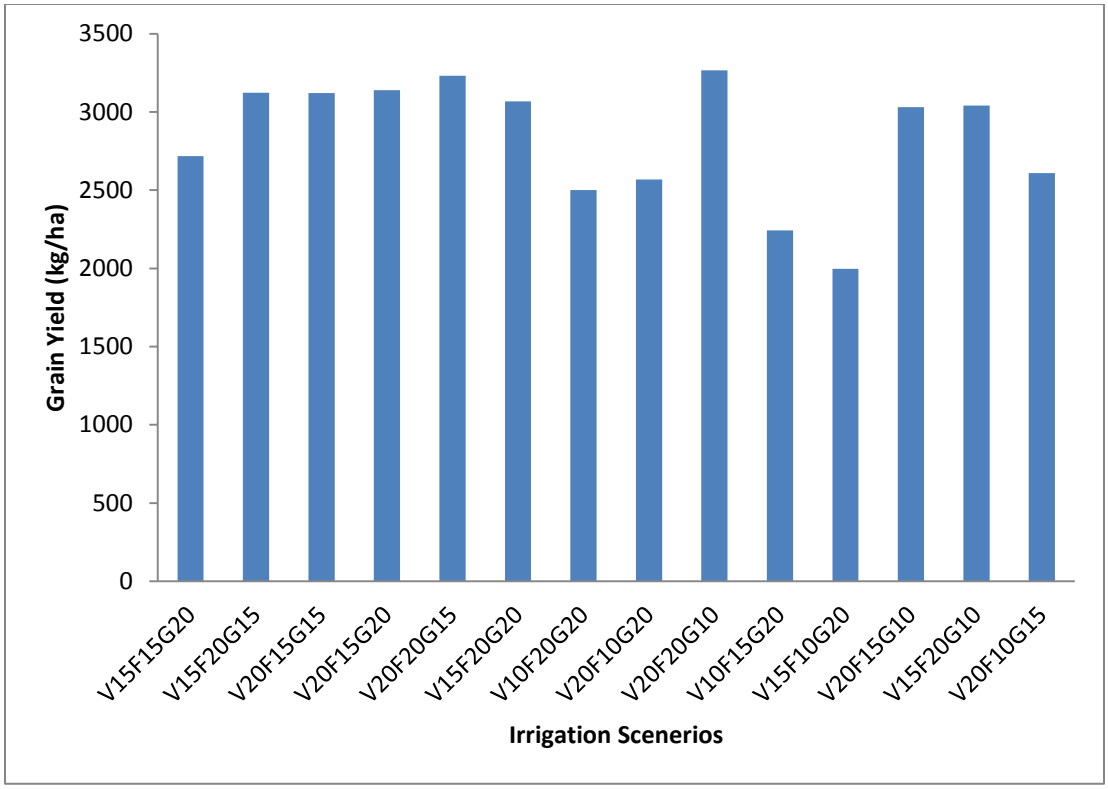


Fig 4.10 Grain yield and varied water application depth along crop growth stages

Water application depth of 15mm at vegetative and grain-filling stage, with flowering (20mm) and WAD of 20, 15 and 15 at vegetative, flowering and grain-filling stage led to grain yield reduction value of 4.6%. When 15mm was applied at flowering (V20F15G20), grain-filling (V20F20G15) and vegetative (V20F15G20), the

corresponding yields reduction values of 4.1, 1.3 and 6.3% were obtained, respectively, as shown in appendix C8. This shows that the vegetative stage is more sensitive to water stress compared to flowering and grain-filling stages, which is a deviation from the account of Angela (2012), that flowering and grain-filling stage are more sensitive to water shortage compared to the vegetative.

The highest biomass yield value of 10470 kg/ha was recorded for treatments V20 F20 G10, while the lowest grain yield value of 6764 kg/ha for treatment V15 F10 G20 as shown in Fig. 4.11. Applying water at 20mm throughout the crop growth stages was used as reference for quantifying the effect of various WAD at different growth stages on yield and water responses.

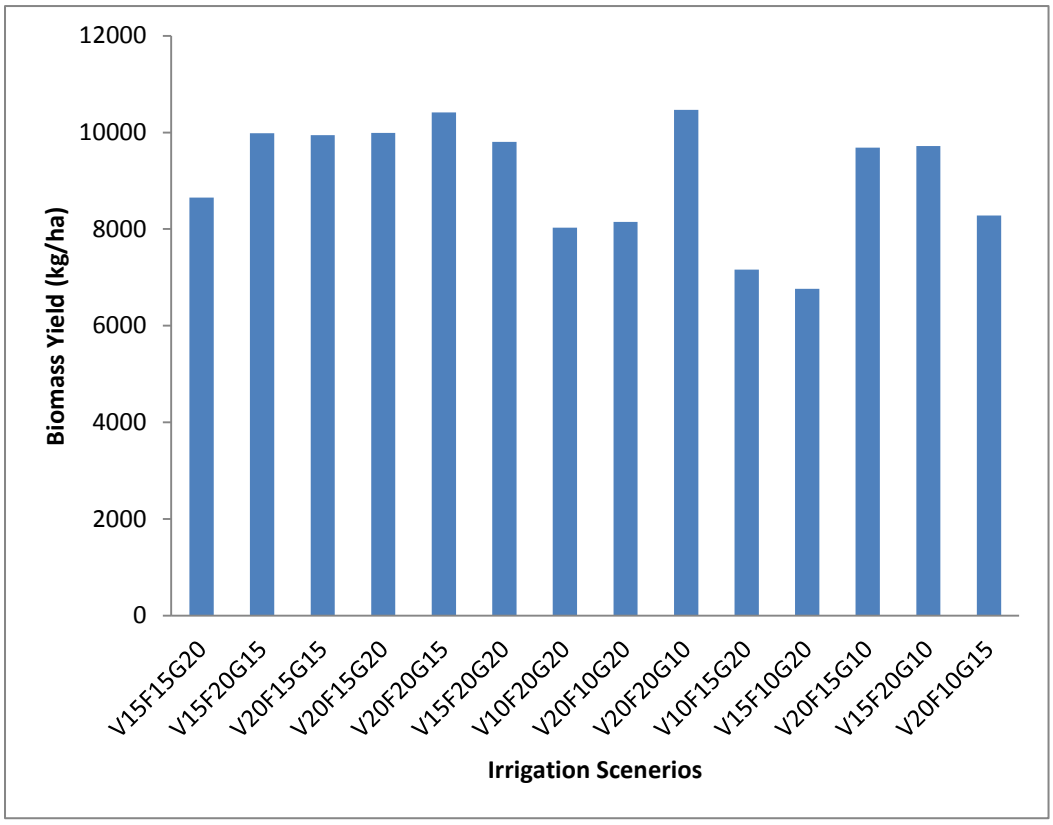


Fig 4.11 Biomass yield and varied water application depth along crop growth stages

The biomass yield reduction ranged from 0.2 - 36 %. Treatment V20F10G20 recorded the highest biomass yield reduction value of 36%, while V20F20G10 recorded the lowest biomass yield reduction value of 0.2%, for the scenarios considered. Treatments V15F20G15 and V20F15G20 recorded the same yield reduction value of 4.6%.

When 10mm of water was applied at vegetative (V10F20G20), flowering stage (V20F10G20) and grain-filling stage (V20F20G10), the corresponding biomass yield reduction values were 24, 22 and 0.2 %, respectively, implying that deficit suffered at vegetative stage is more critical, compared to, when it was applied at flowering and grain-filling stages. Thus, imposing water deficit during the grain-filling stage to maturity is of higher advantage, if the probability of rainfall is high during this stage of the maize crop in the study area.

The seasonal applied water ranged from 440 - 555mm, which was below the range of 500- 800mm recommended by Doorenbos and Kassam (1979). Water applied for treatments V10F20G20 and V15F10G20 was 460 mm, but the grain and biomass yield reductions obtained were 24, 39, 24 and 36%, accordingly; implying that the amount of water applied and at specific growth stages determines the crop yield in the study area, even when the total amount of water remains the same. Also, if deficit spans beyond two growth stages, the grain and biomass yield will dramatically be affected.

The seasonal crop water use obtained ranged from 330- 445 mm as shown in Fig. 4.12. The trends of crop water productivity in terms of crop water use differed with water application depth for the different growth stages. The biomass water productivity and grain water productivity ranged from 2.43 – 2.67 kg/m^3 and 0.77 – 0.83 kg/m^3, grain water productivity as shown in Appendix C8. Better water utilization occurred when deficit irrigation was imposed on the maize crop, but leads to loss in yield as presented in Figs. 4. 9 and 4.10.

