EVALUATION OF YIELD AND SOIL WATER BALANCE OF TWO COWPEA VARIETIES UNDER DEFICIT IRRIGATION AND MULCH IN A WEIGHING-TYPE MICRO LYSIMETER

By

SUNDAY NANMAR, DURVEN

DEPARTMENT OF AGRICULTURAL AND BIO-RESOURCE ENGINEERING
FACULTY OF ENGINEERING,
AHMADU BELLO UNIVERSITY,
ZARIA, NIGERIA

DECEMBER, 2017

EVALUATION OF YIELD AND SOIL WATER BALANCE OF TWO COWPEA VARIETIES UNDER DEFICIT IRRIGATION AND MULCH IN A WEIGHING-TYPE MICRO LYSIMETER

By

SUNDAY NANMAR, DURVEN

DEPARTMENT OF AGRICULTURAL AND BIO-RESOURCE ENGINEERING
FACULTY OF ENGINEERING,
AHMADU BELLO UNIVERSITY, ZARIA
NIGERIA

DECEMBER, 2017

EVALUATION OF YIELD AND SOIL WATER BALANCE OF TWO COWPEA VARIETIES UNDER DEFICIT IRRIGATION AND MULCH IN A WEIGHING-TYPE MICRO LYSIMETER

By

Sunday Nanmar DURVEN B. Eng (A.T.B.U) 2008

P16EGAE8006 (M.Sc/ENG/6593/2009-2010)

A THESIS SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY, ZARIA IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF MASTER OF SCIENCE DEGREE IN AGRICULTURAL ENGINEERING

DEPARTMENT OF AGRICULTURAL AND BIO-RESOURCES ENGINEERING,
FACULTY OF ENGINEERING,
AHMADU BELLO UNIVERSITY, ZARIA
NIGERIA

DECEMBER, 2017

DECLARATION

I declare that the work in this dissertation entitled "Evaluation of yield and soil water balance of two cowpea varieties under deficit irrigation and mulch in a weighing-type micro lysimeter" has been carried out by me in the Department of Agricultural and Bio-resources Engineering under the supervision of Prof. A. A Ramalan and Prof. H.E Igbadun. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at any other institution.

Sunday N. Durven Name of Student	Date

CERTIFICATION

This dissertation**,** entitled **"EVALUATION OF YIELD AND SOIL WATER BALANCE OF TWO COWPEA VARIETIES UNDER DEFICIT IRRIGATION AND MULCH IN A WEIGHING-TYPE MICRO LYSIMETER**" by Sunday Nanmar DURVEN, meets the regulations governing the award of the degree of Master of Science (Agricultural and Bio-Resource Engineering) of Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation.

Prof. A. A Ramalan Chairman, Supervisory Committee	Date
Prof. H. E Igbadun Member, Supervisory committee	Date
Prof. M. L Suleiman Head of Department	Date
Prof. S. Z Abubakar Dean, School of Postgraduate Studies	Date

DEDICATION

This work is dedicated to Almighty God, the source of my inspiration and to all and sundry who contributed greatly to my well-being.

ACKNOWLEDGEMENTS

I wish to express my profound gratitude to God Almighty and to my supervisors, Prof. A. A. Ramalan and Prof. H. E. Igbadun, for the useful guidance they gave me during the course of the study. I have indubitably benefited greatly from their wealth of knowledge and experience. My sincere gratitude also goes to Mrs. Jane O. Ichi, Engr. Musa Kurgwi and all other staff of Agricultural and Bio-Resources Engineering Department, Ahmadu Bello University; Zaria for their keen interest, guidance and assistance.

My appreciation also goes to the Director General, Raw Materials Research and Development Council (RMRDC) Dr. H. D. Ibrahim, the coordinator Benue State office, Mr. Y. A. Alaku and all staff of R.M.R.D.C. To my friends and colleagues who showed interest and concern during the course of the study. Particular reference should be made to Achukwu Manasseh and Engr. (Dr.) Ezekiel Oiganji.

To my dear wife, father, mother, brothers and sisters; and to my other relatives, I say thank you for your patience and understanding throughout the period of the study.

ABSTRACT

The field experiment was conducted during the 2011 dry season at the Irrigation Research Fields of the Institute for Agricultural Research (IAR), Samaru, Nigeria, to evaluate yield and soil water balance of two cowpea varieties under deficit irrigation and mulch using locally assembled weighing- type micro lysimeter. The treatments comprised of three levels of irrigation water application depths (50%, 75% and 100% of weekly reference evapotranspiration (WRETo)) and two levels of mulch (No mulch-NM, and black polyethylene mulch -BPM) and two varieties of cowpea (SAMPEA7 and 9) laid in a group balanced block on split-plot design. The result showed that the yield of the cowpea pods ranged from 0.29 t/ha to 1.29 t/ha. The highest yield was obtained from SAMPEA7 treatment irrigated at 100% WRETo with BPM. The drainage depth ranged from 3.9 mm to 89.5 mm with the least value obtained by SAMPEA9 at 50% WRETo and NM. The highest depth was by SAMPEA9 at 100% WRETo and BPM. In comparison, SAMPEA7 gave less drainage water compared to SAMPEA9. The study showed that crop water use of cowpea ranged from 187.6 mm to 335.6 mm for SAMPEA9 and 191.3 mm to 315.8 mm for SAMPEA7 with the least values occurring at 50% WRETo and NM. The estimated values of Kc for the two cowpea varieties at initial, crop development, mid and late season stage were 0.32, 0.58, 0.63 and 0.39, respectively for SAMPEA7 and 0.32, 0.63, 0.72 and 0.34, respectively, for SAMPEA9 varieties. The highest crop water use efficiency (CWUE) and irrigation water use efficiency (IWUE) were 3.76 kg/ha-mm and 2.11 kg/ha-mm, respectively, for SAMPEA7 variety and 2.94 kg/ha-mm and 1.68 kg/ha-mm, respectively, for SAMPEA9 variety. The crop yield response factor (Ky) was found to be 1.10 for the BPM treatments and 1.22 for the NM treatments. In conclusion, SAMPEA7 variety irrigated at

75% WRETo with BPM gave the highest WUE of 2.11 kg/ha-mm which translates to highest yield per unit depth of water-use.

TABLE OF CONTENTS

CONTENTS	PAGE
Title page	i
Declaration	iii
Certification	iv
Dedication	v
Acknowledgement	vi
Abstract	vii
Table of contents	ix
List of Tables	xiii
List of Figures	xiv
List of Plates	xv
List of Appendices	xvi
CHAPTER ONE:	
INRODUCTION	
1.1 Background of the Study	1
1.2 Statement of the Problem	3
1.3 Justification of the Study	4
1.4 Aim and Objectives of the Study	5
CHAPTER TWO:	
LITERATURE REVIEW	
2.1 Cowpea	6
2.2 Cowpea Varieties Released	6
2.3 Soil-Water –Balance	7
2.3.1 Evapotranspiration (ETc)	8

2.3.2 Separation of evaporation and transpiration 8

2.4 Crop Response and Soil - Water - Balance under Deficit Irrigation Scheduling 9

2.5 Crop Coefficient 10

2.6 Single Crop Coefficient Approach 10

2.7 Dual Crop Coefficient Approach 11

2.8 Crop Coefficient Curve 12

2.9 Water Stress Coefficient (K_s) 13

2.10 Penman-Monteith Equation 13

2.11 Weighing Type Micro Lysimeter 14

2.12 Controlled Deficit Irrigation Practices 15

2.13 Use of Lysimeters to Estimate Soil Water Balance 16

CHAPTER THREE:

MATERIALS AND METHODS

3.1 Description of the Study Area 18

3.2 Treatments and Experimental Design 19

3.3 Calibration of the Micro - lysimeter 22

3.4 Setting up the Micro – lysimeters 23

3.5 Agronomic Practices 26

3.5.1 Land preparation 26

3.5.2 Planting of cowpeas 26

3.5.3 Mulch application 27

3.5.4 Weed control 27

3.5.5 Fertilizer application 27

3.5.6 Pests and disease control 27

3.5.7 Harvesting 27

3.6 Water Application 28

3.7 Data Collection 28

3.8 Data Computation 29

3.8.1 Reference evapotranspiration (ET_o) 29

3.8.2 Conversion of weight of lysimeter tank and drainage volumes to millimeter depth of water 29

3.8.3 Evapotranspiration (ETc) 30

3.8.4 Computation of single crop coefficient (Kc) 30

3.8.5 Computation of dual crop coefficient ($K_{cb} + K_e$) 31

3.9 Computation of Water Stress Coefficient (Ks) 31

3.10 Determination of Yield Response Factor 32

3.11 Determination of Crop Water Use and Irrigation Water Use Efficiency 32

3.12 Crop Data 33

3.13 Data Analysis 33

CHAPTER FOUR:

RESULTS AND DISCUSSION

4.1 Grain Yield 34

4.2 Soil Water Balance Components 38

4.2.1 Irrigation water applied in the micro-lysimeters 38

4.2.2 Drainage obtained from the micro-lysimeters 40

4.2.3 Evapotranspiration (ETc) 42

4.2.4 Transpiration (T) and evaporation (E) components 44

4.3 Irrigation Water Use Efficiency (IWUE) 46

4.4 Crop Water Use Efficiency (CWUE) 47

4.5 Biomass and Grain Yield – Seasonal Crop Water Use 49

4.6 Yield Response Factor 51

4.7 Single Crop Coefficient (Kc) for Irrigated Cowpea under Full Irrigation Conditions 54

4.8 Single Crop Coefficient (Kc) for Irrigated Cowpea under Deficit Irrigation Conditions 57

4.9 Direct Evaporation (Ke) 58

4.10 Dual Crop Coefficient (Kcb + Ke) 59

CHAPTER FIVE:

SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 Summary 63

5.2 Conclusion 64

5.3 Recommendations 65

REFERENCES 66

APPENDICES 74

LIST OF TABLES

TABLE	PAGE
3.1. Average monthly weather data for Samaru, (Feb;-May 2011) Irrigation Cropping Season	18
3.2. Physical Properties of soils at various depths at IAR Irrigation Research Farm	19
3.3 Description of the experimental treatments	20
4.1 Classification of cowpea and dry matter yields in tones/hectare	34
4.2 Grain and dry matter yield of cowpea as affected by variety, irrigation and mulch during 2011 dry season	37
4.3 Growth stages and seasonal irrigation water applied (mm)	39
4.4 Growth Stages, weekly and total drainage (mm)	41
4.5 Growth Stages, weekly and total ETc (mm)	43
4.6 Transpiration (T) and evaporation (E) Components (mm)	45
4.7 Irrigation water use efficiency for cowpea SAMPEA7 and SAMPEA9	47
4.8. Crop water use efficiency for cowpea SAMPEA7 and SAMPEA9	48
4.9. Relative yield and relative seasonal crop water use of cowpea crop for SAMPEA7 and 9	51
4.10a. Average Kc values for SAMPEA 7 variety developed at the end of the study	54
4.10b. Average Kc values for SAMPEA 9 variety developed at the end of the study	55
4.11. Direct evaporation (Ke)	58
4.12a. The mean dual crop coefficient (Kcb+Ke) values computed for cowpea SAMPEA 7	59
4.12b. The mean dual crop coefficient (Kcb+Ke) values computed for cowpea SAMPEA 9	60

LIST OF FIGURES

FIGURES	PAGE
2.1. Crop coefficient curves showing the basal Kcb, soil evaporation Ke and the corresponding single Kc	12
3.1 Experimental field lay out	21
4.1 Biomass, grain yield and seasonal crop water use relationship for no mulch	49
4.2 Biomass, grain yield and seasonal crop water use relationship for BPM mulch	50
4.3. Yield response factor (Ky) of the no - mulch treatment	53
4.4 Yield response factor (Ky) of the black polyethylene mulch treatment	53
4.5 Kc curve for SAMPEA7 and SAMPEA9 for the NM treatment	57

LIST OF PLATE

PLATE	PAGE
I. Calibration of lysimeter on the field	22
II. The weighing unit of the micro-lysimeter	24
III.The Micro-lysimeter Set-up	25
IV. Crops growing in the micro-lysimeters and surrounding field	25

LIST OF APPENDICES

APPENDICES	PAGE
I Seasonal ETc for the various treatments	74
II Average weekly ETc for the various treatments	75
III Average weekly deep percolation for the various treatments	76
IV Average weekly Kc for the various treatments	77
V Calibration of micro-lysimeter on the field	78
VI Digging of pit for micro-lysimeter installation	79
VII Installation of micro-lysimeters	79
VIII Experimental field after irrigation	79

CHAPTER ONE

INTRODUCTION

1.1 Background

Cowpea is one of the most widely adapted, versatile and nutritious of all the cultivated grain legumes (Dugje *et al*., 2009). With the increasing need of this crop, it is necessary to accelerate and expand its production all year round. This could mean making an effort to grow the crop under irrigation so as to have more than one cropping season in a year which would increase its production.

Nigeria has two distinct seasons – the rainy season, lasting from mid of March to the end of October, and the dry season, lasting from November to March. In the dry season, there is virtually no rain and irrigation remains the only option for crop production. There is stiff competition for water by the agricultural, domestic and industrial users during the dry season, hence there is the need for farmers to conserve and make judicious use of the available water (Adekalu and Okunade, 2006).

Studies are needed to increase the efficient use of the available water. Regulated deficit irrigation with mulching is one among many practices that is fast gaining ground, and it appears a very promising option at achieving the goal of more crops per unit volume of water, if properly adopted. The development of new irrigation scheduling techniques such as deficit irrigation and identifying the sensitive crop growth stage to water stress is one way to enhance crop productivity with less water (Bekele and Tilahun, 2007). Regulated deficit irrigation scheduling practice is a technique of withholding or skipping irrigation, or reducing the amount of water applied per irrigation at some stages of the growth with the aim of saving water, labor, and energy without adverse effect on yield

performance. This practice leads to some degree of moisture stress on the crop and likely reduction in crop yield (Smith *et al*., 2002: Prichard *et al*., 2004; Zhang *et al*., 2004).

The objective of regulated deficit irrigation is to save water by subjecting crops to periods of moisture stress with minimal effects on the yields. The water stress results in less evapotranspiration by closure of the stomata, reduced assimilation of carbon, and decreased biomass production. The reduced biomass production has little effect on ultimate yields where the crop is able to compensate in terms of reproductive capacity (Stone *et al*., 2001).

Mulching involves the use of materials to cover the cropped soil surface with the aim of reducing evaporation, conserving soil moisture, modifying soil temperature, structure and improving aeration. It also suppresses weeds and reduces erosion. (Hassan,1996 Plauborg *et al*., 1996). A better understanding of crop yield-water application interaction and the effects of irrigation levels and mulch (covering the soil surface) on the relationship between transpiration, evaporation and evapotranspiration for various crop is necessary to improve the management of irrigation water resources (Kadayifci *et al*., 2004).

Furthermore, evaporation and transpiration occur simultaneously and there is no easy way of distinguishing between the two processes directly on the field. The amount of water required to compensate the evapotranspiration loss from the cropped field is defined as the crop water requirement. Although the values for evapotranspiration and crop water requirements are identical, crop water requirement refers to the amount of water that needs to be supplied, while evapotranspiration refers to the amount of water that is lost (Richard *et al*., 1998). The water balance method provides a simple but robust

means of continuous measurement of evapotranspiration (ET) from different species of vegetation (Granier *et al*., 1990; Gholipoor, 2007).

The Institute for Agricultural Research (IAR), Samaru has released several varieties of cowpeas in the last 15 years. Although some of these varieties are planted under irrigation, the irrigation water requirements and their crop coefficient (Kc) values have not been systematically evaluated. A systematic evaluation of these parameters involves an isolation of the crop growing medium, which is the soil, so that water input and output into and out of the system will be effectively monitored. By so doing, the soil water balance components will be appropriately determined. One device that can be used for such study is the soil lysimeter.

1.2 Statement of the Problem

Despite the potentials and importance of cowpea, there is little, if any documented research information on cowpea production under irrigation in Nigeria. Production practices of a crop under irrigation must necessarily be stated independently from the rain-fed crop because the two seasons are not comparable. Most of the agronomic research to date on cowpea has been focused on the rain-fed crop by the Institute for Agricultural Research (IAR), Samaru Zaria (Mohammad, 2011).

It is an established fact that one of the important factors limiting the development of agriculture in the semi-arid region is water. Samaru which is located within this region is one of agricultural areas in Zaria, Kaduna State. However, there are large potentially irrigatable lands which are not irrigated due to insufficient or lack of irrigation water, which led to the necessity of optimizing and managing the use of water for agricultural production (Oiganji, 2010). There is also uncertainty as to the availability of water in adequate amounts and times, especially where storage facilities such as dams are absent.

This necessitates development of water management strategy to avert water stress in crops; which if proven advantageous, could assist farmers as most of them are at subsistence level and they are economically weak with low ability to withstand risks.

With the recent screening and release of improved cowpea varieties that are high yield photo-insensitive and early maturing, nine varieties of cowpea for different ecologies have been developed and released for production by IAR. The most popular are SAMPEA6 and SAMPEA7 which are resistant to many stress factors, and SAMPEA9 which is dual purpose (high grain and fodder yields) (Agricultural Research Council of Nigeria, 2017). The study therefore applied the use of a weighing-type soil micro-lysimeter to study the yield and water balance of two varieties of cowpea (SAMPEA7 and SAMPEA9), under mulch and deficit irrigation.