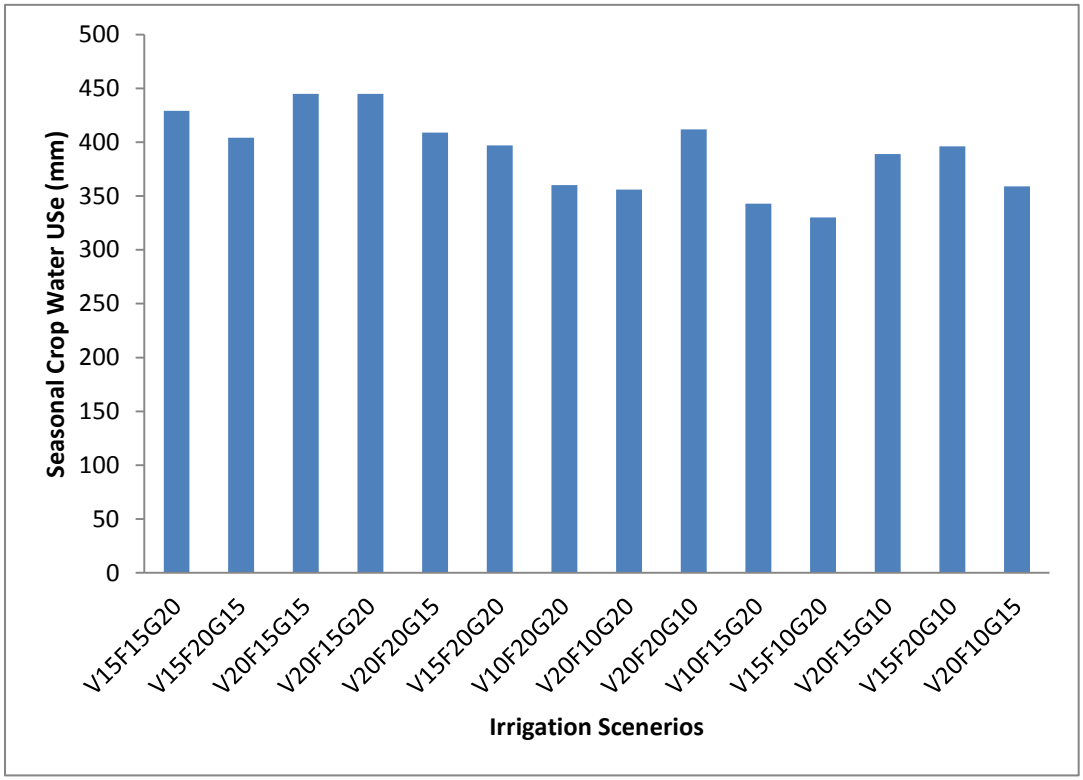


Fig 4.12 seasonal crop water use under different irrigation scenarios

4.11.3 Impacts of Irrigation Intervals beyond 3day at some crop growth stages

Figures 4.13 and 4.14, shows the simulated grain and biomass yield obtained for irrigation intervals beyond 3days, at vegetative, flowering and grain-filling stages, respectively. Water application depth of 20 mm with 3-day irrigation interval was applied per irrigation throughout the crop growth stages with a total number of 30 irrigation cycle was used as reference for estimating the effect of irrigation interval on yield and water responses.

Irrigation intervals were stretched beyond 3days, that is, at 4 and 5-day intervals. The grain yield obtained ranged from 2889 - 3273 kg/ha. The highest grain yield value of 3273 kg/ha was obtained treatment V3F3G3, while the lowest grain yield value of 2889 kg/ha was obtained treatment V5F3G3 from irrigation scenarios considered, as

shown in Fig. 4.13. Irrigation intervals of 4days (V3F3G4) and 5days (V3F3G5) were imposed at the grain-filling stage only which gave the corresponding grain yield reduction as 0.2 and 0.1%. When irrigation intervals of 4days (V3F4G3) and 5days (V3F5G3) were imposed at the flowering stage only, the grain yield reduction obtained were 2.4 and 11.3%, respectively. However, irrigation intervals of 4 and 5days imposed at the vegetative stage led to grain yield decrease that amounted to 9.1 and 11.7 %, respectively.

This implies that, imposing water deficit at grain-filling stage is less critical, compared to the flowering and vegetative stages, because of the high probability of rainfall in the study area, which seems to overturn the effect of imposed stress. The outcome of this research is in accord with what Igbadun (2012) found, that imposing deficit at grain-filling stage is more advantageous in the study area, because of the occurrence of rain during grain-filling stage of the maize crop.

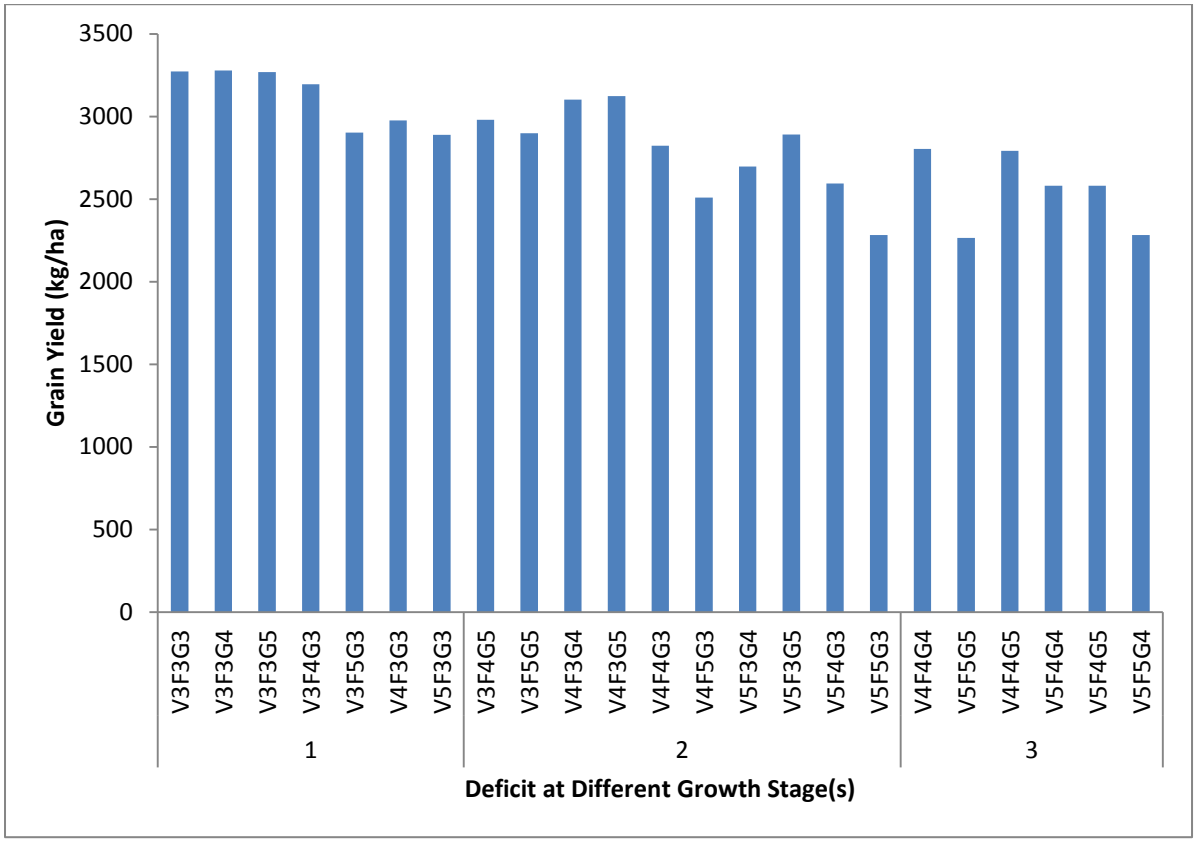


Fig 4.13 impact of deficit at different growth stage(s) on grain yield

The impact of increasing irrigation intervals to 4 -5days at two growth stages at water application depth of 20mm is shown in Fig. 4.13. The highest grain yield reduction of 30.3% was recorded for treatment V5F5G3, while the lowest value of 4.6% was obtained in V4F3G5; It can be observed that when water deficit was imposed at the vegetative and flowering stages, the impact of yield reduction were more, compared to when it was imposed at flowering and grain-filling stage as observed in treatment V4F4G3 and V4F3G4 as shown in Appendix C7. Also, when 20mm depth of water was applied with 5-day irrigation interval at vegetative and grain-filling stage (V5F3G5) the yield reduction was 17.6%, while when 20mm depth of water was applied with 5-day irrigation interval at vegetative and flowering stage (V5F5G3), the yield reduction was 30.3%; implying that, even though the grain-filling stage was less sensitive to moisture stress, if irrigation interval beyond 3-day is imposed on the

vegetative and flowering stage, the yield will be adversely affected.

The impact of increasing irrigation interval to 4 -5days at three vegetative, flowering and grain-filling stages is presented in Fig. 4.13. The grain yield reduction ranged from 14.3 - 30.3%; the highest grain yield reduction value of 30.3% was observed in treatment V5F5G5, while the lowest was of 14.3% was observed in treatment V4F4G4 as presented in Appendix C7. Therefore, irrigation interval beyond 3days with 20mm WAD will adversely reduce grain yield in the study area.

The biomass yield obtained ranged from 92480 -10492 kg/ha when irrigation intervals were extended beyond 3days that is, at 4 and 5days at one growth stage. The highest biomass yield value of 10492 kg/ha was obtained from treatment in V3F3G3, while the lowest biomass yield value of 92480 kg/ha was obtained in treatment V5F3G3 from the irrigation scenario considered, as shown in Fig. 4.14. Irrigation interval of 4 (V3F3G4) and 5days (V3F3G5) was imposed at the grain-filling stage only giving rise to biomass yield reduction value of 0.2 and 0.1%. When irrigation interval of 4 (V3F4G3) and 5days (V3F5G3) were imposed at the flowering stage only, the biomass yield reduction obtained were 3.2 and 12.2%, respectively. However, irrigation interval of 4 and 5days imposed at the vegetative stage led to biomass yield decrease that amounted to 9.1 and 11.9 %, respectively.

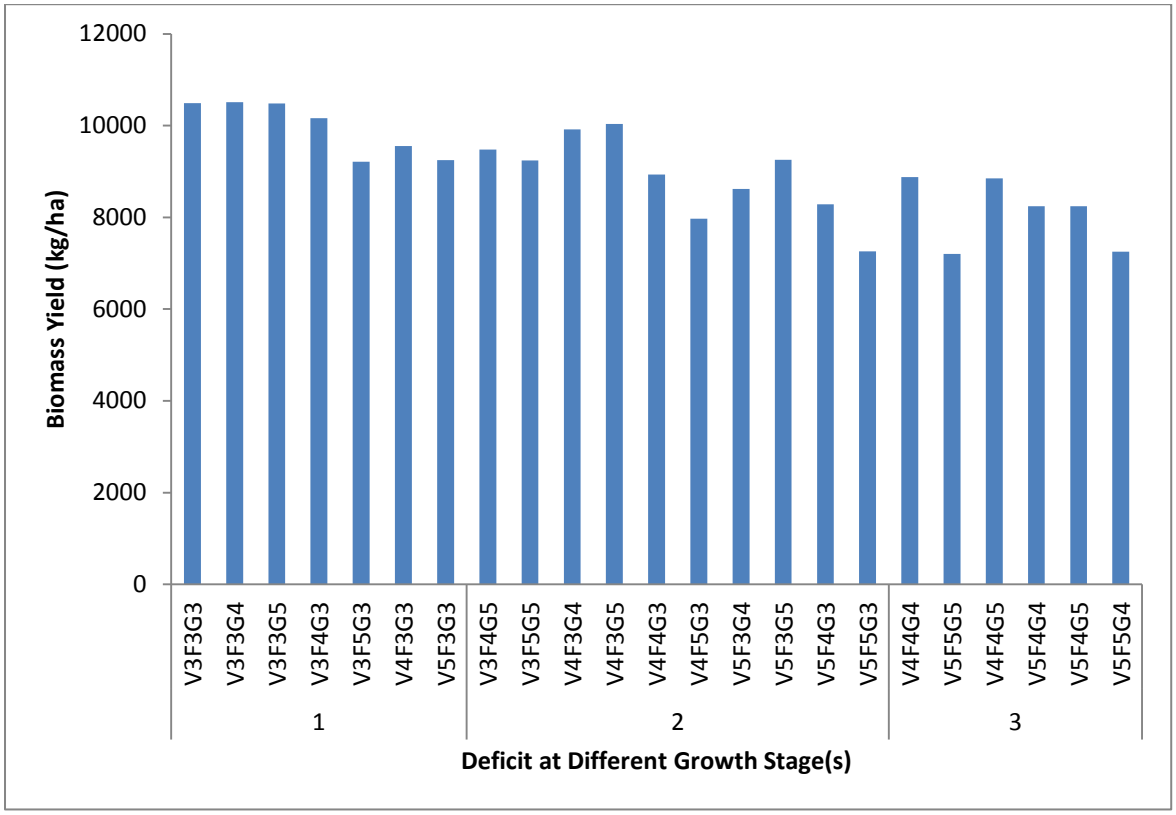


Fig 4.14 impact of deficit at different growth stage(s) on biomass yield

The impact of increasing irrigation interval to 4 -5days at two growth stages at water application depth of 20mm for biomass yield is shown in Fig. 4.14. The highest biomass yield reduction of 30.9% was recorded for treatment V5F5G3, while the lowest value of 4.4% was obtained in V4F3G5 as presented in Appendix C7. It can be observed that when water deficit was imposed at the vegetative and flowering stages, the impact of biomass yield reduction were more, compared to when it was imposed at flowering and grain-filling stage as observed in treatments V4F4G3 (14.8%) and V4F3G4 (5.5%) as shown in Appendix C8.

Similarly, the impact of increasing irrigation interval to 4-5days at three vegetative, flowering and grain-filling stages led the biomass yield reduction which ranged from 15.4 – 31.3%. The highest biomass yield reduction value of 31.3% was observed in treatment V5F5G5, while the lowest value of 15.4% was observed in treatment

V4F4G4.

The seasonal water applied when deficit was applied at one growth stage ranged from 480 – 600 mm which was below the recommendation of 500- 800mm by Doorenbos and Kassam (1979).Treatment V3F3G5 and V4F3G3 received 520mm of water but the corresponding yield obtained were 3269 and 2975 kg/ha as presented in Appendix C8; which implies that the growth stage where deficit is imposed, determines how adversely the yield can be affected. The seasonal crop water use ranged from 430-453mm, when deficit was imposed at one growth stage as presented in Fig. 4.15.

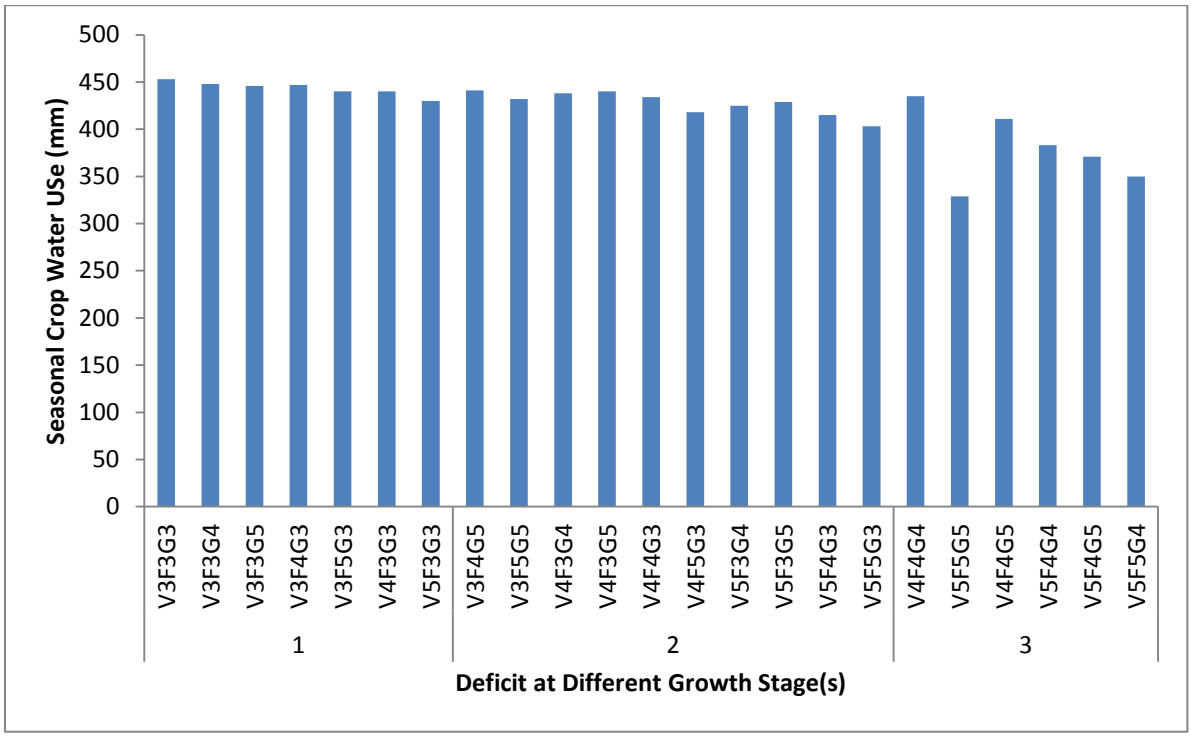


Fig 4.15 impact of deficit at different growth stage(s) on seasonal crop water use

The seasonal water applied when deficit was imposed at two growth stages ranged from 420 - 480mm as presented in Appendix C8. Treatments V4F3G4, V4F3G5, V4F4G3, V4F5G3 and V5F3G4 received 480mm depth of water, but the corresponding yields obtained were 3101, 3124, 2823, 2509 and 2696 kg/ha; implying that the grain-filling stage is less sensitive to water stress. However, the seasonal water use ranged from 403 - 441mm as shown in Fig. 4.15.