1.3 Justification of the Study

In Nigeria, the greatest production of cowpea comes from the northern region. The north produces about 1.7 million tonnes from 4 million hectares. This represents over 60% of total production (FAO, 2005). During the dry season, water is usually provided from both irrigation facilities and residual moisture of wetlands (Inaizumi *et al*., 1999). But water is a limiting factor in the expansion of irrigated areas and in the production of food. As the population increases, greater competition for the water supply makes conservation and efficient use of water imperative (Eric *et al*., 1981).

Rising cost of Irrigation pumping, low commodity prices, inadequate irrigation system capacities and limited irrigation water supplies are the reasons for which many irrigators deliberately apply less water than is required for maximum yield. (Craciun and Craciun, 1999). One means of determining when irrigation should be supplied is through the use of a soil water balance or soil water budget (Tim, 1996). Cowpeas are exposed to

varying levels of environmentally induced stresses during their growth stages, and limited information exists on reliable estimates of evapotranspiration (ETo) to be used for forecasts, to achieve high irrigation water use efficiency in semi-arid environment, particularly under micro-irrigation (MI) system, such as in IAR Research Farm at Samaru Zaria.

Improved irrigation management requires adequate information on the nature and degree of responses of various growth stages to water stress. Hence, with the changes that have taken place in the global climates in the last one decade, and with new varieties of crops released, there is the need to re-validate the existing body of information on crop water requirements, crop coefficients and the water stress coefficients. The reason for this is because these parameters depend on climatic factors and crop characteristics. With these background considerations, a comprehensive field investigation was undertaken to study the water balance components of two IAR cowpea varieties under Irrigation.

1.4 Aim and Objectives of the Study

The aim of this study was to evaluate the yield and water balance of two IAR cowpea varieties (SAMPEA7 and SAMPEA9) under mulch and deficit irrigation using weighing- type micro-lysimeters.

The objectives are;

a) To determine grain yield and crop water use of the cowpea varieties under different water application regimes and mulch practice.

b) To develop crop coefficient curve for the cowpea varieties under limited and unlimited water supply conditions.

c) To express the yields and water use relationship for the cowpea varieties.

CHAPTER TWO

LITERATURE REVIEW

2.1 Cowpea

Cowpea (*Vigna unguiculata* [L.] walp) is a warm-season, annual herbaceous legume. Plant types are often categorized as erect, semi-erect, prostrate or climbing (Davis *et al.*, 1991). Cowpea generally is strongly tap rooted. Maximum effective root depth has been estimated at 0.5-0.7 m, (Richard *et al.*, 1998). They are grown under rain fed conditions as well as irrigation or residual moisture along river or lake flood plains during the dry season, provided that the range of minimum and maximum temperatures are between 28 and 30^0C (night and day) (Davis *et al.*,1991). It performs well in agro ecological zones where the rainfall range is between 500 and 1200 mm/year. However, with the development of extra-early and early maturing cowpea varieties, the crop can thrive in the Sahel where the rainfall is less than 500 mm/year.

Cowpea is drought tolerant and well adapted to sandy and poor soils, being deep-rooted cowpea performs well in sandy soils and is more tolerant to drought than soya beans, and does not tolerate excessively wet conditions or water-logging (Dadson *et al*., 2003). However, best yields are obtained in well-drained sandy loam to clay loam soils with soil pH between 6 and 7.

2.2 Cowpea Varieties Released

Nine (9) varieties of cowpea for different ecologies have been developed and released for production by IAR. The most popular are SAMPEA6 and SAMPEA7 with yield potential of 1.5 t/ha and resistant to many stress factors (Augustine, 2011). Two new varieties SAMPEA8 and SAMPEA9 have also been released. SAMPEA8 is extra-early in maturity while SAMPEA9 is dual purpose (high grain and fodder yields).

SAMPEA7 (IT90K-82-2) is early maturing (70days), erect and a medium sized brown seed that is moderately resistant to insects, pests and diseases. Its yield is about 1.5t/ha and a good crop for dry season farming. SAMPEA9 (IT90K-277-2) is medium maturing (75-80 days), a semi-erect and a medium white seed that has some level of resistance to insect and diseases (Utoh, *et al.*, 2005) and its yield is about 1.3-1.5t/ha (Augustine, 2011). For optimum productivity of cowpea, be it entirely irrigated or partly rain fed, it requires 360-450mm of water per season (Krishna, 2010). Short season summer crop of cowpea needs irrigation between 250-360mm during the season. Hall and Patel (1985) reported that early and erect cowpeas are preferred in dry environment and under irrigation because they flowered earlier (about 30days after sowing).

2.3 Soil – Water – Balance

Measurement of the soil water balance may be undertaken for several purposes. Several studies have shown that the amount of dry matter produced by crops is directly proportional to the amount of water transpired (Gregory, 1991). Estimates of evapotranspiration are frequently obtained from the soil water balance equation and the development of the neutron probe has greatly facilitated this approach because routine measurements of change in soil water storage with a degree of spatial integration have been possible. In some soil however, the change in soil water storage is difficult to measure accurately and estimates of evapotranspiration are complicated by continued drainage and runoff (Gregory, 1991). Moreover, when crop canopies are sparse, evapotranspiration may be a poor indicator of crop productivity. The mass balance for soil water in the root zone is:

$$I + U = E + T + D + R + \Delta s \qquad (2.1)$$

Where;

I is Irrigation; U is upward capillary flux into the root zone; E is direct evaporation from the soil surface; T is transpiration; D is drainage out of the root zone; R is surface runoff; and Δs is the change of water stored in the root zone (Gregory, 1991). In the simplest case, U, D and R are assumed to be Zero so the water use (ET) is readily estimated from I. while Δs is measured with a neutron probe. Actual Evapotranspiration (ET) is the most difficult parameter to estimate accurately in the hydrological cycle. Hitherto, Actual ET was determined by rather complex micro-meteorological and soil physical methods (Shuttleworth, 1988). Similar methods have been presented where approximate estimates of Actual ET are calculated based on potential ET (Veenendaal *et al*., 1996).

2.3.1 Evapotranspiration (ET)

Evaporation and transpiration occur simultaneously and there is no easy way of distinguishing between the two processes. Apart from the water availability in the topsoil, the evaporation from a cropped soil is mainly determined by the fraction of the solar radiation reaching the soil surface (Richard *et al*., 1998). ET depends on the density of vegetation cover and its stage of development. Thus, we distinguish between potential and actual evapotranspiration.

2.3.2 Separation of evaporation and transpiration

In many arid and semi-arid regions, evaporation (E) from the soil surface is a substantial component of the total crop water use (ET), and yield and water use are frequently unrelated (Gregory, 1991). The ability to independently measure soil water evaporation (E) and canopy transpiration (T) is important when examining energy and water balances of sparse vegetation. However, lack of an adequate measurement technique has limited scientists to measurements of ET and daily E.

Reliable measurements to separate E and T are difficult to make and are very time – consuming.

2.4 Crop Response and Soil-Water-Balance under Deficit Irrigation Scheduling

Deficit irrigation, the deliberate and systematic under-irrigation of crops, is a common practice in many areas of the world (Tyagi, 1987; English *et al*., 1990; Trimmer, 1990; Jurriens and Wester, 1994). A number of researchers have analyzed the economics of deficit irrigation in specific circumstances and have concluded that this technique can increase net farm income (Dudley *et al*., 1971; Stewart *et al*., 1974). The potential benefits of deficit irrigation derive from three factors: increased irrigation efficiency, reduced cost of irrigation and the opportunity costs of water (English *et al*., 1990).

Yield reduction in deficit irrigation is minimized through the cost of the water saving or yield increase from new command areas out of water savings from deficit irrigation (English, 1990). The water stress in plant has an important effect on water consumption and yield. Depending on the decrease in the water that can be used in soil, physiological formations in plant damage, the growth slows down and yield decreases (Korukcu and Kanber, 1981; Koksal *et al*., 2001).

Ziska and Hall (1983) reported that cowpea had the ability to maintain seed yields when subjected to drought during the vegetative stage provided subsequent irrigation intervals did not exceed eight days. On the other hand, Turk *et al*., (1980) showed that cowpea is highly sensitive to water stress during the flowering and pod-filling stages. It's apparent that the sensitivity of cowpea yield to drought during different stages of growth has not been adequately established.

2.5 Crop Coefficient

To account for the effect of the crop characteristics on crop water requirements, crop coefficients (Kc) are determined to relate reference crop ET (ETo) to actual crop ET (ETc). The effect of crop characteristics on the above relationships is associated with the resistance to transpiration, such as closed stomata during the day, waxing leaves, crop height, roughness, reflection and ground cover (Doorenbos and Pruitt, 1984). It is necessary to collect local data on growing season and rate of irrigated crop development in order to draw a crop coefficient curve (Allen *et al*., 1998).

The Food and Agriculture Organization (FAO) and WMO (World Meteorological Organization) experts have summarized such evolution in the "crop coefficient curve" to identify the Kc value corresponding to the different crop development and growth stages (initial, middle and late, hence it has Kc_{in}, Kc_{mid}, Kc_{end}) (Tarantino and Spano, 2001). Values of Kc for most agricultural crops increase from a minimum value at planting until maximum Kc is reached at about full canopy cover. The Kc tends to decline at a point after a full cover is reached in the crop season. The declination extent primarily depends on the particular crop growth characteristics (Jensen *et al*., 1990) and the irrigation management during the late season (Allen *et al*., 1998). A Kc curve is the seasonal distribution of Kc, often expressed as a smooth continuous function.

2.6 Single Crop Coefficient Approach

In the single crop coefficient approach, the effect of crop transpiration and soil evaporation are combined into a single Kc coefficient. The coefficient integrates differences in the soil evaporation and crop transpiration rate between the crop and the grass reference surface (Gerson *et al*., 2004). As the single Kc coefficient averages soil evaporation and transpiration, the approach is used to compute ETc for weekly or longer

time periods. Kc is used for planning studies and irrigation system design where the average effects of soil wetting are acceptable and relevant.

2.7 Dual Crop Coefficient Approach ($K_{cb} + K_e$)

In the dual crop coefficient approach, the effect of specific wetting events on the value of Kc and ETc is determined by splitting Kc into two separate coefficients; the basal crop coefficient (K_{cb}) representing the transpiration of the crop; and the soil water evaporation coefficient (K_e) (Gerson *et al*., 2004). The single Kc coefficient is replaced by:

$$Kc = K_{cb} + K_e \quad (2.2)$$

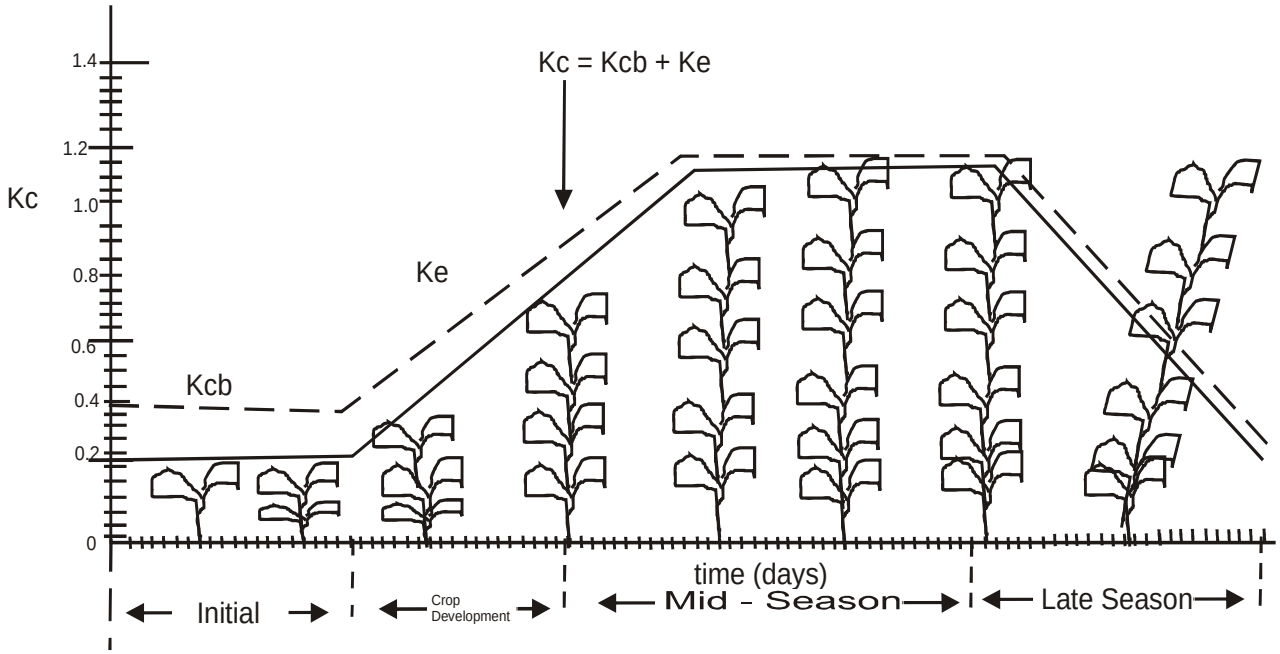
Where; K_{cb} is the basal crop coefficient and K_e is the soil water evaporation coefficient. The K_{cb} is defined as the ratio of ETc to ETo when the soil surface layer is dry, but where the average soil water content of the root zone is adequate to sustain full plant transpiration. If the soil is wet following rain or irrigation, K_e may be large. However, the sum of K_{cb} and K_e can never exceed a maximum value, $K_{c\ max}$ determined by the energy available for ET at the soil surface (Richard *et al*., 1998).

The computation of ($K_{cb} + K_e$) approach may lead to more accurate estimates of daily ETc than using the time averaged single Kc because it takes better into account the dynamics of evaporation from the soil during the earlier phases of a crop, when a significant fraction of the soil surface is exposed to the solar radiation (Allen *et al*., 2005). The dual Kc approach is generally advantageous to incomplete cover crops and to drip irrigated crops, which concentrate soil evaporation from the fraction of the ground wetted by irrigation (Howell *et al*., 2004). Many studies report the application of the dual Kc methodology to several crops, including for cereals, Liu and Pereira (2000), Pereira *et al*., (2003) and Liu and Luo (2010) for the wheat and maize crop sequence of North China; Tolk and Howell (2001) for sorghum, Zhao and Nan (2007) for maize, and

López-Urrea *et al*., (2009) for wheat. Hay and Irmak (2009) report its use for non-growing "dormant" periods. The use of the dual Kc methodology is more demanding than the single Kc approach, which justifies the need for implementing an appropriate model application. However, few model applications are available (Jiang *et al*., 2008; Hillyer and Sayde, 2010).

2.8 Crop Coefficient Curve.

After the selection of the calculation approach, the determination of the lengths for the crop growth stages and the corresponding crop coefficients, a crop coefficient curve can be constructed. The curve represents the changes in the crop coefficient over the length of the growing season (Richard *et al*., 1998). From the curve, the Kc factor and hence ETo can be derived for any period within the growing season. Figure 2.1 illustrates typical shapes for the K_{cb}, K_e and single K_c curves.



(Richard *et al*., 1998)

Figure 2.1 crop coefficient curves showing the basal K_{cb} (Thick line), soil evaporation K_e (Thin line) and the Corresponding single $K_c = K_{cb} + K_e$ curve (dashed line).

2.9 Water Stress Coefficient (K_s)

The effects of soil water stress on crop ET are described by reducing the value for the crop coefficient. This is accomplished by multiplying the crop coefficient by the water stress coefficient (Richard *et al*., 1998).

$$ETc\ adj = (Ks\ K_{cb} + K_e)\ ETo\ . \quad (2.3)$$

Where ; ETc adj is the effect of soil water stress, K_{cb} is the basal crop coefficient and K_e is soil water evaporation coefficient. For soil water limiting conditions, Ks<1. Where there is no soil water stress, Ks = 1. Ks describe the effect of water stress on crop transpiration. Where the single crop coefficient is used, the effect of water stress is incorporated into Kc as:

$$ETc\ adj = KsKc\ ETo \quad (2.4)$$

Because Ks impacts only on crop transpiration rather than evaporation from soil, Equation (2.3) is generally more valid.

2.10 Penman – Monteith Equation

Owing to the difficulty of obtaining accurate field measurements, ET is commonly computed from weather data. A large number of empirical or semi- empirical equations have been developed for assessing meteorological data (Richard *et al*., 1998). Some of the methods are only valid under specific climate and agronomic conditions different from those under which they were originally developed. As a result of an expert consultation held in May 1990, the FAO Penman- Monteith method is now recommended as the standard method for the definition and computation of the reference evapotranspiration (ETo). The FAO Penman – Monteith equation is given by;

$$ETo = \frac{0.408\Delta\ (Rn-G)+\gamma\frac{900}{T+273}\ U2(es-ea)}{\Delta+\gamma(1+0.34U2)} \quad (2.5)$$

Where;

Δ= Slope of saturation vapour pressure curve (Kpa^oC^{-1}),

Rn= Net Radiation ($MJm^{-2}day^{-1}$),

G= soil heat flux [$MJ\ m^{-2}\ day^{-1}$],

γ= psychrometric constant [$kPa\ °C^{-1}$],

T= air temperature [°C],

U_2= wind speed at 2 m above ground surface [$m\ s^{-1}$],

(e_s-e_a)= saturation vapour pressure deficit (Kpa)

2.11 Weighing- Type Micro Lysimeter

Many observations of ET are made in soil containers variously known as tanks, evapotranspirometers and lysimeters in which ET is computed by maintaining a water budget (Paola and Gianfranco, 1999). The first two terms customarily refer to containers with sealed bottoms, while lysimeter has pervious bottoms or a mechanism for maintaining negative pressure at the bottom. Lysimeter is a device that allows an area of a field to be isolated from the rest, and yet experience similar conditions (Paola and Gianfranco 1999). The weighing lysimeter continuously weighs water contained inside the lysimeter.

All the methods for determining ET have some limitations and superiorities. Evapotranspiration determination includes various measurement techniques and modeling techniques (also direct and indirect), which simulate evapotranspiration as a biophysical process or calculate it using the empirical methods (Rana and Katerji, 2000). Some of which include; the direct measurement at the plot scale (weighing lysimeter), indirect measurement at the plot scale (micrometeorological approach), and measurement based on the soil water balance, measurement on the plant scale, the direct

and indirect estimation of ET. Weighing lysimeters are the most accurate and direct method (Jensen *et al*., 1990).

Weighing lysimeters can provide precise information on soil moisture changes for daily or even hourly periods. The weighing lysimeter is placed inside another tank which is in contact with the surrounding soil. The inside container is free for weighing by scales. Also, the weighing lysimeter tank can be floated in water; a suitable heavy liquid ($ZnCl_2$) is used whereby the change in liquid displacement is a measure for the water gain or loss to or from the lysimeter tank. Apart from the high cost, the major problems with weighing lysimeters are the restricted root growth, the disturbed soil structure in the lysimeter causing changes in water movement and possibly the tank temperature regime, resulting in condensation of water on the walls of the container. Harrold and Dreilbelbis (1967) estimated that errors due to dew formation were in the order of 250 mm per annum. Other limitations include the 'bouquet effect' whereby the canopy of the plants grown in the lysimeter is above and extends over the surrounding crop, resulting in a higher evapotranspiration rate. In spite of these limitations, it is the best technique for precise studies on evapotranspiration.

2.12 Controlled Deficit Irrigation Practices

With increasing municipal and industrial demands for water, its allocation for agriculture is decreasing steadily. Therefore; innovations are needed to increase the efficiency of use of the water that is available. There are several possible approaches. Irrigation technologies and irrigation scheduling may be adapted for more effective and rational uses of limited supplies of water. Deficit (or regulated deficit) irrigation is one way of maximizing water use efficiency (WUE) for higher yields per unit of irrigation water applied (FAO, 2002). Irrigation scheduling based on deficit irrigation requires careful

evaluation to ensure enhanced efficiency of use of increasingly scarce supplies of irrigation water.

Ziska and Hall (1983), reported that cowpea had the ability to maintain seed yields when subjected to drought during the vegetative growth stage provided subsequent irrigation intervals did not exceed eight days. Thomas *et al*., (1976) found that plants that suffered a gentle water stress during the vegetative period showed higher tolerance of water deficit imposed later as a result of adaptation to existing soil water status. Where water scarcity exists at the regional level, irrigation managers should adopt the same approach to sustain regional crop production and thereby maximize income (Stegman *et al*., 1980). This new concept of irrigation scheduling has different names such as; regulated deficit irrigation, pre-planned deficit evapotranspiration and deficit irrigation (English *et al*., 1990).

2.13 Use of Lysimeters to Estimate Soil Water Balance

Direct measurement of soil evaporation is difficult. The most common and direct method is using a weighing lysimeter. However, this method has several disadvantages and a simple measurement of evaporation is often preferable. The use of micro-lysimeter has been introduced and analyzed as detailed by Boast and Robertson (1982). Since then, a number of researchers have employed this method. Some worked on the internal diameter, the depth, and the lifetime of the micro-lysimeter (Allen *et al*., 2005). The good agreements were gotten between soil evaporation from bare soil determined by micro-lysimeter and those measured by other methods, such as the large weighing lysimeter method (Batchelor, 1992), the water balance method (Allen *et al*., 2005), and the infrared thermometer method (Matthias *et al*., 1986).

Martin *et al*., (1985) found that micro-lysimeter over-measured soil evaporation beneath a growing crop because plant extraction of moisture was excluded. Also, Allen *et al*., (2005), found the micro-lysimeter technique to be reliable only during rain-free periods.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of the Study Area

The study was conducted between February to May, 2011 dry season at the Irrigation Research Farm of IAR Samaru Zaria (latitude 11°11'N,longitude 7°38'E at altitude 686 m), above sea level within the Northern Guinea Savannah ecological zone of Nigeria with a semi-arid climate. Several meteorological information of the site were collected from the Institute for Agricultural Research meteorological station located 150m away from the experimental plots as shown in Table 3.1.The table shows that maximum temperature ranges from 36-39^{o}C, while minimum temperature ranges from 18-23^{o}C, which is quite high considering the range of minimum and maximum temperatures for cowpea production of 28-30^{o}C (Dugje *et al*., 2009). Table 3.2 presents information on physical properties of the experimental plot which was predominantly sandy loam in texture.

Table 3.1 Average Monthly Weather data for Samaru, (Feb;-May, 2011) irrigation cropping season.

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

Source: I.A.R Meteorological Station

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

b. Average monthly ET_o for 10 years (2000-2010) using Modified Penman Monteith

Table 3.2 Physical Properties of soils at various depths at IAR Irrigation Research Farm.

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

a. Based on USDA textural classification.

3.2 Treatments and Experimental Design

A three-factor experiment comprising of two cowpea varieties (IAR SAMPEA7 and 9), three levels of deficit irrigation (water application depths 100%, 75% and 50% of weekly reference evapotranspiration ($WRET_o$) applied on weekly basis, referred to as I_{100}, I_{75}, and I_{50}) and two levels of mulching (No mulch NM and Black polyethylene mulch BPM), making a total of twelve (12) treatments, were used in this study. The treatments were replicated three times and laid in a Group Balanced Block superimposed on the Split-plot Design resulting in what is generally called the Group Balanced Block in Split-plot Design (Kwanchai and Arturo, 1983). Further description of the experimental treatment is shown in Table 3.3. The experimental field was prepared into ridges 38m long each, and at an intra-row and inter-row spacing of 25cm and 75cm respectively. A total number of 22 ridges were made, occupying a total area of about 605 m^2 (0.06ha) surrounding the lysimeters. In practice, this irrigated area is maintained around the lysimeters to ensure they are in an environment similar to large-scale irrigated agriculture. This helps to promote representative measurements of the crop ETc (Linda and Clawson, 2009). The field was further divided into six (6) sub- plots measuring about $4.8m^2$ (0.0005ha). All agronomic practices for the cultivation of cowpea were followed and Figure 3.1 shows the field layout.

Table 3.3 Description of the experimental treatments

Treatment No.	Treatment label	Description of treatment combinations
1.	V_1,I_{100},NM	SAMPEA 9 Variety, 100% weekly ET_o and no mulch
2.	V_1,I_{100},BPM	SAMPEA9 variety, 100% weekly ET_o and black polyethylene mulch
3.	V_1,I_{75},NM	SAMPEA 9 Variety, 75% weekly ET_o and no mulch
4.	V_1,I_{75},BPM	SAMPEA 9 Variety, 75% weekly ET_o and black polyethylene mulch
5.	V_1,I_{50},NM	SAMPEA 9 Variety, 50% weekly ET_o and no mulch
6.	V_1,I_{50},BPM	SAMPEA 9 Variety, 50% weekly ET_o and black polyethylene mulch
7.	V_2,I_{100},NM	SAMPEA 7 Variety, 100% weekly ET_o and no mulch
8.	V_2,I_{100},BPM	SAMPEA 7 Variety, 100% weekly ET_o and black polyethylene mulch
9.	V_2,I_{75},NM	SAMPEA 7 Variety, 75% weekly ET_o and no mulch
10.	V_2,I_{75},BPM	SAMPEA 7 Variety, 75% weekly ET_o and black polyethylene mulch
11.	V_2,I_{50},NM	SAMPEA 7 Variety, 50% weekly ET_o and no mulch
12.	V_2,I_{50},BPM	SAMPEA 7 Variety,50% weekly ET_o and black polyethylene mulch

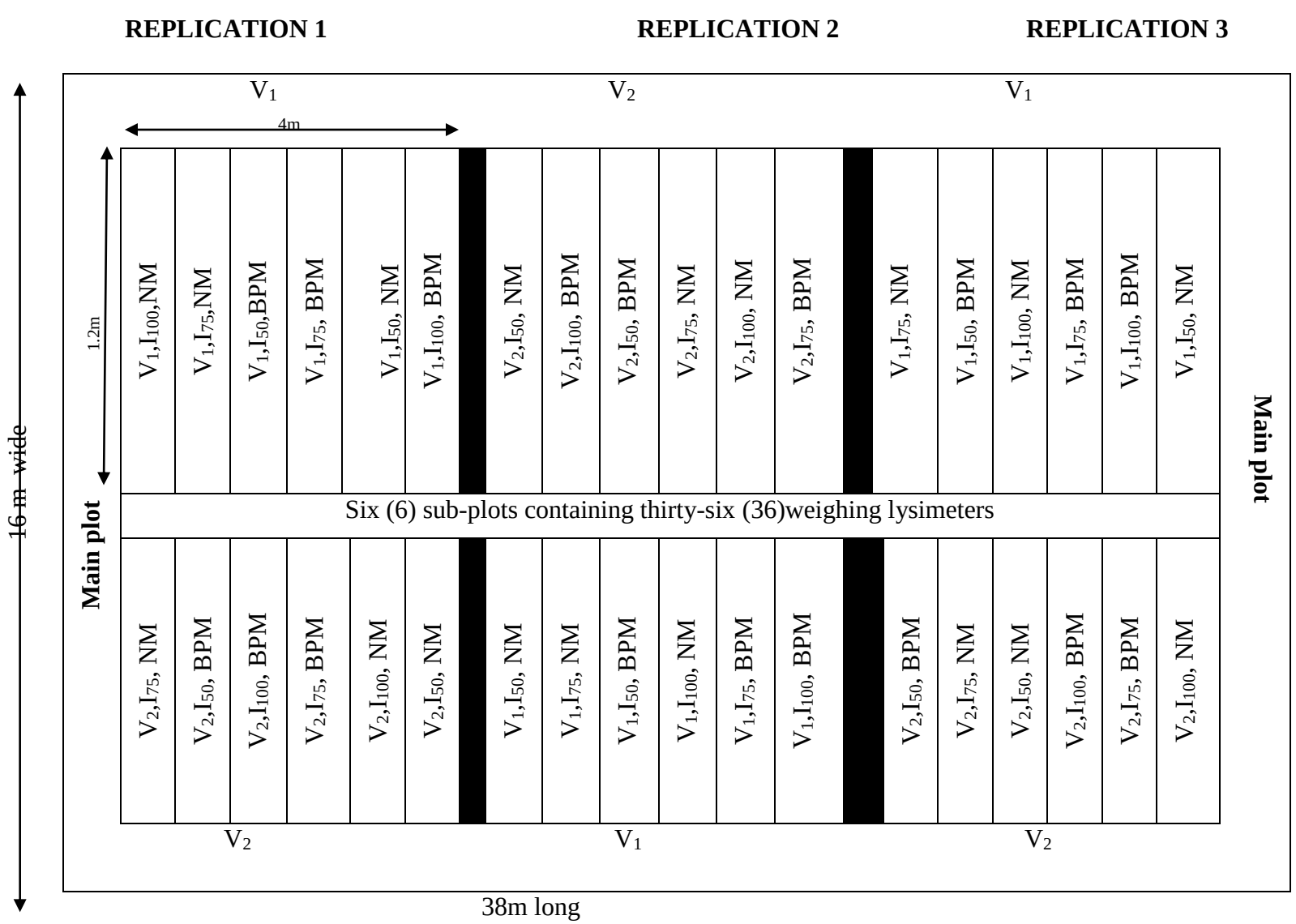


Figure 3.1 Experimental field Layout

3.3 Calibration of the Micro Lysimeter

Prior to field installation of the lysimeters and planting of crops on the field, the relationship between lysimeter load and the height of water displacement in the manometer tube was determined. This was carried out by loading and unloading the lysimeter with blocks of known weights (ranging from 6.20-7.00 kg), while the height of water in the manometer tube was recorded. The maximum weight loaded in the lysimeter tank ranges from 98.75-105.15 kg. The blocks were loaded one at a time in two piles inside the lysimeter tank and then in like manner, unloaded and carefully removed from the tank. Similarly, the calibration was also done on the field using soil excavated from the field. The water level in the manometer tube for each weight of soil placed was recorded every time the lysimeter tank was loaded or unloaded as shown in plate I. The calibration, however, showed some hysteresis in the height of the manometer water level when loading and unloading the lysimeter tank, so the average height of water level was used. A graph of the weight of lysimeter tank against the height of water level is plotted to determine the calibration function.



Plate I Calibration of lysimeter on the field

3.4 Setting up the Micro-lysimeters

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

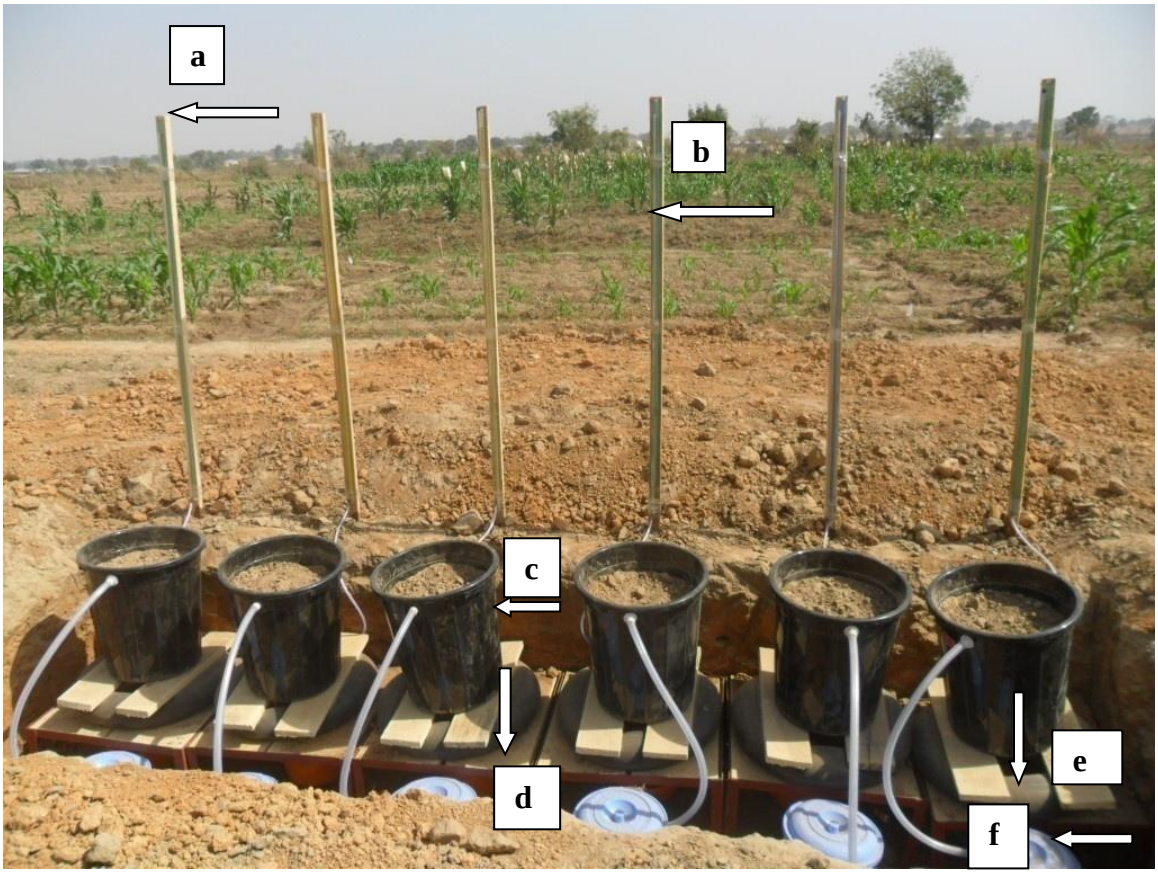
The weighing system of the lysimeter comprises of a water-filled size 13 rim Michelin automobile tube connected to a graduated manometer glass tube using a rubber hose. The valve cover and the valve of the tube were removed and the tube filled with water through the rubber hose connected to its mouth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

The manometer glass tube was fixed to a graduated pole in a vertical position to aid easy and accurate reading of the water displacement in it. The graduated pole was laminated

to prevent rainfall from washing away its calibration. The pole was constructed from a soft wood (2cm thick and 180cm long) and was driven into holes dug from the soil which was later cemented for stability. The platform upon which the lysimeter tank and the weighing system rest was constructed from hard plywood 2cm thick, of length 60cm and width 40cm which was wider than the base of the lysimeter tank. A hole (25cm in diameter) was made at the middle of the platform. The water from the lysimeter soil under saturation condition drips into the drainage collector below the edge of the hole. Plates II, III and IV further illustrate the micro-lysimeter setup.