4.11.4 Impacts of plants density on crop yield, soil water balance of Irrigated Maize Crop

Table 4.31 shows the effect of plant density on simulated yield, soil water balance and water productivity of maize. Water application depth of 20mm with 3-day irrigation intervals was adopted and planting was assumed done on the 3rd of March. The model simulated output for different plant densities were compared using 53,333 plants/ha as reference, being the conventional practice for maize production in the study area.

Table 4.24 Plant densities, yield and soil water balance of Irrigated Maize Crop

Plant Density (Plants/ha)	GY (kg/ha)	ΔGY (%)	BY (kg/ha)	ΔBY (%)	SCU (mm)	BWP (kg/m^3)	GWP (kg/m^3)
55556	3273	0.2	10492	0.2	453	2.65	0.83
74074	3326	1.8	10658	1.8	463	2.66	0.83
53333	3266	0.0	10471	0.0	450	2.65	0.83
66667	3306	1.2	10594	1.2	459	2.67	0.83
44444	3235	0.9	10376	0.9	448	2.64	0.82

The average yield ranged from 3235kg/ha with 44444 plants/ha to 3326kg/ha with 74,074 plants/ha. There was percentage grain yield increase value of 0.21, 1.84 and 1.22% for the following plant densities, 55556, 74074 and 66,667 , while percentage reduction value of 0.95% was recorded when 44444 plants/ha was adopted. The yield of irrigated maize (SAMAZ 14) for Samaru locality has been put at 2.05- 3.98 t/ha (Lyocks *et al.*, 2013) which is consistent with the simulated values obtained. The simulated biomass yield ranged from 10376kg/ha with plant density of 55,556 to 10658 kg/ha with plant density of 74,074. The percentage biomass yield reductions were 1.8 and 1.2% for plant density 74,074 and 66,667, respectively.

The crop water use ranged from 448 - 453mm. The highest crop water use value of

453mm was recorded for plant density 74,074, while the lowest value of 448mm was recorded for plant density 44,444. Viswanatha *et al.* (2002) reported crop water use of 424 -517mm which is consistent with the simulated values reported herein.

The biomass water productivity ranged from 2.65 - 2.67 kg/m^3 and the grain water productivity ranged from 0.82 - 0.83 kg/m^3. This implies that 265 -267 kg/m^3 and 82-83 kg/m^3 of maize biomass and grain were produced from every 100 m^3 of crop water applied to the field. When plant density beyond 44,444 was adopted, the water productivity for grain was observed to be 83 kg/m^3.

4.12 Contribution to Knowledge

The study demonstrated that:

1. Water application depth of 20mm with 3-day irrigation interval, throughout the crop growth stages, produced maximum grain and biomass yield of SAMMAZ 14 maize variety under drip irrigation system.
2. Measured versus predicted values for grain yield, biomass yield and seasonal crop water use gave R^2 values of 0.84, 0.82 and 0.93, respectively, using the AquaCrop simulation model.
3. Applying deficit at one growth stage, the vegetative stage led to a yield reduction value of 9.1%, when compared to the flowering (2.4%) and grain-filling stages. (0.2%).

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 Summary

This study was carried out at the Institute for Agricultural Research (I.A.R) Irrigation farm, Samaru-Nigeria during the 2012/2013 and 2013/2014 cropping season, with the main aim of providing insight into the impact of deficit irrigation schedulling strategies on yields, soil water balance and water productivity of Maize. The drip system used was evaluated based on uniformity of water application. The hydraulic characteristics of the drip irrigation system evaluated were: Emitter flow rate, Emission uniformity, Discharge coefficient of variation, Application Efficiency, Discharge uniformity, Coefficient of uniformity, Emitter Flow Rate and Soil wetting capacities of drippers.

Furthermore, the test crop (Maize) was grown using the recommended agronomic practices for two seasons. The grain and biomass yield, soil water balance, irrigation water productivity, crop yield – seasonal ET relationship, Relative Yield Decrease, Seasonal Crop water use deficit and yield response factor were determined.

AquaCrop model was calibrated with the first season's field data, while the validation was done with the second year field data, across field and seasons. The model was further used as a tool to investigate the impact of different deficit irrigation schedulling scenarios on crop yield, soil water balance and crop water productivity responses. The following scenarios were evaluated:

Increasing irrigation interval from 3 to 4, 5 and 6 days at water application depth of 15, 20, 25 and 30mm. A fixed irrigation interval of 3days, with various water application depths (WAD) of 15, 20 and 25mm applied along crop growth stages; the impact of deficit irrigation at one, two and three growth stages, with water application

depth of 20mm for 3 to 4 and 5days were investigated to ascertain the impact on crop and water productivity; different planting pattern compatible with farmers practice to check the effect of plant density on yield and water utilization of the maize crop.

5.2 Conclusion

The following conclusions were made from the study:

1. AquaCrop model was able to simulate grain and biomass yield, seasonal crop water use, biomass and grain water productivity accurately.
2. Analyses of the deficit irrigation schedulling scenarios showed that the highest grain and biomass yield were obtained by applying 20mm water application depth with 3-day irrigation interval at vegetative, flowering and grain-filling, while a null grain yield and very low biomass yield were obtained when 15mm water application depth with 6-day at vegetative, flowering and grain-filling.
3. Crop yield, soil water balance and crop water productivity responses to increase in irrigation interval beyond 3days at the vegetative stage led to more yield reduction than flowering and grain-filling stage. When water deficit was imposed at two growth stages such as the vegetative and flowering stages, the yield reduction were more compared to when it was imposed at flowering and grain-filling stage. Furthermore, when water deficit was imposed on three growth stages, the highest yield reduction was observed when 5-day irrigation interval was observed throughout the growth stages compared to 4-day irrigation interval.
4. The AquaCrop was found to be user friendly due to minimum input data that are readily available. The model can be useful for on-the-desk assessment of the impact of irrigation schedulling protocols. The possible consequences of a

deficit irrigation schedulling on the crop and its environment could be analysed without going to the field. AquaCrop model can be a great tool in the hand of policy makers, researchers and extension workers.

5.3 Recommendations

The results of this research reveal considerable areas of concern which necessitate that the following recommendations be made:

1) Further research on simulating maize growth and yield under different water and fertilizer availability scenarios as compared to other models needs to be carried out in study area
2) AquaCrop model should be used to simulate Soil water content of root zone and soil salinity stress on maize growth and yield.
3) Irrigation schedulling strategies with the use AquaCrop model should be developed for other crops within the mandate of Institute for Agricultural Research, with surface irrigation methods.