Plate II The weighing unit of the micro-lysimeter



* (a) = wooden pole, * (b) = glass manometer tube, * (c) = lysimetre tank, * (d) = wooden platform, * (e) = automobile tube, * (f) = plastic runoff collector
Plate III The Micro-lysimeters set-up



Plate IV Crops growing in the micro-lysimeters and surrounding field

3.5 Agronomic Practices

All the agronomy practices carried out in the field was also done at the same time to the crops in the micro-lysimeters.

3.5.1 Land preparation

The experimental sites were ploughed, harrowed twice and then divided into three replications with each consisting of two sub-plots of about 9.6 m^2. The experimental field was surveyed to mark the length of the pit to be excavated with respect to the row crop. To excavate the marked area, a digger and a shovel was used to excavate the 400 cm long, 120 cm wide and 80 cm deep pits. An 80 cm deep pit was dug by summing up the depth of the lysimeter bowl, the height of the wooden stand (platform) of which the lysimeter rests upon, and the height of the tube. They were of equal dimensions across the six pits so chosen. The depth of the pit was dug such that the soil in the lysimeter is at the same level and height with that of the ridges when installed.

3.5.2 Planting of cowpeas

The lysimeters were filled with repacked soil and effort was made to simulate the environment cropped with cowpeas in which the lysimeters was to be installed. Six (6) micro-lysimeters were constructed and installed in the middle of the six (6) sub-plots. Thirty-six (36) micro-lysimeters were installed in the main plot, one lysimeter for each variety, to measure the evapotranspiration. Three (3) lysimeters were installed (without crop) in the farm to estimate the rate of evaporation. A total of Thirty-nine (39) micro-lysimeters were used for the set up. Cowpea seeds were sown by hand, 3 to 4cm deep in the field and also in the micro-lysimeter tanks filled with soil from the field on the 22nd February, 2011.

3.5.3 Mulch application

After the establishment stage at fifteen days after planting (15 DAP), black polyethylene sheet and the deficit irrigation was introduced to the crops planted in the lysimeter tank .The mulch plastic was cut into strips of about 0.40 m x 0.40 m and placed as a cover to the lysimeter tank, to prevent evaporation.

3.5.4 Weed control

Weeding was done manually and adequately controlled during the entire growth stages of the plant. Also weeds growing in and around the micro-lysimeters were removed as they appear.

3.5.5 Fertilizer application

Single super phosphate (SSP) fertilizer application of 30 kg/ha was applied on the 12th March 2011, at least fifteen days (15 DAP) after planting, as recommended by the Food and Agriculture Organization (FAO, 2005).

3.5.6 Pests and disease control

75 ml of Dimethrin insecticide and 30 g of Benlate (Benomyl) were also applied by spraying, twenty-one days (21 DAP) after planting to control insect pests and diseases. The insecticide spraying was done at two weeks interval until sixty-four days (64 DAP) after planting.

3.5.7 Harvesting

The crops attained physiological maturity at about 70 days after planting and were harvested at 90 days after planting.

3.6 Water Application

Surface irrigation method was used to convey water through field ditches which ran parallel to the crops planted in the field surrounding the lysimeter installations. Water was released from the main canal into a lateral ditch which conveyed the water by gravity to the field ditches which service the experimental plots. The crops surrounding the lysimeter installations were given full irrigation at I_{100}. However, the crops in the lysimeter tank were irrigated manually using graduated plastic buckets to apply the depth of water. The irrigation interval was seven (7) days and water application depth per irrigation were obtained from a computation of weekly reference evapotranspiration for a period of ten years data (2000-2010) for the study area using Modified Penman - Monteith equation. The order of irrigation and water application depth per irrigation for the season are shown in Table 4.1.

3.7 Data Collection

Data were collected on drainage water, irrigation water applied and the change in water level in the manometer glass tube at an interval of 24 hours (evapotranspiration), the soil evaporation component and the cowpea crops harvested both in the lysimeter and on the field. The drainage water was collected in the calibrated plastic buckets and later poured into a laboratory measuring cylinder calibrated in millimeters. Weather data from the IAR meteorological station was also obtained for the purpose of computing the irrigation water applied. The evapotranspiration (ETc) was obtained from the change in water level inside the manometer tube (cm) and then converted to millimeters (mm) of water using a conversion factor (3.8 mm). The evaporation component was obtained from the change in water level inside the manometer tube of the lysimeter tank containing only soil with no plants in it.

After harvesting, the yield of the crops were converted to tons/ha by multiplying net plot yield by a factor which was obtained by dividing 10,000 m^2 by the net plot areas and multiplied by yield of each net plot.

3.8 Data Computation

3.8.1 Reference evapotranspiration (ET_o)

The daily ETo was computed from the data of 2000-2010 using equation 2.5

$$ETo=\frac{0.408\Delta(Rn-G)+\gamma\frac{900}{T+273}U2(es-ea)}{\Delta+\gamma(1+0.34U2)} \quad (3.1)$$

3.8.2 Conversion of weight of lysimeter tank and drainage volumes to millimeter depth of water.

When plants are irrigated, the lysimeter tank containing the soil and crop vegetation increases in weight and exerts pressure on the water-filled tube of the weighing system. It then displaces certain volume of water which was indicated in the rise of the level of water in the graduated manometer glass tube. As the crop used water, the water level in the glass tube falls with time due to decrease in weight of the lysimeter tank resulting from loss of water from the soil and plant foliage by evapotranspiration and from that which goes out as runoff and drainage. The daily water displacement in the glass tube was noted during the early hours of the day (7:00am) at an interval of 24hours and the weight of the lysimeter tank at this interval was determined from the function,

$Y = 2.2085x - 44.982$ (Kg) (Which relates the weight of the tank to the water displacement in the glass tube) derived from the calibration of the micro-lysimeter. The daily water use from the lysimeter was determined by multiplying the daily differences in weight of the lysimeter tank by a conversion factor of (3.8) which converts the weight to millimeter depth of water. Thereafter, the daily evapotranspiration of the test crop was computed using equation (3.2).

Since there was little or no change in the lysimeter soil, the daily change in weight of the lysimeter tank was due to the daily water use. The density of water is 1kg/l, which implies that one litre of water weighs one kg. In converting one kg of water to mm depth of water, its equivalent in cubic meter ($0.001m^3$) was divided by the area of the lysimeter tank ($0.2639\ m^2$) to obtain the conversion factor in meter which was further converted to mm depth of water. The conversion factor obtained was 3.8 mm depth of water. Therefore, one kg of water with respect to the micro-lysimeter tank was 3.8 mm.

3.8.3 Evapotranspiration (ETc)

The daily evapotranspiration (ETc) was obtained from the water balance method re-arranged as:

$$ET = I_i - R_i - D_i - (W_i - W_{i+1})cf \quad (3.2)$$

Where;

I_i= Irrigation water applied (mm) of day i

R_i = Runoff (mm) of day i

D_i= Drainage (mm) of day i

W_i= Weight of the lysimeter soil on day i

W_{i+1}= Weight of the lysimeter soil the next day at an interval of 24hours.

cf= Conversion factor expressing the change in weight of lysimeter tank to mm depth of water, obtained as 3.8 mm.

ET_i= Evapotranspiration of day i (mm)

3.8.4 Computation of single crop coefficient (Kc)

The single crop coefficient estimated as a ratio of the ETc to ETo as given by Allen *et al*., (1998)

$$Kc = \frac{ETc}{ETo} \quad (3.3)$$

Where;

Kc= Crop coefficient, ETc= Crop evapotranspiration (mm/day), ETo= reference crop evapotranspiration (mm/day)

3.8.5 Computation of dual crop coefficient ($K_{cb} + K_e$)

For K_{cb} and K_e to be obtained, T and E components must be separated. The transpiration component (T) was obtained from the treatments that were mulched. Using the black polyethylene plastic mulch eradicates the evaporation component (E). The E component was obtained from the lysimeter tanks that had no plants in them. Therefore, K_{cb} and K_e were estimated as a ratio of;

$$K_{cb} = \frac{T}{ETo} \quad (3.4)$$

$$K_e = \frac{E}{ETo} \quad (3.5)$$

(Allen *et al*., 1998)

Where;

K_{cb}= basal crop coefficient, Ke= soil evaporation coefficient, T= Transpiration component (mm/day), E= Evaporation component (mm/day) and ETo = reference evapotranspiration (mm)

3.9 Computation of Water Stress Coefficient (Ks)

The water stress coefficient (Ks) integrates the crop and soil factors that make the actual crop water use of the deficit irrigated condition differ from crop water use under fully irrigated condition. Richard *et al*., (1998) stated that, when the potential energy of the soil water drops below a threshold value, the crop is said to be water stressed. The

effects of soil water stress are described by multiplying the crop coefficient by the water stress coefficient (Ks) and determined using equation (2.4).

3.10 Determination of Yield Response Factor

Doorenbos and Kassam (1979) introduced the yield response factor (Ky) which relates the decline in yield per unit decrease in seasonal consumptive water use (SCWU) to describe the relationship between SCWU deficit ($1 - \frac{SCWUdeficit}{SCWU}$) and yield reduction ($1 - \frac{Ya}{Ym}$).

$$(1 - \frac{Ya}{Ym}) = Ky\ (1 - \frac{SCWUdeficit}{SCWU}) \quad (3.7)$$

Where;

Ya = actual yield for each treatment (t/ha)

Ym = maximum yield obtained (t/ha)

$SCWU_{deficit}$= seasonal consumptive water use of the deficit irrigated treatments (mm)

SCWU= crop water use of the fully irrigated treatment ((mm)

Ky = yield response factor.

3.11 Determination of Crop Water Use and Irrigation Water Use Efficiencies

The crop water use efficiency (CWUE) was determined as the crop yield divided by the seasonal crop water use (seasonal evapotranspiration) in line with (Flenet *et al.*, 1996), and the irrigation water use efficiency (IWUE) was evaluated as the crop yield divided by the total irrigation water applied in line with (Ibragimov *et al.*, 2007, Howell *et al.*, 1990) and the values were recorded.

3.12 Crop Data

Grain yield was estimated from seed weight per net plot. This was determined by harvesting the pods in the net plots, dried, threshed and then measured using a weighing balance.

3.13 Data Analysis

The data collected were statistically analyzed using the analysis of variance procedure of S AS. Significant treatment means were compared using Duncan Multiple Range test (DMRT) at 5% level of probability.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Grain Yield

Table 4.1 shows the grain yield obtained in tons per hectare (t/ha). SAMPEA7 variety under full irrigation of 100% weekly ETo (I_{100}) produces the highest yield of 1.29 t/ha for the BPM treatments while the treatment under deficit irrigation of 50% weekly ETo (I_{50}) produced a lower yield of 0.42 t/ha for the BPM crop. It could be deduced that the BPM treatments produced higher yields than the NM treatments with a percentage difference of about 14%. Tolk and Howell (2001), Liu and Luo (2010) have concluded that mulching increases soil moisture and nutrients availability to plant roots, in turn, leading to higher grain yield.

Table 4.1 Classification of cowpea and dry matter yields in tons/hectare

S/NO	Varieties	Treatments	Grain yield (t/ha)	Dry matter (t/ha)
1		V_1,I_{100},NM	0.83	3.06
2		V_1,I_{75}, NM	0.53	2.64
3	SAMPEA 9	V_1,I_{50}, NM	0.29	2.49
4		V_1,I_{100},BPM	1.12	3.22
5		V_1,I_{75}, BPM	0.76	3.13
6		V_1,I_{50}, BPM	0.63	2.73
7		V_2,I_{100}, NM	1.04	3.36
8		V_2,I_{75}, NM	0.87	3.30
9		V_2, I_{50}, NM	0.54	2.68
10	SAMPEA 7	V_2,I_{100}, BPM	1.29	3.83
11		V_2, I_{75}, BPM	1.14	3.37
12		V_2, I_{50}, BPM	0.42	2.80

SAMPEA9 variety under full irrigation of 100% weekly ETo (I_{100}) produced a high yield of 1.12 t/ha for the BPM treatment and 0.29 t/ha was produced by I_{50} for the NM treatment. The BPM treatments also produced higher yields than the NM treatments with a percentage difference of about 34%.

The impact of deficit irrigation on grain and dry matter yields of SAMPEA7 variety ranged from 16 to 48% and 2 to 20%, respectively for the NM treatments, a range of 12 to 68% and 12 to 30% for the grain and dry matter yields respectively of the BPM treatments, with the highest values in the range occurring at 50% weekly ETo (I_{50}). This confirmed that grain yields and dry matter yields of cowpea SAMPEA7 could be reduced by up to 48% and 20%, respectively for the NM treatments, 68% and 30% for the BPM treatments due to deficit irrigation.

Similarly, the magnitude of impact due to deficit irrigation on grain and dry matter yields of SAMPEA9 variety ranged from 36 to 65% and 14 to 19%, respectively for the NM treatments, a range of 33 to 44% and 3 to 15% for the grain and dry matter yields respectively of the BPM treatments, with the highest values in the range occurring at 50% weekly ETo. This entails that grain yields and dry matter yields of cowpea SAMPEA9 could be reduced by up to 65% and 19%, respectively for the NM treatments, 44% and 15% for the BPM treatments due to deficit irrigation. Abbas *et al*., 2017 reported the impact of deficit irrigation on cowpea grain yields at the range of 4 to 58.8%.

According to the results of this study, cowpea grain and biomass yields decreases with increasing moisture stress because of the intense heat in the months of March and April

during growth period and reduction in the flowering. Turk and Hall (1980) reported that irrigation stress reduces yield during flowering and grain filling about 44 and 29% compared to full irrigation system, respectively. Acosta-Gallegos and Adams (1991) said that water stress significantly reduces grain yield and yield components in beans. The results of this study are consistent with the results of the presented investigations.

SAMPEA7 variety performed better than SAMPEA9 variety with a percentage difference of about 21% at the same agronomic conditions. The highest yield of 1.29 t/ha was lower than that of farmer's practice (1.5 t/ha) as reported by Dugje *et al*., (2009), under rain fed conditions. Similarly, Faloye *et al*., (2015), obtained a range of 0.62 – 1.27 tons/ha for *ife brown* cowpea variety, under sprinkler irrigation.

Table 4.2 shows the mean grain and dry matter yields of cowpea as affected by variety, irrigation and mulch during the 2011 dry season. Statistically, it was observed that treatment means of cowpea grain and dry matter yield were significantly different at 5% level of probability with respect to the varieties, deficit irrigation levels and mulch. Yields of treatments at I_{100} are significantly different from that of I_{75} and I_{50}. In general, the cowpea yield declined with decrease in percent irrigation levels from 100-50%. There was no interaction among the tested factors for grain yield and dry matter yield respectively.

Under the cowpea varieties, the treatments means of SAMPEA7 (V_2) performed better than SAMPEA9 (V_1) with the highest grain and dry matter yields of 0.88 t/ha and 3.22 t/ha, respectively. Considering the irrigation treatments, the highest grain and dry matter yields were obtained at I_{100} with 1.07 t/ha and 3.37 t/ha, respectively, followed by I_{75} with 0.82 t/ha and 3.11 t/ha and the least at I_{50} with 0.47 t/ha and 2.68 t/ha.

Under mulching, there was significant difference (at p>0.05) between the BPM and NM treatments. It was noticed that the highest grain and dry matter yield was obtained by the BPM mulched treatment which recorded 0.89 t/ha and 3.18 t/ha, respectively.

Table 4.2 Mean grain and dry matter yield of cowpea as affected by variety, irrigation and mulch during 2011 dry season

Treatment	Dry matter yield (t/ha)	Grain yield (t/ha)
Variety		
SAMPEA 7	3.223a	0.88a
SAMPEA 9	2.877b	0.69b
SE±	0.045	0.025
Irrigation		
1_{100}	3.37a	1.07a
I_{75}	3.11b	0.82b
I_{50}	2.68c	0.47c
SE±	0.056	0.031
Mulch		
BPM	3.18a	0.89a
NM	2.92b	0.68b
SE±	0.045	0.026
Interaction		
V x I	NS	NS
V x M	NS	NS
I x M	NS	NS
V x I x M	NS	NS

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

In general, SAMPEA7 at 100% ETo and using the BPM mulch gave the highest yield compared to SAMPEA9 at any irrigation and mulch levels. The increased grain yield was mainly due to adequate soil moisture availability to the growth stages of crop and

effective nutrients uptake throughout the crop growth stages since both the inputs exerted beneficial effect on yield contributing factors.

4.2 Soil Water Balance Components

4.2.1 Irrigation water applied in the micro-lysimeters

Table 4.3 shows the total irrigation water applied during the cropping season in relation to the various treatments at 100%, 75% and 50% irrigation levels and mulching. The highest irrigation water applied under irrigation treatment was at I_{100} with 545 mm and the least was at I_{50} with 275 mm. Hall and Patel (1985), reported that most short duration cowpea cultivars require 600 mm rains per annum while medium to long duration cowpeas require 600 –1500 mm rains. It would be noticed that the peak amount of water applied was at the mid-season stage across all treatments in both varieties. This was because of high crop water requirement at the mid-growth stage and climatic factors such as high temperature, sunshine hours and wind speed in the months of March to April, 2011 in Samaru, Zaria.

Considering the trend along the different irrigation levels indicated that the irrigation water applied, decreases with increase in deficit irrigation. While the irrigation water applied increases, along the plant growth stage from the initial stage to the mid-season stage and declines towards the late-season stage. The highest irrigation water applied was 63 mm/day at 50-59 days after planting (DAP) for the I_{100} treatments in both varieties. The least water applied was 14 mm/day at 1-5 DAP for the I_{50} treatments in both varieties.

Table 4.3 Growth stages and seasonal irrigation water applied (mm)

Treatment			Initial stage			Development stage			Mid-Season stage			Late-Season stage			
			DAYS AFTER PLANTING												
			1-5	**6-14**	**15-21**	**22-28**	**29-35**	**36-42**	**43-49**	**50-59**	**60-63**	**64-70**	**71-79**	**80-90**	**Total**
V_1	**NM**	I_{100}	28	45	42	45	48	44	49	63	48	40	48	45	**545**
		I_{75}	21	34	32	34	36	33	37	48	36	30	36	34	**411**
		I_{50}	14	23	21	23	24	22	25	32	24	20	24	23	**275**
	BPM	I_{100}	28	45	42	45	48	44	49	63	48	40	48	45	**545**
		I_{75}	21	34	32	34	36	33	37	48	36	30	36	34	**411**
		I_{50}	14	23	21	23	24	22	25	32	24	20	24	23	**275**
V_2	**NM**	I_{100}	28	45	42	45	48	44	49	63	48	40	48	45	**545**
		I_{75}	21	34	32	34	36	33	37	48	36	30	36	34	**411**
		I_{50}	14	23	21	23	24	22	25	32	24	20	24	23	**275**
	BPM	I_{100}	28	45	42	45	48	44	49	63	48	40	48	45	**545**
		I_{75}	21	34	32	34	36	33	37	48	36	30	36	34	**411**
		I_{50}	14	23	21	23	24	22	25	32	24	20	24	23	**275**

4.2.2 Drainage obtained from the micro-lysimeters

Table 4.4 shows the weekly and total drainage per treatment along the growth stages, during the period of the study. The seasonal drainage ranged from 3.9 to 88.6 mm for SAMPEA7 and 6.0 to 89.5 mm for SAMPEA9, with the highest range occurring at the mulched treatments. A comparison of the weekly water lost to drainage on the bases of irrigation treatment indicated that weekly and total drainage water decreased with increase in deficit irrigation. Similarly, in comparison of the drainage water on the bases of mulched treatments indicated that drainage increases with the BPM treatments than the NM treatments.

The decrease in drainage due to increase in deficit irrigation ranged from 40 to 95% for SAMPEA7 variety and 18 to 93% for SAMPEA9 variety, with the highest values in the range occurring at I_{50} treatments with no mulch (NM). The pattern of decrease in drainage as a result of deficit irrigation was expected since deficit irrigation reduces the amount of water available in the soil and as such, little or no drainage will be available. The study however reveals that applying water at I_{50} reduces peak drainage in the two cowpea varieties by about 94%.

A careful study of the trend of the total drainage reveals that for the two varieties, the drainage of the BPM treatments, irrespective of irrigation regime, were about 47% higher than the NM treatments at the initial and 84% higher at the development stages of the plant. At mid-season stage, the drainage of the BPM treatments was 72% higher than the NM treatments and 53% higher than the NM treatments at the late-season stage. This confirms that much drainage water was lost by the BPM treatments when compared to the NM treatments, particularly at the development stage of the plant.

Table 4.4 Growth stages, weekly and total drainage (mm)

			Initial stage			Development stage			Mid-Season stage				Late-Season stage		
			DAYS AFTER PLANTING												
Treatment			**1-5**	**6-14**	**15-21**	**22-28**	**29-35**	**36-42**	**43-49**	**50-59**	**60-63**	**64-70**	**71-79**	**80-90**	**Total**
	NM	I_{100}	0.0	0.0	5.0	4.9	3.7	1.4	2.4	11.4	0.0	0.0	0.9	3.2	**32.9**
		I_{75}	0.0	0.0	0.7	0.0	0.0	0.0	5.1	0.0	4.2	0.0	7.2	0.8	**18.0**
		I_{50}	0.0	0.0	0.2	0.0	0.0	0.0	1.9	1.0	0.0	0.0	0.5	2.4	**6.0**
V_1															
	BPM	I_{100}	0.0	0.3	1.1	6.2	15.0	15.0	12.5	16.5	3.5	10.4	5.0	4.0	**89.5**
		I_{75}	0.0	0.0	1.2	2.1	9.2	16.8	10.2	7.8	0.0	4.7	17.8	3.4	**73.2**
		I_{50}	0.0	0.0	4.1	0.0	0.0	1.1	2.5	0.0	0.0	0.8	0.0	1.8	**10.2**
	NM	I_{100}	0.0	0.0	1.3	4.2	6.6	1.9	2.0	7.3	0.0	0.0	0.0	1.6	**24.9**
		I_{75}	0.0	0.0	0.2	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.8	**5.2**
		I_{50}	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.9	**3.9**
V_2															
	BPM	I_{100}	0.0	0.0	4.2	8.1	19.6	21.1	10.5	5.2	4.7	4.1	7.8	3.3	**88.6**
		I_{75}	0.0	0.0	0.0	3.4	10.2	14.5	12.1	4.9	2.7	0.0	3.4	1.5	**52.9**
		I_{50}	0.0	0.0	3.9	2.0	2.3	5.2	3.7	0.0	0.4	0.9	2.6	1.1	**22.1**

This implies that the higher the irrigation water applied, the higher the drainage volume obtained. This was further supported by the use of the black polyethylene mulch which reduces the evaporation component, thereby conserving more moisture within the lysimeter. At the same depth of water applied, SAMPEA7 gave less drainage water compared to SAMPEA9.

4.2.3 Evapotranspiration (ETc)

Table 4.5 shows the weekly and total (ETc) of the various treatments (mm) across the various growth stages. It shows differences in the amount of water consumed daily by cowpea due to transpiration through the plant foliage and evaporation from the surface of the leaves and adjacent soil surface. There was a gradual rise in the ETc for the NM treatments from the initial stage to the mid-season stage, this was due to high wind velocity, increases in the available soil moisture and loses of water from the plant foliage thereafter, and the ETc starts declining immediately after the mid-season stage across the two cowpea varieties.

The total ETc ranged from 187.6 to 335.6 mm day^{-1} across the two varieties (SAMPEA's 7 and 9). This range of values are much higher than those seasonal ETc range of 131 to 255 mm and 159.5 to 262.5 mm reported by Moroke *et al*., (2011), Adekalu and Okunade, (2006), respectively and a much lower value than the result of 457.70 mm reported by Hashim *et al*., (2012). A comparison of the weekly and total ETc on the bases of irrigation treatment indicated that weekly crop water use (ETc) decreased with increase in deficit irrigation. The average daily peak consumptive use of the treatments given full irrigation (I_{100}) was 5.3 mm day^{-1} and 6.3 mm day^{-1} at the mid-season stage for SAMPEA7 and SAMPEA9, respectively.

Table 4.5 Growth stages, weekly and total ETc (mm)

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

Liyanage *et al*., (1992) observed that lysimeters measurement showed a peak daily evapotranspiration of cowpea during early pod filling stage and averaged to be about 8 mm. The highest ETc obtained show that Cowpea needs much more application of water during the fruiting stage than at emergence (initial stage) and senescence. Similar observation was reported by (Aboamera, 2010; Souza *et al*., 2005). They reported an increase in evapotranspiration of cowpea, during the fruiting (mid season stage) using the water balance method. The decrease in crop consumptive use due to deficit irrigation ranged from 2 to 37% for SAMPEA7 and 1 to 40% for SAMPEA9, with the highest values in the range occurring at I_{50} treatments.

The pattern of decrease in consumptive use (ETc) as a result of deficit irrigation was expected since deficit irrigation reduces the amount of water available in the soil for plant uptake. The study however reveals that applying water at 75% ETo, reduces peak consumptive use of the cowpea crop by about 15% in SAMPEA7 and 20% in SAMPEA9. More so, if water is applied at 50% ETo, the peak consumptive use of the cowpea crop will be reduced by about 37% in SAMPEA7 and 40% in SAMPEA9.

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

4.2.4 Transpiration (T) and evaporation (E) components

The transpiration (T) and evaporation (E) components are shown in Table 4.6. The transpiration components were obtained from the mulched treatments (BPM) while the

Table 4.6 Transpiration (T) and evaporation (E) components (mm)

			Initial stage			Development stage			Mid-Season stage				Late-Season stage		
			DAYS AFTER PLANTING												
Treatment			**1-5**	**6-14**	**15-21**	**22-28**	**29-35**	**36-42**	**43-49**	**50-59**	**60-63**	**64-70**	**71-79**	**80-90**	**Total**
	E	I_{100}	11.4	19.8	25.4	18.7	17.6	17.5	17.5	17.3	16.9	10.7	13.7	14.9	**201.3**
		I_{75}	10.7	20.4	20.4	18.6	15.3	15.0	14.9	14.8	12.4	12.7	11.6	12.3	**179.1**
		I_{50}	10.8	20.2	16.9	15.2	12.3	12.3	12.3	12.2	10.6	9.8	10.2	10.5	**153.3**
V_1															
	T	I_{100}	10.9	20.8	18.9	15.2	18.4	19.7	20.2	30.3	13.5	19.9	18.7	18.2	**224.7**
		I_{75}	10.8	20.9	18.5	15.0	16.3	18.8	20.6	31.2	13.8	19.7	18.5	16.0	**220.2**
		I_{50}	11.2	20.9	17.3	14.9	14.0	14.4	15.2	25.1	12.2	15.6	13.4	13.5	**187.6**
	E	I_{100}	11.4	19.8	25.4	18.7	17.6	17.5	17.5	17.3	16.9	10.7	13.7	14.9	**201.3**
		I_{75}	10.7	20.4	20.4	18.6	15.3	15.0	14.9	14.8	12.4	12.7	11.6	12.3	**179.1**
		I_{50}	10.8	20.2	16.9	15.2	12.3	12.3	12.3	12.2	10.6	9.8	10.2	10.5	**153.3**
V_2															
	T	I_{100}	11.2	20.9	17.3	15.4	18.1	19.4	19.7	29.1	12.7	20.9	18.6	18.0	**221.3**
		I_{75}	11.4	20.3	18.4	15.2	16.2	17.9	19.5	29.0	12.8	20.7	18.5	16.1	**216.0**
		I_{50}	11.2	20.6	17.6	15.3	15.8	15.8	15.6	25.1	11.3	15.8	13.6	13.6	**191.3**

evaporation components were computed from the uncropped lysimeters. The total E ranged from 153.3 to 201.3 mm with the least occurring at I_{50} and the highest at I_{100} across the irrigation regime. The deficit irrigation and mulching were imposed on the treatments at 15 DAP until harvest. The E of I_{100} treatment achieves its peak of 25.4 mm at the initial stage and continually decreases along the growth stages until the late season stage. This is because when the crop is small, water is predominately lost by soil evaporation but once the crop is well developed and completely covers the soil, transpiration becomes the main process (Richard *et al*., 1998). It would be noticed that the E also decreases as the deficit irrigation increases.

The T component however, shows an inverse relationship with the E component. While the E component decreases along the crop growth stages, the T component increases. This was as a result of growth increase in the crop and plant foliage therefore leading to more water losses. The trend of the T component also indicates that it decreases along the irrigation regimes as the deficit irrigation increases. The total T component was higher than the total E component by 15% in both SAMPEA7 and SAMPEA9. This implies that water lost through transpiration was 15% higher than that lost from evaporation.

4.3 Irrigation Water Use Efficiency (IWUE)

Table 4.7 shows the irrigation water use efficiency (IWUE) of cowpea SAMPEA7 and SAMPEA9. The IWUE ranged from 1.52 kg/ha-mm to 2.77 kg/ha-mm and 1.06 kg/ha-mm to 2.30 kg/ha-mm for SAMPEA7 and SAMPEA9 respectively. 75% weekly ETo with BPM gave the highest IWUE in SAMPEA7 and 50% weekly ETo with BPM gave the highest IWUE in SAMEA9. This result confirms that limiting soil evaporation with mulches is a key action to save irrigation water and to improve the IWUE.

Table 4.7 Irrigation water use efficiency for cowpea SAMPEA7 and SAMPEA9

	Treatments		IWUE kg/ha-mm
V1	**NM**	I_{100}	1.53
		I_{75}	1.29
		I_{50}	1.06
	BPM	I_{100}	2.06
		I_{75}	1.84
		I_{50}	2.30
V2	**NM**	I_{100}	1.90
		I_{75}	2.12
		I_{50}	1.52
	BPM	I_{100}	2.36
		I_{75}	2.77
		I_{50}	1.98

Furthermore, the increase in IWUE due to black polythene mulching occurred from better moisture utilization by checking evaporation loss and fall of soil temperature during winter and lesser competition of weeds. Similar results were also reported by Saifullah *et al*., (1996) and Pessala (1994) in tomato, cabbage and kohlrabi, respectively.

4.4 Crop Water Use Efficiency (CWUE)

Table 4.8 shows the CWUE for both SAMPEA7 and SAMPEA9 cowpea varieties. It was deduced from Table 4.8 that the average water use efficiency ranged from 2.18 kg/ha-mm to 5.82 kg/ha-mm for SAMPEA7 and 1.45 kg/ha-mm to 5.01kg/ha-mm for SAMPEA9, with the highest values in the range occurring at 100% weekly ETo and BPM treatments. The highest CUWE obtained from this study were higher than CWUE of 1.15 kg/ha- mm obtained by Binny *et al*., (2016) for cowpea, under sprinkler irrigation.

Table 4.8 Crop water use efficiency of cowpea for SAMPEA7 and SAMPEA9

	Treatments		CWUE kg/ha-mm
V1	**NM**	I_{100}	2.49
		I_{75}	1.98
		I_{50}	1.45
	BPM	I_{100}	5.01
		I_{75}	3.34
		I_{50}	3.37
V2	**NM**	I_{100}	3.29
		I_{75}	3.27
		I_{50}	2.18
	BPM	I_{100}	5.82
		I_{75}	5.26
		I_{50}	2.76

Among the two cowpea varieties, the CWUE for SAMPEA7 was higher than the CWUE for SAMPEA9 by about 16% at 100% weekly ETo. The highest CWUE values produced by SAMPEA7 according to Blum (2005), may be probably due to cowpea SAMPEA7 ability to reduce their crop water use, which is reflected in higher water use efficiency, and is generally achieved by plant traits (for example, small plant size, small leaf area, reduced growth, etc.) and environmental responses that reduce yield potential. Considering the trend along irrigation levels indicated that the CWUE decreases with increase in deficit irrigation. The increased CWUE at 100% weekly ETo was mainly due to adequate soil moisture available to the growth stages of crop and increased nutrients uptake throughout the crop growth stages since both the inputs exerted beneficial effect on yield contributing factors. The observed results are inconformity with the findings of

Singh *et al*., (2006) and Abu and Malgwi, (2012). The lower CWUE were ascribed to reduction in grain yield under limited irrigations (50% weekly ETo) and NM.

4.5 Biomass and Grain Yield – Seasonal Crop Water Use

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

$$Biomass\ yield\ (BY) = 1.685 + 0.004ETc \quad (4.1)$$

$$Grain\ yield\ (GY) = -0.339 + 0.003ETc \quad (4.2)$$

From figure 4.1, it reveals that an evapotranspiration threshold of 146 mm is required before grain yield initiation. Water use also had a positive correlation with the grain yield.

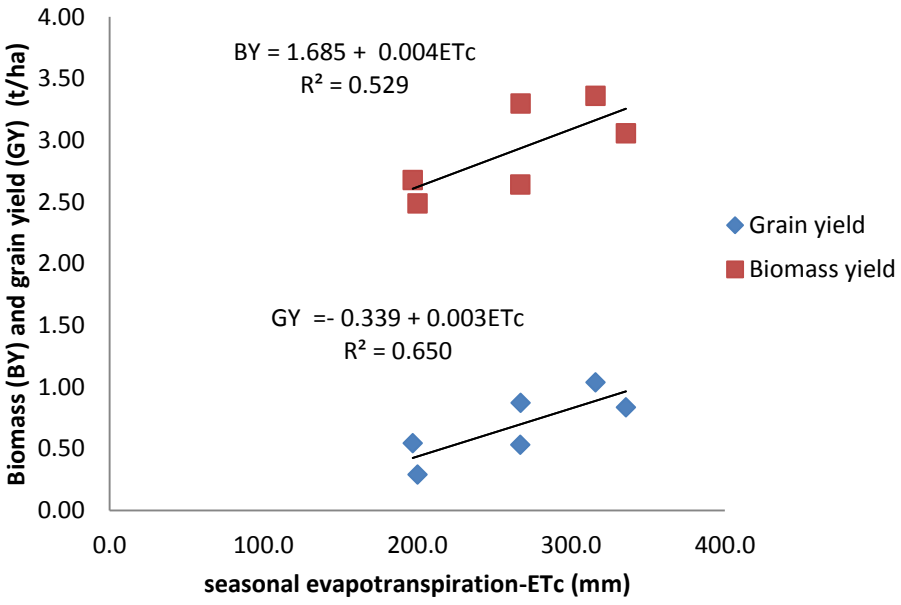


Figure 4.1 Biomass, grain yield and seasonal crop water use relationship for No mulch.