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APPENDIX A

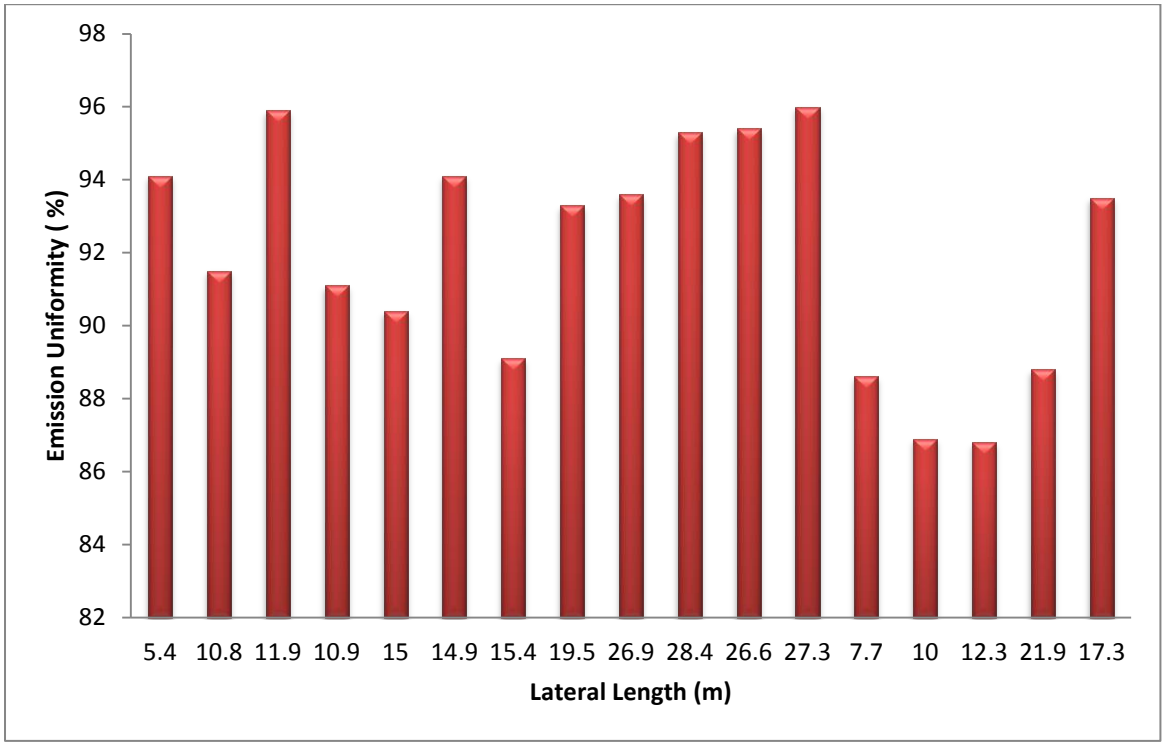


Fig. A1: Emission Uniformity against lateral length

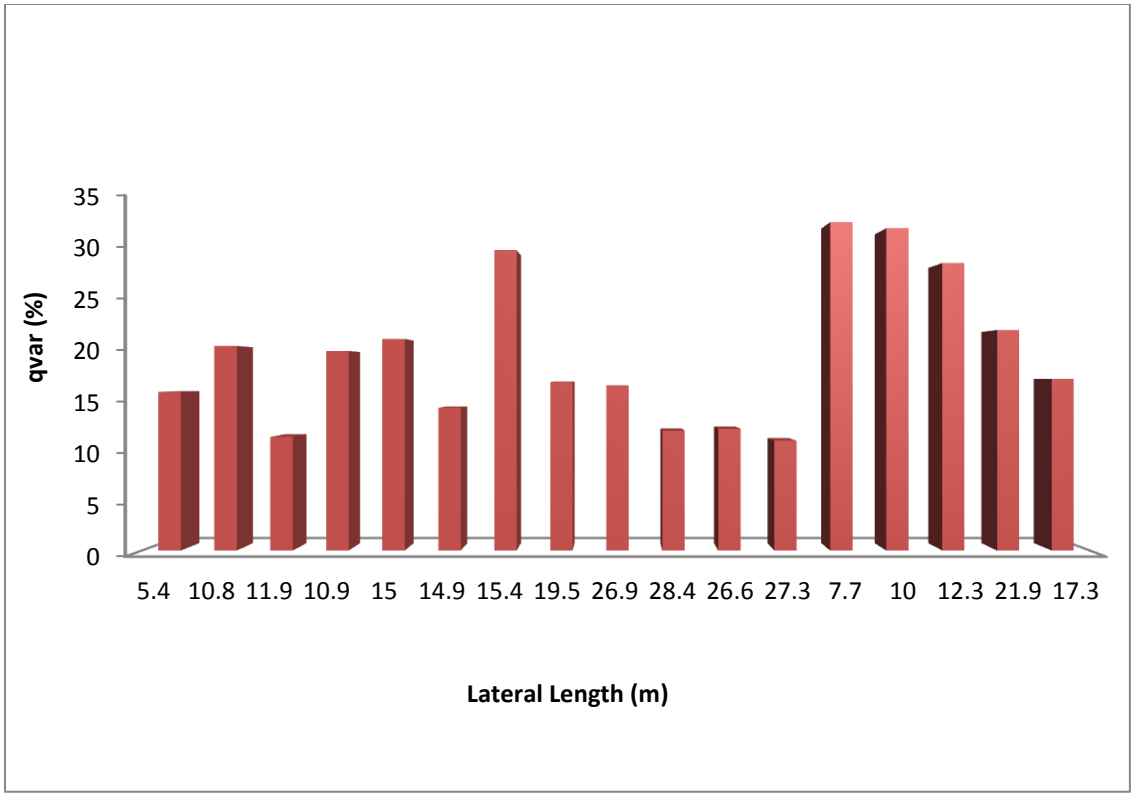


Fig. A2: Coefficient of Variation against lateral length

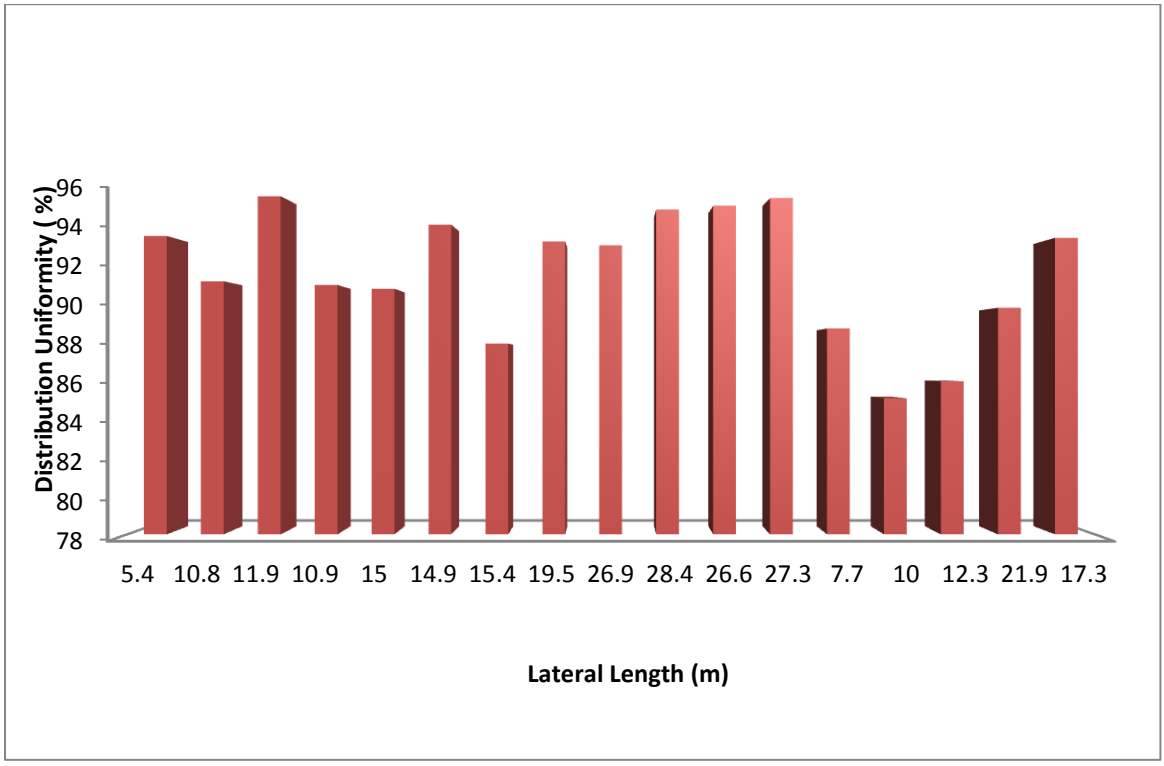


Fig. A3: Distribution Uniformity against lateral length

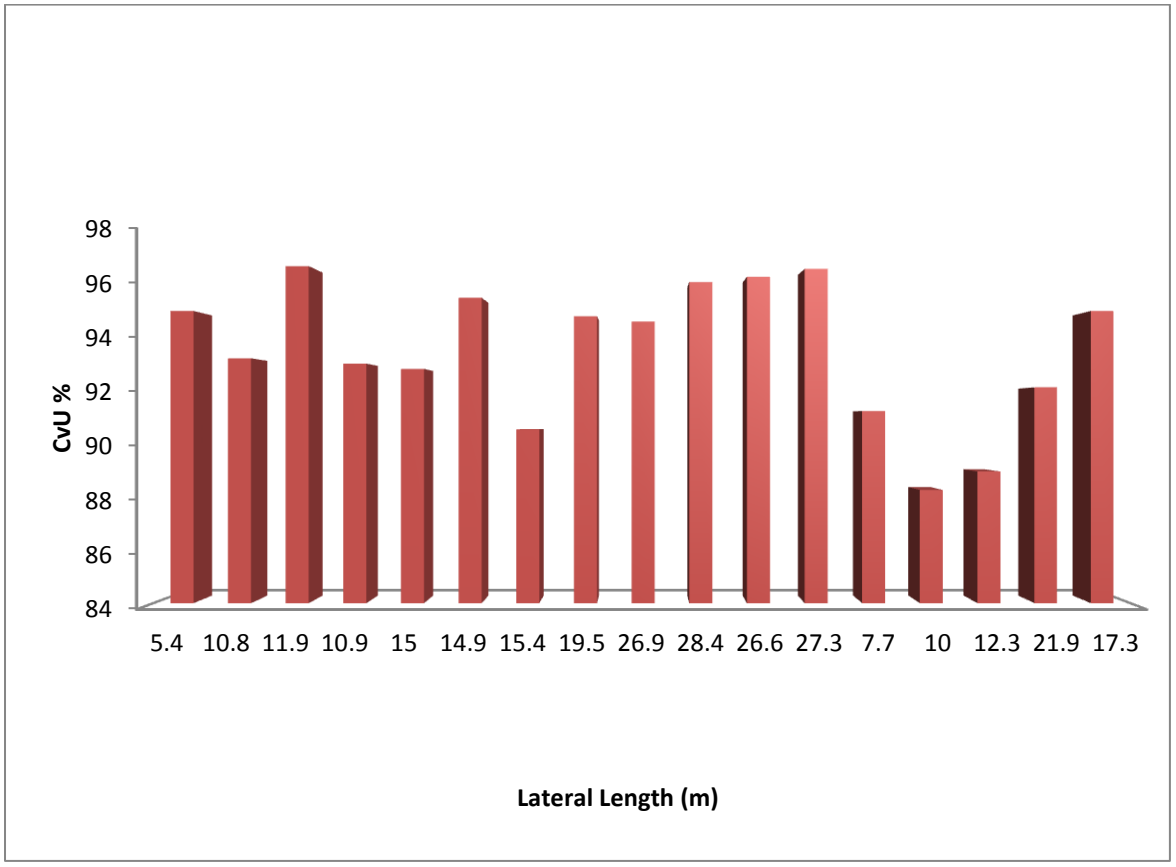