These relationships gave a regression coefficient (r^2) which shows that, about 50% of total biomass yield and 60% grain yield of the NM treatments were due to limited soil water as a result of regulated deficit irrigation by I_{75} and I_{50} treatments. This effect caused reduction in the biomass yield and grain yield of SAMPEA7 and SAMPEA9 cowpea varieties. Seed yield variation is related to the amount of moisture available to the crop; in the late season cropping period, declining status of stored soil water from irrigation and increasing intensities of stressful situations had profound effect on cowpea biomass and seed yields. Pressman *et al*., (2002) also attributed low crop yield to extreme weather condition enhanced dehydration of pollen and poor pollination and embryo abortion.

Figure 4.2 is the biomass yield and grain yield of black polyethylene mulch (BPM) plotted against the seasonal evapotranspiration.

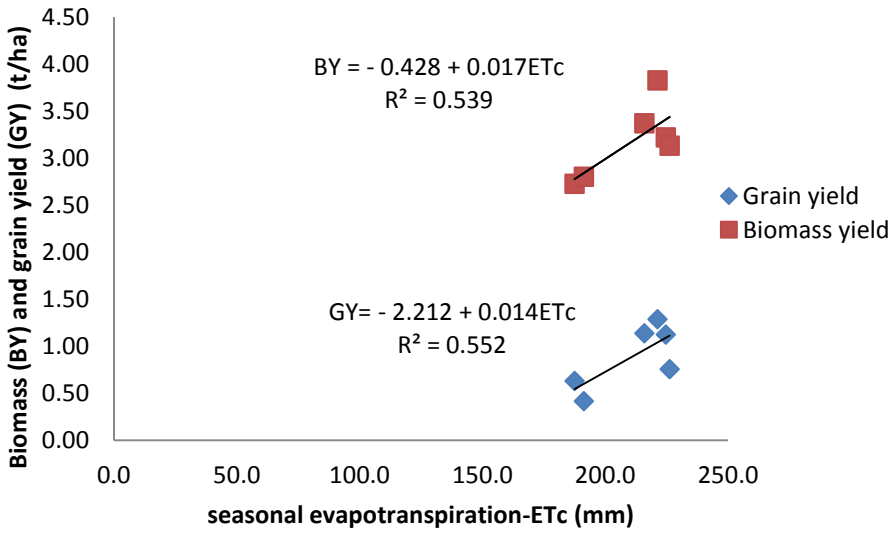


Figure 4.2 Biomass, grain yield and seasonal crop water use relationship for BPM mulch

The relationship gave the linear equation below;

$$Biomass\ yield\ (BY) = -0.428 + 0.017ETc \quad (4.3)$$

$$Grain\ yield\ (GY) = -2.212 + 0.014ETc \quad (4.4)$$

The seasonal evapotranspiration ranged from 187 mm to 225 mm and the grain yield ranged from 0.42 t/ha to 1.29 t/ha. The biomass yield and grain yield also show a positive correlation with the crop water use under the BPM treatments. They gave a correlation (r^2) value of 50% and 60% for the biomass and grain yield respectively. This was because the use of black polyethylene mulch (BPM) improved soil water storage in all the growth stages of the cowpea varieties, resulting in higher yields compared to the no mulch (NM) treatments.

4.6 Yield Response Factor

Table 4.9 shows the relative decreases in seasonal crop water use and grain yield. The computation of the relative yield decrease was done with reference to the fully irrigated treatment in order to be consistent.

Table 4.9 Relative yield and relative seasonal crop water use of cowpea crop for SAMPEA's 7 and 9.

Varieties	Treatments	Relative SCWU deficit	Relative decreasing yield
	V_1,I_{100},NM	0.00	0.00
	V_1,I_{75},NM	0.20	0.21
SAMPEA 9	V_1,I_{50},NM	0.40	0.51
	V_1,I_{100},BPM	0.00	0.00
	V_1,I_{75},BPM	0.33	0.32
	V_1,I_{50}, BPM	0.39	0.43
	V_2,I_{100}, NM	0.00	0.00
	V_2,I_{75}, NM	0.15	0.16
SAMPEA 7	V_2,I_{50}, NM	0.38	0.47
	V_2,I_{100}, BPM	0.00	0.00
	V_2,I_{75}, BPM	0.33	0.31
	V_2,I_{50}, BPM	0.40	0.47

The relative yield decrease ($1 - \frac{Ya}{Ym}$) and relative seasonal crop water use (SCWU) – $\left(1 - \frac{ETa}{ETm}\right)$ deficit were noticed to increase with increase in irrigation deficit in the mulched and or no-mulch practices. It may be noticed from Table 4.9, that relative decreases in seasonal crop water use of the I_{75} treatments were only between 12 and 26%, while the relative yield decreases were also between 11 and 22% for SAMPEA7 treatments. The relative decreases in SCWU of the I_{50} treatments ranged between 30 and 31% and relative yield loss of 33%.

It was observed that the I_{50} treatments had no much difference in SCWU and yield losses when compared with the NM and BPM. While for SAMPEA9 treatments, the relative decreases in SCWU of the I_{75} treatments were between 15 and 25%, and the relative yield decreases were between 14 and 21%. The relative decrease in SCWU of the I_{50} treatments was approximately 30% and relative yield loss of between 29 and 35%. Figures 4.3 and 4.4 show the yield response factors (Ky) for NM and BPM treatments, respectively, obtained by plotting the pooled data of the relative yields and relative seasonal crop water use. The Ky values were obtained as 1.22 and 1.10 for the NM and BPM, respectively.

The Ky values obtained from this study closely agree with Doorenbos and Kassam (1979) which gave seasonal Ky value of cowpeas as 1.15. The coefficient of determination (r^2) for the NM was 0.991 and 0.977 for BPM treatments. Before implementing a deficit irrigation programme, it is necessary to know crop yield responses to water stress, either during defined growth stages or throughout the whole season (Kirda and Kanber, 1999).

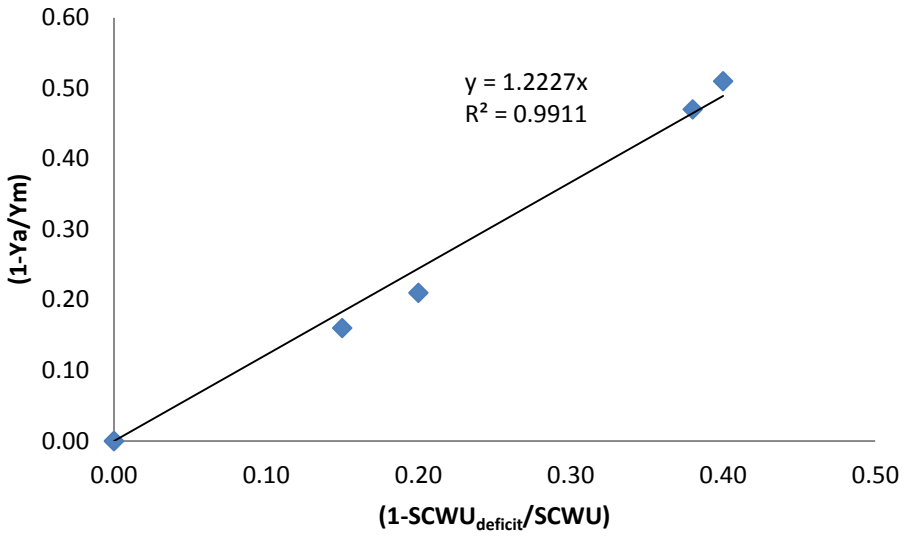


Figure 4.3 Yield response factor (Ky) of the no-mulch treatment.

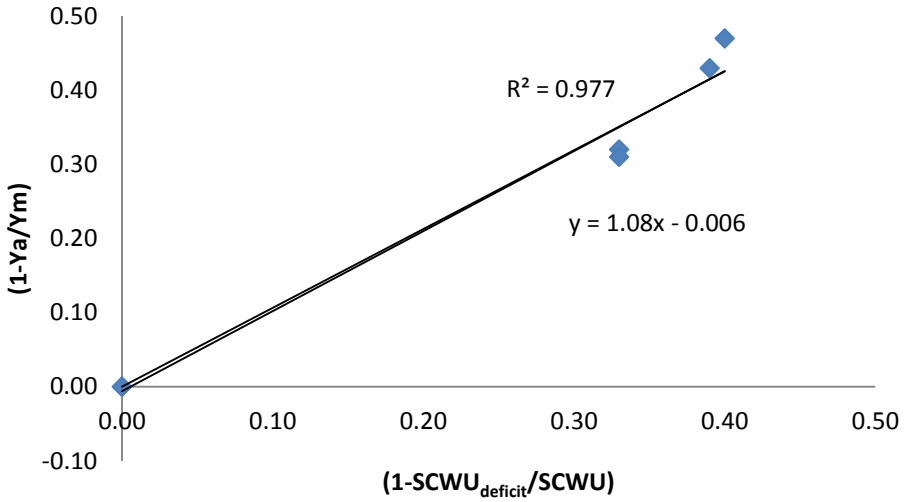


Figure 4.4 Yield response factor (Ky) of the black polyethylene mulch treatment.

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

1.0. The results of this study show that with or without mulch, the yield decreases of the cowpea crop were proportionally greater with increase in evapotranspiration deficit. It is however noticed that the Ky value of the no-mulch treatment was higher than the mulched treatment by about 10%. This implies that the proportional decrease in yield under the no mulch condition was much higher than the mulched condition. It also suggests that mulching helped to cushion the impact of the deficit irrigation on yield. Among the two cowpea varieties, SAMPEA7 cushioned the relative decrease in yield as a result of water deficit more than SAMPEA9. This further confirms that SAMPEA7 is more tolerant to water stress than SAMPEA9.

4.7 Single Crop Coefficient (Kc) for Irrigated Cowpea under Full Irrigation Conditions.

Table 4.10 (a and b) show the crop coefficient values for the growth stages of the two cowpea varieties for 2011 irrigation season.

Table 4.10a The average Kc values for SAMPEA7 variety developed at the end of the study

		GROWTH STAGES			
Treatment		**Initial (0-21) DAP**	**Development (22-42) DAP**	**Mid-season (43-70) DAP**	**Late-season (71-90) DAP**
		Kc of NM treatment			
	I_{100}	0.34	0.59	0.64	0.42
		$Kc_{deficit}$ of NM treatment			
NM	I_{75}	0.34	0.48	0.52	0.34
	I_{50}	0.34	0.34	0.34	0.23
V_2					
		Kc of BPM treatment			
	I_{100}	0.34	0.37	0.40	0.31
BPM		**$Kc_{deficit}$ of BPM**			
	I_{75}	0.34	0.35	0.39	0.30
	I_{50}	0.33	0.33	0.32	0.24

Table 4.10b The average Kc values for SAMPEA9 variety developed at the end of the study

Treatment			GROWTH STAGES Initial (0-21)	Development (22-42)DAP	Mid-season (43-70) DAP	Late-season (71-90)DAP
			Kc of NM treatment			
		I_{100}	0.34	0.63	0.73	0.36
			$Kc_{deficit}$ of NM treatment			
	NM	I_{75}	0.35	0.46	0.53	0.34
		I_{50}	0.33	0.35	0.36	0.22
V_1			**Kc of BPM treatment**			
		I_{100}	0.34	0.38	0.40	0.32
			$Kc_{deficit}$ of BPM treatment			
	BPM	I_{75}	0.34	0.37	0.40	0.30
		I_{50}	0.33	0.31	0.33	0.23

The Kc of the fully irrigated treatments for SAMPEA7 NM treatments are 0.34 for the initial stage, range of 0.34 to 0.59 for the development stage, 0.34 to 0.64 for the mid-season stage and 0.23 to 0.42 for the late-season stage. The SAMPEA7 BPM treatments have a Kc range of 0.33 to 0.34 for the initial stage, 0.33 to 0.37 for the development stage, 0.32 to 0.40 for the mid-season stage and 0.24 to 0.31 for the late-season stage. While the Kc of the fully irrigated treatments for SAMPEA9 NM treatments ranged from 0.33 to 0.35 in the initial stage, 0.35 to 0.63 in the development stage, 0.36 to 0.73 in the mid-season stage and 0.22 to 0.36 in the late-season stage.

The SAMPEA9 BPM treatments have a Kc range of 0.33 to 0.34 for the initial stage, 0.31 to 0.38 for the development stage, 0.33 to 0.40 for the mid-season stage and 0.23 to 0.32 for the late-season stage. The least values observed in the ranges above were either the Kc at the beginning of the season (which may be taken as the $Kc_{initial}$) or the end of the season (which may be taken as Kc_{end}), while the highest values were the peak Kc

which may be taken as the Kc_{mid}. The Kc_{mid} values were recorded at the latter part of pods formation to earlier part of pods enlargement stages in both varieties. Declining Kc values during maturity stage might be due to reduced sensitivity of the stomata as leaves begin to senescence (Fraust, 1989). The Kc result show that the highest water requirement occur at flowering and pod formation (mid season) stage.

The mean Kc values of the no-mulch (NM) of I_{100} treatment for four growth stages of the crop: initial, development, mid-season and late-season stages were found to be 0.34, 0.59, 0.64, 0.42, respectively for SAMPEA7 and 0.34, 0.63, 0.73, 0.36, respectively for SAMPEA9. The mean Kc values for the four growth stages of the BPM of I_{100} treatment for SAMPEA7 were 0.34, 0.37, 0.40 and 0.31 for the initial, development, mid-season and late-season respectively, while for SAMPEA9 the values were obtained as 0.34, 0.38, 0.40 and 0.32, respectively.

The largest Kc value of 0.73 was recorded from SAMPEA9 at the mid season stage where it witnessed its peak water use, while the Kc value of 0.64 was recorded from SAMPEA7 as shown in Figure 4.5. Aboamera, (2010) also obtained a Kc of 0.67 for Cowpea at the mid Season stage under irrigation system. These Values were quite lower than Kc Value of 1.05 as recorded by Allen *et al*., (1998).

A comparison of the Kc values of the different management conditions showed that for SAMPEA7, the Kc values of the NM treatment were higher than the BPM treatment by about 22.2%, 22.5% and 9.3% for development, mid-season and late-season stages, respectively. While for SAMPEA9, the Kc values of the NM treatment were higher than the BPM treatment by about 26.1%, 37.3% and 1.4% for development, mid-season and late-season stages, respectively. These findings agrees with (Allen *et al*., 1998) which suggested that Kc values of horticultural crops at mid- and late-seasons under plastic

mulch may be less by 10 to 30% compared with no mulch condition, depending on the frequency of irrigation. The decrease, they said, is associated with reduction in soil evaporation.

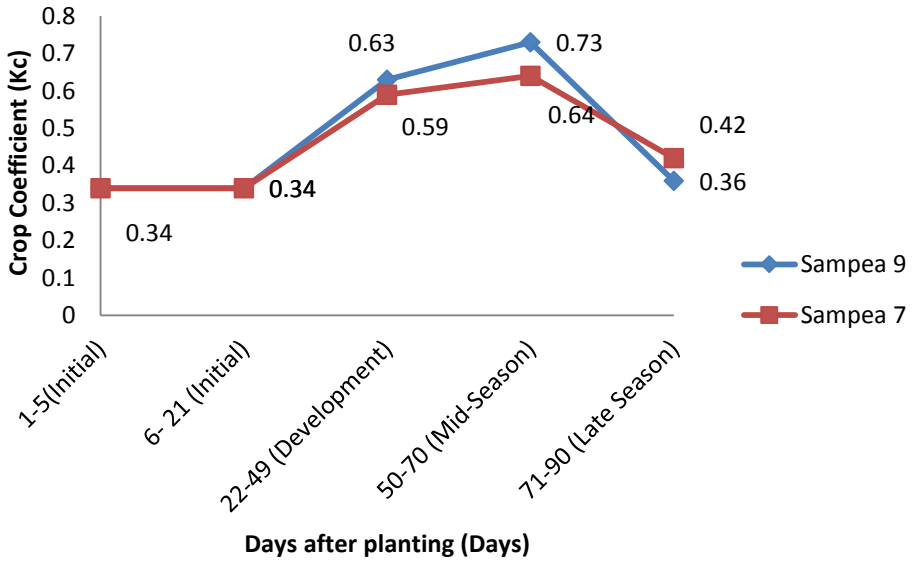


Figure 4.5 Kc curve for SAMPEA7 and SAMPEA9 for the NM Treatment.

4.8 Single Crop Coefficient (Kc) for Irrigated Cowpea under Deficit Irrigation Conditions

Table 4.10 (a and b) also shows the crop coefficient values under deficit irrigation conditions for the different management practices ($Kc_{deficit}$) and the two cowpea varieties. It can be noticed that crop coefficients were affected by irrigation deficits, as the values decreases with increase in deficit irrigation. A comparison of Kc (fully irrigated treatments) and $Kc_{deficit}$ showed that the mean values of Kc were higher than $Kc_{deficit}$ for SAMPEA7 by about 8.7% and 16% for the I_{75} and I_{50} NM treatments and 1.4 and 4.2% for the I_{75} and I_{50} BPM treatments. The peak Kc values of the respective mulch management conditions were observed to be higher than the peak Kc deficit values by about 1.3 – 21%. Whereas for SAMPEA9, the mean values of Kc were higher than

$Kc_{deficit}$ by about 11% and 18% for the I_{75} and I_{50} NM treatments and 0.0 and 4.4% for the I_{75} and I_{50} BPM treatments. The peak Kc values of the respective mulch management conditions were noticed to be higher than the peak Kc deficit values by about 0.0 – 25%. This suggests that under deficit irrigation, peak crop coefficient values may be reduced by up to 25%.

The mean $Kc_{deficit}$ values of the no-mulch treatment for four growth stages of SAMPEA7 crop as shown in Table 4.10a were; 0.34, 0.41, 0.43 and 0.29 for initial, development, mid-season and late-season respectively and 0.34, 0.34, 0.36 and 0.27 for BPM treatments. While the mean $Kc_{deficit}$ values of the no-mulch treatment for four growth stages of SAMPEA9 crop as shown in Table 4.10b were; 0.34, 0.41, 0.45 and 0.28 for initial, development, mid-season and late-season respectively and 0.34, 0.35, 0.37, and 0.27 for BPM treatments. It was noticed that there was no much differences among the mean Kc_{defict} values of mulched and no-mulch treatments, which implies that mulching did not necessarily influence crop coefficient under deficit irrigation.

4.9 Direct Evaporation (Ke)

Table 4.11 shows the direct evaporation (Ke) values obtained from the three bare micro-lysimeters installed on the field.

Table 4.11 Direct evaporation (Ke)

	Stages of water application			
Ke	**Initial**	**Development**	**Mid-season**	**Late-season**
	0.33	0.38	0.33	0.24

It would be observed that the mean Kc values of SAMPEA7 variety (from table 4.10a) for the four growth stages are higher than the Ke values by percentage difference of

about 1.5, 21.6, 32 and 27.3% at the initial, development, mid-season and late-season stages respectively for the NM treatments and 1.5, 0.0, 9.6 and 12.7% for the BPM treatments. This confirms that the use of plastic mulch helps to conserve water by reducing evaporation from soil surface, controlling weed growth and reducing soil compaction. According to Ramakrishna *et al*., (2006), evaporation from the soil accounts for 25-50% of the total quantity of water used. The Ke also vary with the frequency of precipitation or irrigation (Jagtap and Jones, 1989). Following the crop emergence, transpiration is limited and soil evaporation constitutes the major part of ET, especially following an irrigation or rainfall.

4.10 Dual Crop Coefficient (Kcb+Ke)

Table 4.12 (a and b) shows the dual crop coefficient (Kcb+Ke) values computed for cowpea SAMPEA's 7 and 9. At the initial growth stage, Ke is almost equivalent to Kc for the NM treatments; this implies that all the water losses incurred at the initial growth stage of the crop was as a result of evaporation effect (Ke). As the crop matures into the development stage and bearing its leaves, Ke decreases steadily while Kcb increases.

Table 4.12a The mean dual crop coefficient (Kcb+Ke) values computed for cowpea SAMPEA7

Treatments			Kcb_{ini}	Kcb_{mid}	Kcb_{end}	Ke_{ini}	Ke_{mid}	Ke_{end}
	NM	I_{100}	0.19	0.40	0.31	0.35	0.33	0.24
		I_{75}	0.18	0.39	0.30	0.27	0.25	0.18
		I_{50}	0.17	0.32	0.24	0.18	0.18	0.12
V2								
	BPM	I_{100}	0.36	0.40	0.31	0.00	0.00	0.00
		I_{75}	0.35	0.39	0.30	0.00	0.00	0.00
		I_{50}	0.33	0.32	0.24	0.00	0.00	0.00

Table 4.12b The mean dual crop coefficient (Kcb+Ke) values computed for cowpea SAMPEA9

Treatments			Kcb_{ini}	Kcb_{mid}	Kcb_{end}	Ke_{ini}	Ke_{mid}	Ke_{end}
V1	NM	I_{100}	0.20	0.40	0.32	0.35	0.33	0.24
		I_{75}	0.20	0.41	0.30	0.27	0.25	0.18
		I_{50}	0.16	0.33	0.23	0.18	0.18	0.12
	BPM	I_{100}	0.36	0.40	0.32	0.00	0.00	0.00
		I_{75}	0.37	0.41	0.30	0.00	0.00	0.00
		I_{50}	0.32	0.33	0.23	0.00	0.00	0.00

Kcb increases rapidly towards the mid-Season stage as a result of the full effect of transpiration. Towards the late season stage when the leaves began to wither, Ke and Kcb decreases. The Kcb of the fully irrigated treatments for SAMPEA7 ranged from 0.19 to 0.40, 0.31 to 0.40 for the NM and BPM treatments, respectively. While the Kcb of the fully irrigated treatments for SAMPEA9 ranged from 0.20 to 0.40, 0.32 to 0.40 for the NM and BPM treatments, respectively. The Kcb_{mid} value of 0.40 obtained under the no-mulch condition was lower than the Kcb_{mid} of 1.00 reported by (Allen *et al*., 1998). While the Kcb_{end} value of 0.31 closely agree with the Kcb_{end} of the range between 0.25-0.55 as obtained by (Allen *et al*., 1998). Some studies, carried out in different regions of the world, have compared the results of Kcb using the approach described by Allen *et al*., (1998) with those resulting from other methodologies, such as the sap flow method.

From this comparison, results that some limitations should be expected in the application of the dual crop coefficient FAO 56 approach. Dragoni *et al*., (2004), measured actual transpiration in an apple orchard in cool, humid climate (New York, USA) and showed a significant overestimation (over 15%) of basal crop coefficients by the FAO 56 method compared to measurements (sap flow). Similarly, Benli *et al*., (2006) and Paço *et al*., (2006) reported basal crop coefficients higher with respect to those tabulated by (Allen *et al*., 1998). Er-Raki *et al*., 2009 concluded that Kcb value of 1.00 reported by FAO 56

bulletin cannot be utilized in all climatic regions of the world. Furthermore, the basal crop coefficient is affected by variability due to climate conditions and crop management.

A comparison of Kcb (fully irrigated treatments) and $Kcb_{deficit}$ showed that the mean values of Kcb were higher than $Kcb_{deficit}$ for SAMPEA7 by about 3% and 23% for the I_{75} and I_{50} NM treatments and 3% and 20% for the I_{75} and I_{50} BPM treatments. The peak Kcb values of the respective mulch management conditions were noticed to be higher than the peak $Kcb_{deficit}$ values by about 8-11% in both varieties, which suggest that under deficit irrigation, peak basal crop coefficient values may be reduced by up to 11%. The mean $Kcb_{deficit}$ values of the no-mulch treatment for the initial, mid-season and end-season stages (taken as Kcb_{ini}, Kcb_{mid} and Kcb_{end} respectively) were found to be 0.18, 0.36 and 0.27 respectively for SAMPEA7 and 0.18, 0.37 and 0.27, respectively for SAMPEA9. The mean $Kcb_{deficit}$ values of the treatment mulched with black polyethelene were also found to be 0.34, 0.36 and 0.27, respectively for SAMPEA7 and 0.34, 0.37 and 0.27, respectively for SAMPEA9.

Table 12 (a and b) revealed that there were differences among the mean $Kcb_{deficit}$ values of mulched and no-mulch treatments at the Kcb_{ini} only. The Kcb_{mid} and Kcb_{end} did not show any difference among the two cowpea varieties which implies that mulching influenced basal crop coefficient under deficit irrigation only at the initial stage. Wen *et al*., (2017) reported that basal crop coefficients for initial, mid and late stage were separately 0.10, 0.75 and 0.30 for spring wheat without mulch and 0.15, 0.90 and 0.70 for spring wheat with mulch. The basal crop coefficient in mid stage was relatively lower in this research compared to the recommended value in FAO-56 due to the

difference in variety, district and climate. The larger basal crop coefficient for plastic mulch led to a higher transpiration of spring wheat in the whole stage, which adjusted the structure of evapotranspiration efficiently.

The evaporation component (Ke) of the fully irrigated treatment ranged from 0.24-0.35 in both SAMPEA7 and 9, for the NM treatments. The least Ke value occurred at the late season stage referred to as Ke_{late}, while the peak Ke value of 0.35 was recorded at the initial stage referred to as Ke_{ini}. It was observed that the Ke values decreases with increase in deficit irrigation and also decreases along the plant growth stages across all treatments. It would be noticed also that the Ke components of the BPM treatments were zero (0.00) for both varieties, because mulching reduces evaporation from the soil surface. These findings agree with (Allen *et al*., 1998) which suggested that evaporation occurs predominantly from the exposed soil fraction. Hence, evaporation is restricted at any moment by the energy available at the exposed soil fraction.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary

Field experiment was conducted in 2011 dry season at the Institute for Agricultural Research (IAR) Irrigation farm in Samaru, Zaria and studied the water balance components of two IAR cowpea varieties (SAMPEA7 and 9), the effects of deficit irrigation and mulch levels on yield, crop coefficient, crop and irrigation water use efficiency and yield response factor using the micro-lysimeter. The micro-lysimeters were set up using locally available materials. The set up consisted of a lysimeter tank filled with soil where the cowpea crop was grown, under limited and unlimited water supply conditions. The treatments were replicated three times and laid in a Group Balanced Block in Split-plot Design.

The cowpea yields were found to vary from 0.29 t/ha to 1.29 t/ha. The maximum cowpea yield of 1.29 t/ha was obtained when the crop was irrigated at 100% WRETo using black polyethylene as mulch material, while the lowest crop yield of 0.29 t/ha was obtained when the crop was irrigated at 50% deficit irrigation level, and without mulch. The Crop water use was found to vary from 187.60 mm/season (V_2,I_{50},BPM) to 335.60 mm/season (V_1,I_{100},NM). It was deduced that SAMPEA9 recorded the highest water use than SAMPEA7. The irrigation water use varies from 275 mm/season to 545 mm/season.

The Kc values range from 0.32 to 0.63 for SAMPEA7 variety and 0.32 to 0.72 for SAMPEA9 variety. The highest crop water use efficiency and irrigation water use efficiency was from SAMPEA7 variety with 3.76 kg/ha-mm and 2.11 kg/ha-mm, respectively. However, the highest IWUE was at I_{75} for the irrigation treatment means with 2.01 kg/ha-mm. The mulched treatment means of the BPM with 4.16 kg/ha-mm

and 2.14 kg/ha-mm CWUE and IWUE, respectively were higher than the NM treatment means. The Ky values obtained were 1.22 for the NM treatments and 1.10 for the BPM treatments.

5.2 Conclusion

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

1. The highest yield of 1.29 t/ha for cowpea SAMPEA7 variety was obtained using BPM and the least was 0.42 t/ha with 100% and 50% WRETo, respectively. The highest yield of 1.12 t/ha for cowpea SAMPEA9 variety was obtained using BPM and the least was 0.29 t/ha with 100% and 50% WRETo, respectively. Also, the highest crop water use (CWU) for cowpea SAMPEA7 was the NM with 315.8 mm and the least was the BPM with 191.3 mm of 100% and 50% WRETo, respectively. While the highest CWU for cowpea SAMPEA9 was the NM with 335.6 mm and the least was the BPM with 187.6 mm of 100% and 50% WRETo, respectively.

2. The crop coefficient curve for both SAMPEA7 and SAMPEA9 were developed at the end of the study. The average Kc values of SAMPEA7 variety for the full irrigation (I_{100}) and NM were, 0.34, 0.59, 0.64 and 0.42 for the initial, development, mid-season and late-season stages, respectively. The BPM Kc values were 0.34, 0.37, 0.40 and 0.31 for the initial, development, mid-season and late-season stages, respectively. While the average Kc values of SAMPEA9 variety for the full irrigation (I_{100}) and NM were 0.34, 0.63, 0.73 and 0.36 for the initial, development, mid-season and late-season stages, respectively. The BPM Kc values were 0.34, 0.38, 0.40 and 0.32 for the initial, development, mid-season and late-season stages, respectively.

3. The yield-water use relationship for the cowpea varieties were established with the correlation values (r^2) of 0.53 and 0.65 of total biomass and grain yields, respectively for the NM treatments, 0.54 and 0.55 of the total biomass and grain yields, respectively for

the BPM treatments. A linear relationship was found between the yield and seasonal crop water use. It reveals that an evapotranspiration threshold of 146 mm is required before grain yield initiation. Water use also had a positive correlation with the grain yield. The yield response factor (Ky) were obtained as 1.22 and 1.10 for the NM and BPM respectively.

5.3 Recommendations

Cowpea SAMPEA7 recorded much higher yield of about 55% of the total yield and relatively resistant to water stress. It is thus recommended for areas with relatively low rainfall events and most suitable for irrigation practices. The crop should be irrigated with 75% WRETo, using the BPM at 7 days irrigation interval.

The following recommendations are presented for consideration of future work relating to different irrigation levels and mulch practice.

1. Different crops and other improved varieties of cowpea should be used under different irrigation levels and different mulch materials to obtain the best combination of mulch and irrigation level without adverse effect on the crop yield.

2. The aspect of soil temperature as affected by the black polyethylene mulch should be incorporated in the calculation of crop water use.

REFERENCES

Abbas, M., Negar, E., and Afsaneh, A. B. (2017). Impact of deficit irrigation on yield components, water use efficiency and yield response factor of cowpea in Khorramabad Iran. *Journal of Engineering and Applied Sciences* 12(9):2471-2479.

Aboamera, M.A. (2010). Response of cowpea to water deficit under semi-portable sprinkler irrigation system. Misr. *Journal of Agric. Engineering*; 27 (1) : 170-190.

Abu, T., and Malgwi, W. B. (2012). Effects of irrigation regime and frequency on soil physical quality, water use efficiency, water productivity and economic returns of paddy rice. *ARPN Journal of Agricultural and Biological Science*, 7(2): 86- 99

Acosta-Gallegos, J.A and Adams M.W (1991). Plant traits and yield stability of dry bean (*Phaseolus Vulgaris*) cultivars under drought stress. *Journal of Agric Science* 117:213-219.

Adekalu, K.O. and Okunade, D.A. (2006). Effect of irrigation amount and tillage system on yield and water use efficiency of cowpea. Communication in Soil Sci. and Plant Analysis, 37, 225-228.

Agricultural Research Council of Nigeria (2017). *Crop-based technologies*. Institute for Agricultural Research *(I-A-R).* Retrieved June23, 2017 from http://arcnigeria.org/arcn/2016/07/23/institute-for-agricultural- research-iar/.

Allen, R.G., Pereira, L.S., Raes, D., and Smith, M. (1998). Crop Evapotranspiration: Guideline for Computing Crop Water Requirements. FAO Irrig. *Drainage Paper* 56:300

Allen, R.G., Pereira, L.S., Raes, D., Smith, M., and Wright, J.L. (2005). FAO-56 dual crop coefficient method for estimating evaporation from soil and application extensions. *Journal of Irrigation and Drainage Engineering* (ASCE) 131, 2–13.

Augustine, A. J. (2011). *Response of Cowpea (vigna unguiculata L. walp) varieties to inter-row and intra-row spacings*. (Unpublished master's thesis). Dept of Agronomy, Faculty of Agric A.B.U Zaria, pp 11, 14-16.

Batchelor, C. (1992). Technical Report, Institute of hydrology. U.K

Bekele, S., and Tilahun, K. (2007). Regulated deficit irrigation scheduling of onion in semi arid region of Ethiopia. *Agric Water Management* 89, 148-152.

Benli, B., Kodal, S., Ilbeyi, A., and Ustun, H. (2006). Determination of evapotranspiration and basal crop coefficient of alfalfa with a weighing lysimeter. *Agric.Water. Management* 81: 358- 370.

Binny, D., Veer Singh, H. S., Kushwaha, A. S., and Shri, Ram (2016). Water use efficiency and yield of cowpea and nutrient loss in lysimeter experiment under varying water table depth, irrigation schedules and irrigation method *AARC Journal of Agri., 14(2): 46-55 (2016) doi: http://dx.doi.org/10.3329/sja.v14i2.31244*.

Blum, A. (2005). Drought resistance, water-use efficiency, and yield potential-are they compatible, dissonant, or mutually exclusive? *Aus. J. Agric. Res.,* 56: 1159–1168.

Boast, C.W., and Robertson, T.M. (1982). Soil science SOC. *AM Journal*. 46:689.

Craciun, I., and Craciun, M. (1999). *Water and Nitrogen use efficiency under limited water supply for Maize to Increase land productivity*. Kluwer Academic publishers, the Netherlands, pp 87-94.

Dadson, R.B., Hashem, F.M., Javaid, I., Joshi, J., Allen, A.L., and Devine, T.E. (2003). Effect of water stress on the yield of cowpea (Vigna ungiculata (L.) walp) Genotypes in the Delmarva region of the United States. *Journal of Agronomy and crop science*.Vol 191, Issue 3, pp 210-217.

Davis, D.W., Oelke, E.A., Oplinger, E.S., Doll, J.D., Hanson, C.V., and Putnam, D.H. (1991). Alternative field crops manual, University of Wisconsin-Madison. Pp. 3-8.

Doorenbos, J., and Kassam, A.H. (1979). Yield response to water. U.N. Food and Agriculture Organization Irrigation and Drainage Paper No. 33, Rome.pp. 108-110.

Doorenbos, J., and Pruitt, W.O. (1984). Guidelines for predicting crop water requirements. FAO Irrigation and Drainage paper 24, Rome.pp. 144.

Dragoni, D., Lakso, A.N., and Piccioni, R.M. (2004). Transpiration of an apple orchard in a cool humid climate: measurement and modelling. Acta Horticolture, 664: 175–180.