Fig. A4: Coefficient of Uniformity against lateral length

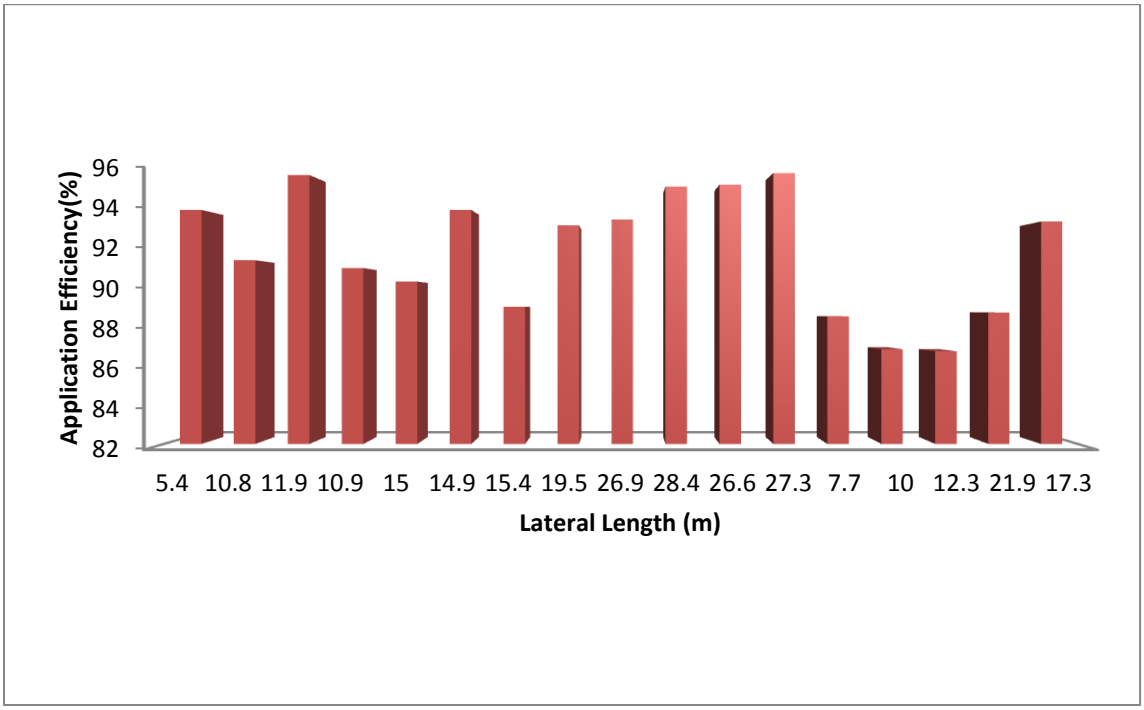


Fig. A5: Application Efficiency against lateral length

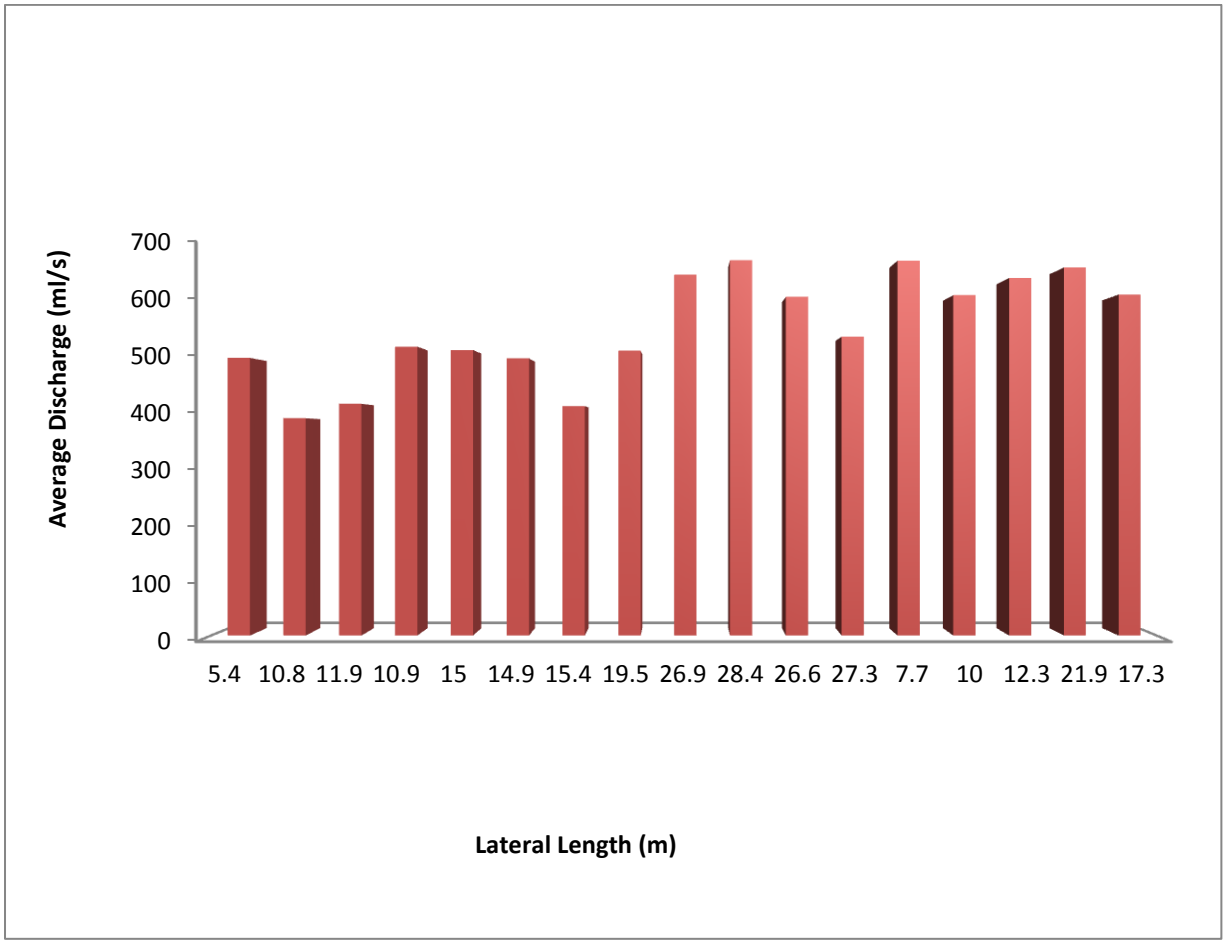


Fig. A6: Average Discharge against lateral length

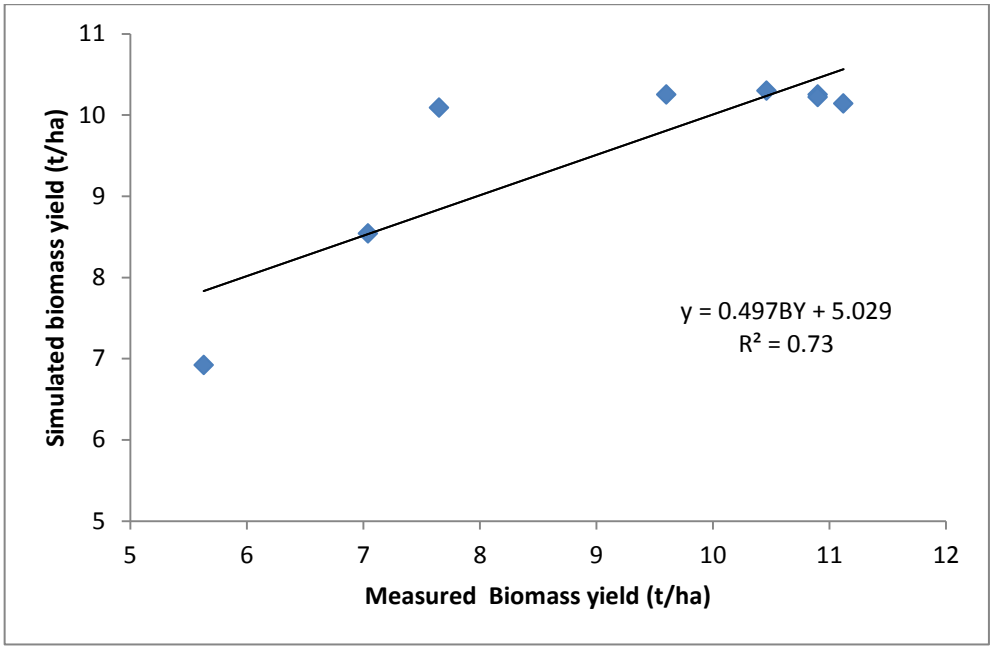


Fig A7: Model validation results in simulating Biomass yield of maize for 2012/2013 season

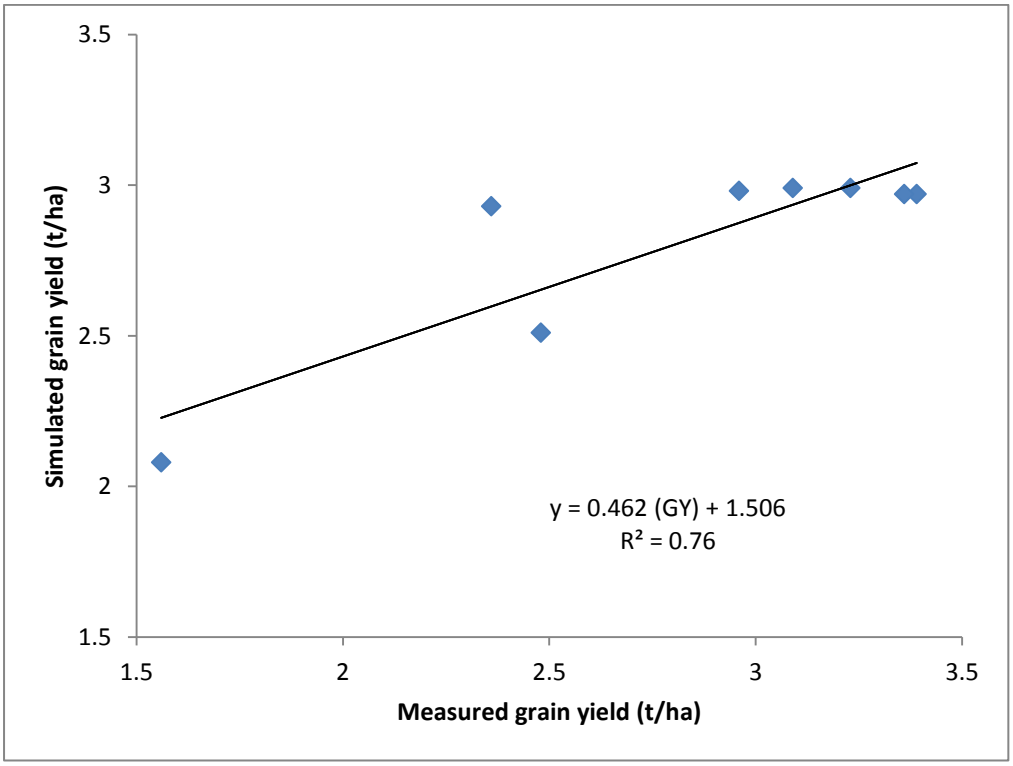


Fig A8: Model validation results in simulating grain yield of maize for 2013/2014 season

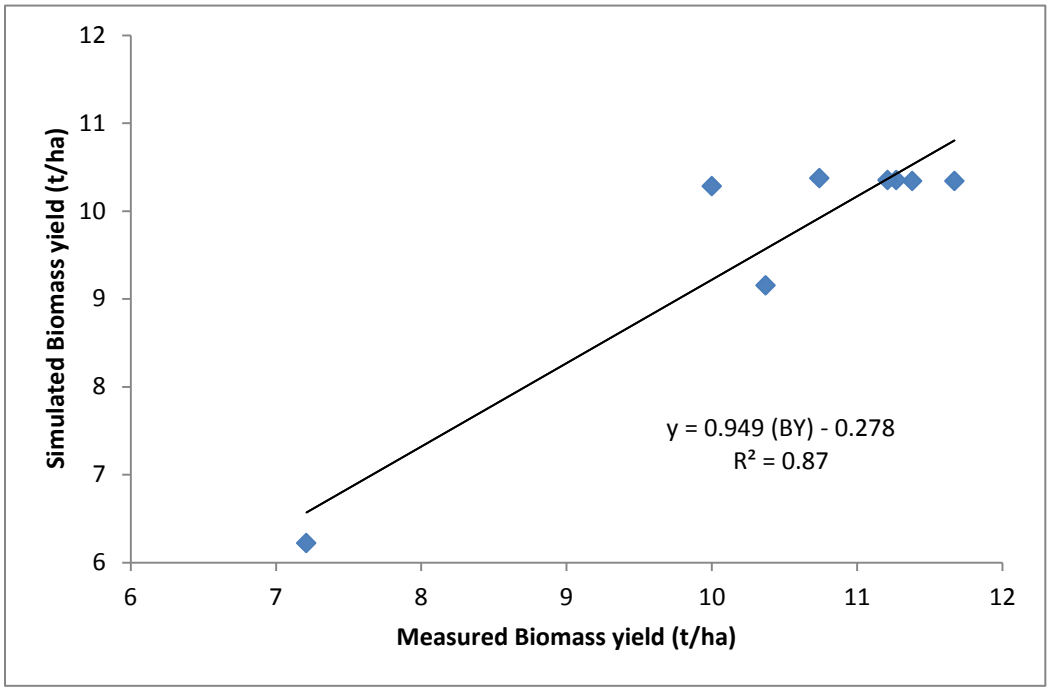


Fig A9: Model validation results in simulating biomass yield of maize for 2013/2014 season

APPENDIX B



Plate B1 : Maize crop at establishment stage (12 DAP)



Plate B2 : Fertilizer application at the rate of 60kgN/ha at three weeks after planting



Plate B3 : Maize crop at vegetative stage (32DAP)



Plate B4 : Maize crop at flowering stage (55DAP)

APPENDIX C

C 1: Relative yield and relative seasonal crop water use of the maize for 2012/2013 season for Field A

Treatments	1-GYa/GYm	1-BYa/BYm	1-ETa/ETm
$V_{100}F_{100}G_{100A}$	*0.00*	*0.000*	*0.000*
V_{75} $F_{100}G_{100A}$	*0.21*	*0.208*	*0.087*
V_{50} $F_{100}G_{100A}$	*0.37*	*0.369*	*0.137*
V_{100} $F_{75}G_{100A}$	*0.17*	*0.169*	*0.059*
$V_{100}F_{50}$ G_{100A}	*0.25*	*0.254*	*0.115*
V_{100} $F_{100}G_{75A}$	*0.10*	*0.102*	*0.028*
V_{100} $F_{100}G_{50A}$	*0.14*	*0.136*	*0.040*
V_{50} F_{50} G_{50A}	*0.45*	*0.453*	*0.339*

C2: Relative yield and relative seasonal crop water use of the maize for 2012/2013 season for Field B

Treatments	1-GYa/GYm	1-BYa/BYm	1-ETa/ETm
$V_{100}F_{100}G_{100B}$	0.000	0.000	0.000
V_{80} $F_{100}G_{100B}$	0.098	0.101	0.094
V_{60} F_{100} G_{100B}	0.197	0.206	0.140
V_{100} $F_{80}G_{100B}$	0.080	0.089	0.025
$V_{100}F_{60}$ G_{100B}	0.235	0.244	0.200
V_{100} $F_{100}G_{80B}$	0.068	0.077	0.011
V_{100} $F_{100}G_{60B}$	0.095	0.104	0.040
V_{60} F_{60} G_{60B}	0.409	0.415	0.372

C 3: Relative yield and relative seasonal crop water use of the maize 2013/2014 cropping season

Treatments	1-GYa/GYm	1-BYa/BYm	1-ETa/ETm
$V_{100}F_{100}G_{100A}$	0.00	0.00	0.00
V_{75} $F_{100}G_{100A}$	0.26	0.20	0.09
V_{50} $F_{100}G_{100A}$	0.34	0.25	0.19
V_{100} $F_{75}G_{100A}$	0.17	0.13	0.07
$V_{100}F_{50}$ G_{100A}	0.30	0.23	0.12
V_{100} $F_{100}G_{75A}$	0.12	0.09	0.04
V_{100} $F_{100}G_{50A}$	0.21	0.16	0.09
V_{50} F_{50} G_{50A}	0.58	0.43	0.36

C 4: Calibration Results of Grain yield, Biomass yield and Seasonal Evapotranspiration for field B

	Grain yield (ton/ha)		Biomass yield (ton/ha)		Crop water use (mm)	
Treatment	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.
V_{100} $F_{100}G_{100B}$	3.03	3.52	10.3	11.53	*430*	483
V_{80} F_{100} G_{100B}	2.99	3.17	10.32	10.37	*429*	441
V_{60} F_{100} G_{100B}	2.98	2.83	10.29	9.16	*419*	417
V_{100} F_{80} G_{100B}	3.01	3.24	10.29	10.51	*431*	453
$V_{100}F_{60}$ G_{100B}	2.79	2.69	9.49	8.72	*413*	428
V_{100} F_{100} G_{80B}	2.98	3.28	10.31	10.64	*429*	470
V_{100} F_{100} G_{60B}	2.99	3.19	10.31	10.33	*429*	464
V_{60} F_{60} G_{60B}	2.18	2.08	7.15	6.75	*318*	320

C 5: Predicted and Measured Crop yield, Soil water Balance and Water productivity for 2012/2013

	Gyp (t/ha)	GYm (t/ha)	BYp (t/ha)	BYm (t/ha)	SWUp (mm)	SWUm (mm)	BwPp (kg/m^3)	BwPm (kg/m^3)	GwPp (kg/m^3)	GwPm (kg/m^3)
1	2.94	3.39	10.14	11.12	473	483	2.55	2.30	0.74	0.70
2	2.99	2.96	10.32	9.6	478	441	2.55	2.18	0.74	0.67
3	2.95	2.36	9.97	7.65	443	417	2.66	1.83	0.77	0.57
4	2.9	3.09	9.97	10.9	440	453	2.67	2.41	0.78	0.68
5	1.87	2.48	6.42	7.04	381	428	2.12	1.64	0.62	0.58
6	2.93	3.36	10.09	10.9	444	470	2.68	2.32	0.78	0.71
7	2.93	3.23	10.09	10.46	443	464	2.7	2.25	0.78	0.70
8	1.49	1.56	5.32	5.63	361	320	1.88	1.76	0.53	0.49

Gyp = predicted grain yield, Gym = measured grain yield, BYm = measured biomass yield, BYp = predicted grain and biomass yield, SWUp = predicted seasonal crop water use, SWUm = measured seasonal crop water use, Bwpm= measured biomass water productivity , BWPp = predicted biomass water productivity

C6 scenario of different irrigation schedulling on yield and water productivity

WAD (mm)	Irrigation interval (Days)	GY (kg/ha)	BY (kg/ha)	SWU (mm)	Applied Water (mm)	BWP (kg/m3)	GWP (kg/m3)
15	3	2714	8638	429	450	2.44	0.77
	4	181	6187	372	330	2.23	0.65
	5	997	3446	332	270	1.55	0.44
	6	0	2401	218	225	1.81	0.00
20	3	3273	10492	453	600	2.65	0.83
	4	2804	8880	435	460	2.57	0.81
	5	2265	7205	332	360	2.49	0.78
	6	1702	5798	280	300	2.3	0.61
25	3	3156	10180	450	750	2.65	0.82
	4	3229	10308	456	550	2.72	0.85
	5	2818	8970	426	450	2.73	0.86
	6	2457	7830	289	375	2.6	0.83
30	3	3029	9772	449	870	2.64	0.82
	4	3274	10557	448	660	2.76	0.85
	5	3161	10090	437	540	2.83	0.88
	6	2814	8985	432	450	2.79	0.87

C7 Scenario of deficit irrigation at different growth stage(s) on yield and water productivity

Growth Stage	Treatment	GY (kg/ha)	BY (kg/ha)	SWU (mm)	SWA (mm)	BWP (kg/m3)	GWP (kg/m3)
1	V3F3G3	3273	10492	453	600	2.65	0.83
	V3F3G4	3279	10509	448	560	2.66	0.83
	V3F3G5	3269	10480	446	520	2.68	0.84
	V3F4G3	3194	10158	447	560	2.65	0.83
	V3F5G3	2902	92130	440	540	2.52	0.79
	V4F3G3	2975	95520	440	520	2.66	0.83
	V5F3G3	2889	92480	430	480	2.67	0.84
2	V3F4G5	2979	9477	441	460	2.62	0.82
	V3F5G5	2899	9242	432	460	2.66	0.84
	V4F3G4	3101	9915	438	480	2.69	0.84
	V4F3G5	3124	10035	440	480	2.71	0.84
	V4F4G3	2823	8936	434	480	2.58	0.81
	V4F5G3	2509	7971	418	480	2.48	0.78
	V5F3G4	2696	8622	425	480	2.59	0.81
	V5F3G5	2890	9252	429	420	2.7	0.89
	V5F4G3	2595	8286	415	440	2.61	0.82
	V5F5G3	2282	7255	403	440	2.44	0.77
3	V4F4G4	2804	8880	435	460	2.57	0.81
	V5F5G5	2265	7205	329	360	2.49	0.78
	V4F4G5	2792	8848	411	420	2.63	0.83
	V5F4G4	2581	8244	383	400	2.65	0.83
	V5F4G5	2581	8244	371	400	2.65	0.83
	V5F5G4	2282	7254	350	380	2.44	0.77

C8 Irrigation interval and varied WAD on Yields and Water Balance Responses of Maize

Treatment	GY (kg/ha)	ΔGY (%)	BY (kg/ha)	ΔBY (%)	SWU (mm)	SWA (mm)	BWP (kg/m^3)	GWP (kg/m^3)	DP (mm)
V15F15G20	2718	17	8652	18	429	470	2.45	0.77	109
V15F20G15	3122	4.6	9986	4.8	404	485	2.56	0.80	74
V20F15G15	3121	4.6	9944	5.2	445	505	2.62	0.82	120
V20F15G20	3139	4.1	9993	4.8	445	540	2.62	0.82	152
V20F20G15	3231	1.3	10415	0.7	409	555	2.67	0.83	137
V15F20G20	3067	6.3	9806	6.5	397	510	2.57	0.80	120
V10F20G20	2501	24	8030	24	360	460	2.35	0.73	92
V20F10G20	2568	22	8152	22	356	520	2.41	0.76	156
V20F20G10	3266	0.2	10470	0.2	412	510	2.66	0.83	116
V10F15G20	2242	32	7163	32	343	425	2.21	0.69	75
V15F10G20	1998	39	6764	36	330	460	2.17	0.64	122
V20F15G10	3031	7.4	9686	7.7	389	475	2.62	0.82	116
V15F20G10	3040	7.1	9720	7.4	396	440	2.58	0.81	67
V20F10G15	2609	20	8284	21	359	485	2.43	0.77	124

APPENDIX D

CALCULATIONS FOR DETERMINATIONS OF FIXED COST FOR TANK, PUMP, METAL STAND AND DRIP KITS USED FOR

5-YEAR ECONOMIC ANALYSIS

FIXED COST CALCULATION

Item	Cost (₦)	Life cycle
Tank	25000	5
Pump	25000	10
Metal stand	50,000	15
Drip Kit	167,000	5

Present worth values:

Tank	25,000.00
Pump	25,000.00
Salvage Value	-12,500.00
Metal Stand	50,000.00
Salvage value	-16,666.00
Drip Kit	167,000.00
Total	**254,483.00**
Annual cost	
Depreciation and interest	63,766.00
Maintenance and repairs:	
Tank	0.00
Pump	1,250.00
Metal stand	0.00
Drip Kit	11,690.00
Total	**76,706.00**

The annual cost for 0.2ha was ₦ 76,706.00, therefore, the total fixed cost for 1 hectare = ₦ 383, 530.00/ha/yr.

The annual operation, maintenance, and repair cost were obtained by direct application of the appropriate percentage values to the initial cost of each component. The tank and

metal stand used operation and maintenance cost was fixed at zero, while that of the

pump and drip kits were fixed at 5 and 7% of the initial cost of each

SALVAGE VALUE CALCULATIONS

The salvage values were obtained by using a straight-line depreciation method to determine the values which are not fully depreciated at the end of the analysis period which was 5years.

Tank

The salvage value for tank was zero since the life cycle was fixed for 5years.

PUMP

Purchased price = ₦ 25,000

Life span = 10 years

Salvage value @ 5years = 5/10 X 25,000

= ₦ 12,500

METAL STAND FOR TANK

Purchased price = ₦ 50,000

Life span = 15 years

Salvage value @ 5years = 5/15 X 50,000

= ₦ 16,666

DRIP KITS

Purchased price = N 167,000

Life span = 5 years

Salvage value @ 5years = 0

Annual cost

The annual value of depreciation and interest was obtained by applying the capital recovery factor to the present worth value of the investment.

Annual Value = present worth x CRF

$$= 254{,}483 \text{ x } \left(\frac{0.08(1+0.08)^5}{(1+0.08)^5}\right)$$

Annual value = ₦ 63,766.00