Dudley, N.J., Howell, D.T., and Musgrave, W.J. (1971). Optimal intraseasonal irrigation Water allocation, *Water Resources. Research*., 7(5): 1051-1063.

Dugje, I.Y., Omoigui, L.O., Ekeleme, F., Kamara, A.Y., and Ajeigbe, H. (2009). *Farmers' Guide to Cowpea Production in West Africa*. IITA: Ibadan, Nigeria. 20.

English, M.J. (1990). Deficit irrigation. I: Analytical framework. *Journal. Am. Sot. Civil Engineering*., 116(lR3): 399-412.

English, M.J., Musick, J.T., and Murty, U.V. (1990). Deficit irrigation. In: Hoffman, G.J., Towell, T.A., and Solomon, K.H. eds. Management of farm irrigation systems, st. Joseph, Michigan, United states of America, ASAE.

Eric L.J., French, O.F., Bucks, D.A., and Harris, K. (1981). Consumptive use of water by major crops in the South-Western United States . *United States Department of Agriculture, conservation Research report no*. 29, pp1-15.

Er-Raki, S., Chehbouni, A., Guemouria, N., Ezzahar, J., Khabba, S., Boulet, G., and Hanich, L. (2009). Citrus orchard evapotranspiration: Comparison between eddy covariance measurements and the FAO-56 approach estimates. Plant Biosystems, 00(0): 1-8.

Faloye, O.T., and M. O, Alatise (2015). Effect of Varying Water Applications on Evapotran spiration and Yield of Cowpea under Sprinkler Irrigation System. *International Journal of Agriculture and Crop Sciences*. Vol., 8 (3), 307-319, 2015

FAO, (2002). Deficit irrigation practices. Water Report No. 22, Rome.

FAO, (2005). Cowpea production database for Nigeria, 1990-2004. Food and Agricultural Organisation. http://www.faostat.fao.org/.

Flenet, F., Bouniols, A., and Saraiva, C. (1996). Sunflower response to a range of soil moisture content. Euro *Journal of Agronomy* 5:161-167.

Fraust, M. (1989). Physiology of temperature zone fruit trees. Wiley, New York. Pp l52.

Gerson, A.M., Arruda, F.B., and Sakai, E. (2004) Crop coefficient for Irrigated beans derived using three reference evaporation methods. Agricultural and forest meterology; Brazil. pp.1-9.

Gholipoor, M. (2007). Potential effects of individual versus simultaneous climate change factors on growth and water use of chickpea. *International Journal of Plant Production*, Vol. 1, No. 2, pp: 189-204.

Granier, A., Bobay, V., Gash, J.H.C., Gelpe, J., Sangier, B., and Shuttleworth, W.J. (1990). Vapour flux density and transpiration rate comparisons in a stand of maritime pine (Pinus Pinaster Ait) in Les Lendes forest. *Agric. For Meteorol*. 51: 309 – 319.

Gregory P.J. (1991). Soil and plant factors affecting the estimation of water extraction bycrops . CSIRO; Wembley, Western Australia . Pp. 261-271.

Hall, A.E., and Patel, P.N. (1985). *Breeding for resistance to drought and heat*. In: Singh, S.R., Rachie, K.O. (Eds.), Cowpea Research, Production, and Utilization. Wiley, New York, pp. 137–151.

Harrold, L.L., and Dreilbelbis, F.R. (1967). Evaporation of Agricultural Hydrology by Monolith Lysimeter, USDA Tech; Bulletin No. 1179

Hashim, M. A., Siam, N., Al-Dosari, A., Al-Gaadi, K. A., Patil, V. C., Tola, E. H. M.,… Samdani, M. S. (2012). Determination of water requirement and crop waterproductivity of crops grown in the Makkah Region of Saudi Arabia. *Australian Journal of Basicand Applied Sciences*,6, 196–201

Hassan, M. J. (1996). *Effect of soil moisture management and nitrogen levels on growth and yield of garlic*. M.Sc Thesis, Department of Horticulture Bangladesh Agricultural University, Mymensingh Bangladash.

Hay, C.H., and Irmak, S. (2009). Actual and reference evaporative losses and surface coefficients of a maize field during nongrowing dormant periods. *Journal of Irrigation and Drainage Engineering* (ASCE) 135 (3), 313–322.

Hillyer, C.C., and Sayde, C. (2010). A web based advisory service for optimum irrigation management. Paper No. IRR10-9854. In: 5th National Decennial Irrigation Conference.ASABE and Irrigation Association, Phoenix, Arizona USA.

Howell, T.A., Cuenca, R.H., Solomon, K.H. (1990). Crop Yield Response. In: Management of Farm Irrigation Systems. ASAE, St. Joseph, MI. pp. 93-122.

Howell, T.A., Evett, R., Tolk, J.A., and Schneider, A.D. (2004). Evapotranspiration of full, deficit-irrigated, and dryland cotton on the Northern Texas High Plains. *Journal of Irrigation and Drainage Engineering* (ASCE) 130, 277–285.

Ibragimov, N., Evett, S.R., Esanbekov, Y., Kamilov, B.S., Mirzaev, L., Lamers, J.P.A. (2007). Water Use Efficiency for Irrigated Cotton in Uzbekistan under Drip and Furrow irrigation. *Agric Water Management* 90:112-120.

Inaizumi, H., Singh, B.B., Sanginga, P.C., Manyong, V.M., Adesina, A.A., and Tarawali, S. (1999). *Adoption and Impact of dry-season dual-purpose cowpea in the semiarid zone of Nigeria*. L.W Lambourn and Co; Carolyn House UK. Pp 3.

Jagtap, S.S., and Jones, J.W. (1989) Stability of crop coefficients under different climate and irrigation management practices. *Irrigation Science*, 10: 231-244.

Jensen, M.E., Burman, R.D., and Allen, R.G. (ed.) (1990). *Evapotranspiration and irrigation water requirements*. ASCE Manual 70.

Jiang, J., Zhang, Y., Wegehenkel, M., Yu, Q., and Xia, J. (2008). Estimation of soil water content and evapotranspiration from irrigated cropland on the North China Plain. *Journal of Soil Science and Plant Nutrition* 171, 751–761.

Jurriens, M., and Wester, P. (1994). Protective irrigation in India. 1994 Annual Report, International Institute for Land Reclamation and Improvement, Wagenmgen, The Netherlands.

Kadayifci, A., Tuylu, G.I., Ucar, Y., and Carmak, B. (2004). Effects of Mulch and Irrigation water amounts on lettuce's yield, evaporation, transpiration and soil evaporation in Isparta location, Turkey. *Journal of biological sciences* 4: (6) 751-755, 2004.

Kirda, C., and Kanber, R. (1999). Water, no longer a plentiful resource, should be used sparingly in irrigated agriculture. In: C. Kirda, P. Moutonnet, C. Hera & D.R. Nielsen, eds. *Crop yield response to deficit irrigation*, Dordrecht, The Netherlands, Kluwer Academic Publishers.

Koksal, H., Tari, A.F., Kanber, R., and Unlu, M. (2001). Water-yield relationships. General Directorate of Rural Services Main Project, Konya Turkey.

Korukcu, A., and Kanber, R. (1981). Water-yield relationships. Soil-Water Main Project 435-1, Tarsus Turkey.

Krishna, K.R. (2010). Agroecosystems of south India: Nutrient Dynamics, Ecology and productivity. Pp 385-389. www.brownwalker.com

Kwanchai, A.G., and Arturo, A.G. (Eds). (1983). *Statistical procedures for Agricultural Research*. (pp. 116-117). New York: John Wiley and Sons, inc.

Linda, B., and Clawson E. (2009). *Weighing Lysimeters Measure Crop Water Use*. Retrieved December 13, 2017 from www.lsuagcenter.com/ publications/agmag/archive/2009/winter/weighing-lysimeters-measure-crop-water-use.

Liu, Y., and Pereira, L.S. (2000). Validation of FAO methods for estimating crop coefficients. Transactions of the CSAE 16 (5), 26–30.

Liu, Y.J., and Luo, Y. (2010). A consolidated evaluation of the FAO-56 dual crop coefficient approach using the lysimeter data in the North China Plain. *Agricultural Water Management* 97, 31–40.

Liyanage, N., Goonasekera, K.G.A., and Koga, K. (1992). Water use, soil water relations and yield of cowpea under a minor irrigation tank. pp 4

López-Urrea, R., Montoro, A., González-Piqueras, J., López-Fuster, P., and Fereres, E. (2009). Water use of spring wheat to raise water productivity. *Agricultural Water Management* 96, 1305–1310.

Martin, D., Broclclin, J.van., and Wilmes, G. (1985). Operating rules for deficit irrigation management. Trans. ASAE, 32(4): 1207-1215.

Matthias, A.D., Salehi, R., and Warrick, A.W. (1986). *Agric water management*. 11:257

Mohamed, A.S. (2011). Estimating water consumptive use for some crops under stress conditions using neutron scattering method. Pp 34-35.

Moroke, T.S., Schwartz,R.C., Brown, K.W., and Juo,A.S.R. (2011). Crop water productivity of drylandcowpea, sorghum and sunflower under reduced tillage. *Soil and Tillage Research*, 112: 76-84.

Oiganji, E. (2010); *Yield and soil water balance response of onions under mulch and deficit irrigation*. Unpublished M.Sc Thesis, Dept. of Agricultural Engineering, ABU, Zaria, Nigeria.

Paço, T.A., Ferreira, M.I., and Conceição, N. (2006). Peach orchard evapotranspiration in a sandy soil: comparison between eddy covariance measurements and estimates by FAO 56 approach. *Agric.Water Management*. 85: 305-313.

Paola, Lazzara., and Rana, Gianfranco. (1999). *The crop coefficient (Kc) values of the major crops grown under Mediterranean climate*. CRA-Research Unit for Agricultural in Dry Environments, via C. Ulpiani, 5, 70125 Bari, Italy.

Pereira, L.S., Cai, L.G., and Hann, M.J. (2003). Farm water and soil management for improved water use in the North China Plain. Irrigation and Drainage 52 (4), 299–317.

Pessala, R. (1994). Influence of covering with fiber cloth and plastic on timing, yield and quality of kohlrabi. *Acta Hortic.*, 371: 291-295.

Plauborg, F., Andersen, M. N., Heidmann, T., and Olesen, J. E. (1996). MARKVAND: an irrigation scheduling system for use under limited irrigation capacity in a temperate humid climate. Irrigation theory and practice. Water reports 8. FAO-ICID-CIID, Rome. Pp. 177-184.

Pressman, E., Peet, M.M., and Pharr, D.M. (2002).The effect of heat stress on tomato pollen characteristics is associated with changes in carbohydrate concentration in the developing anthers. *Annals of Botany* vol. 90 pg. 631-636

Prichard, T., Hanson, B., Schwankl, L., verdegaal, P., and Smith, R., (2004). Deficit Irrigation of Quality wine grapes using micro-irrigation techniques. Publication of university of California Co-peration Extension, Department of Land, Air and Water resources, University of California, Davis, 5Pp.

Ramakrishna, A., Tam, H.M., Wani, S.P., and Long, T.D. (2006). Effect of mulch on soil temperature, moisture, weed infestation and yield of groundnut in northern Vietnam. *Field Crops Res.*, 95, 115–125.

Rana, G., and Katerji, N., (2000), Measurement and estimation of actual evapotranspiration in the filed under Mediterranean climate: a review, European *Journal Agronomy*, 13(2-3), 125-153.

Richard, G.A, Pereira, L.S., Raes, D., and Smith, M. (1998). Crop Evapotranspiration Guidelines for computing crop water requirements-FAO Irrigation and Drainage paper 56; Rome .pp.284.

Saifullah, M., Ahmed, S.U. and Rahman, M.H. (1996). Effect of mulching on the growth and yield of cabbage. *Prog. Agric.*, 7: 15-19.

Shaw, R.H (1959). Water use from plastic –covered and uncovered corn plots. *Agronomy. Journal*; 51: 172-173.

Shuttleworth, W.J. (1988). Evaporation from Amazonian rainforest. Proceedings of the royal society of London. Series B *Biological sciences* 233:pp321-346

Singh, R. J., Idnani, L. K., and Rai, R. K. (2006). Grain yield, water use efficiency, economics and soil moisture extraction pattern of summer green gram (*Vigna radiata* L.) as influenced by planting and irrigation methods, irrigation schedules and VAM inoculation. *Annals of Agricultural Research*, 27(3): 306-310

Smith, M., Kivumbi, D., and Heng, L. K. (2002). Use of FAO CROPWAT model in deficit irrigation studies. Deficit irrigation practice. Water report. No. 22. Food and Agriculture Organisation of the United Nations, Rome. Pp. 17-28.

Souza, M.S., Bizerra, F.M., and Teofilo, E.M. (2005). Crop coefficients for cowpea in the coastal region of the state of ceara (Brazil). *Irrigation Botucatu* 10 (3), 241 – 248 (in Portuguese with abstract in English).

Stegman, E.C., Musick, J.T., and Stewart, J.I. (1980). Irrigation water management In: Jensen M.E ed. *Design and operation of farm irrigation systems*. St. Joseph, Michigan, united states of America, ASAE.

Stewart, J.I., Hagan, R.M., and Pruitt, W.O. (1974). Functions to predict optimal irrigationprograms. *Journal. Am. Sot. Civil Engineering*., lOdIR2): 179- 199.

Stone, P. J., Wilson, D. R., Beid, J.B., and Gillespie, R.N. (2001). Water Deficit effects on sweet corn water use, radiation use efficiency, growth and yield. *Journal. Agri. Research* 52: 103-113.

Tarantino, E., and Spano, D. (2001). La valutazione dei fabbisogni irrigui, Rivista di Irrigazione e Drenaggio. 48 (4), 21–35 (in Italian).

Thomas, J.C., Brown, K.W., and Jordan, J.R. (1976). Stomatal response to leaf water potential as affected by preconditioning water stress in the field. *Journal of agronomy* 68:706-708.

Tim, Hess. (1996). Evapotranspiration estimates for water balance scheduling in the U.K. Irrigation news, 25.pp31-36.

Tolk, J.A., and Howell, T.A. (2001). Measured and simulated evapotranspiration of grain sorghum grown with full and limited irrigation in three high plains soils. Transactions of the ASAE 44 (6), 1553–1558.

Trimmer, W.L. (1990). Partial irrigation In Pakistan. Journal. ASCE *Irrigation Drainage Division*. 16(3): 342-353.

Turk, K.J., and Hall, A.E. (1980). Drought adaptation of cowpeas. II. Influence of plant water status and relations with seed yield. *Agronomy Journal* 72:421-427.

Turk, K.J., Hall, A.E., and Asbell, C.W. (1980). Drought adaptation of cowpea. 1. Influence of drought on seed yield. *Agronomy Journal* 72:413-420.

Tyagi, N.K. (1987). Managing rotational canal water supplies on the farm. *Water Resources Bull*., 23(3): 455-462.

Utoh, N.O. (1994). Seed production planning and implementation. *InEvolving the Nigerian seed development plan*, edited by N.O. Adedipe, I.A. Usman, andN.S. Maini. Federal Department of Agriculture, Abuja, Nigeria. Pages 115−120.

Veenendaal E.M, Swaine, M.D., Blay, D., Yelifari, N.B., and Mullins, C.E. (1996). Seasonal and long term water regime in West African tropical forest. *Journal of vegetation science* 7: 473-484.

Wen, Yeqiang., Jian, Yang., and Songhao, Shang. (2017). *Analysis on evapotranspiration and water balance of cropland with plastic mulch in arid region using dual crop coefficient approach* Volume 33, Number 1, 1 January 2017, pp. 138-147(10)

Zhang, Y., Yu, Q., Liu, C., Jiang, J., and Zhang, X. (2004). Estimation of winter wheat evapotranspiration under stress with semi- empirical approach. *Agronomy journal*, 96: 159-168.

Zhao, C., and Nan, Z. (2007). Estimating water needs of maize (Zea mays L.) using the dual crop coefficient method in the arid region of northwestern China. *African Journal of Agricultural Research* 2 (7), 325–333.

Ziska, L.H., and Hall, A.E. (1983). Seed yields and water use of cowpeas (Vigna unguiculata L. Walp.) subjected to planned water deficit irrigation. *Irrigation Science* 3: 237-245.

Appendix I Seasonal ETc for the various treatments.

S/NO.	Treatments	ETc (mm)
1	V1,I100,Nm	335.6
2	V1,I175,Nm	267.0
3	V1,I50,Nm	200.2
4	V1,I100,BPm	308.7
5	V1,I75,BPm	206.3
6	V1,I50,BPm	187.6
7	V2,I100,Nm	315.8
8	V2,I75,Nm	267.1
9	V2,I50,Nm	197.0
10	V2,I100,BPm	301.3
11	V2,I75,BPm	202.0
12	V2,I50,BPm	183.3

Appendix II Average weekly ETc for the various treatments

Treatments	WEEKS											
	1	2	3	4	5	6	7	8	9	10	11	12
V1,I100,Nm	2.2	2.2	2.9	3.7	4.1	4.7	5.2	5.6	6.3	5.1	2.7	1.6
V1,I75,Nm	2.5	2.3	2.6	3.0	3.1	3.3	3.7	4.1	4.8	3.5	2.4	1.7
V1,I50,Nm	2.2	2.3	2.6	2.2	2.4	2.4	2.5	2.8	3.1	2.5	1.4	1.2
V1,I100,Bpm	2.2	2.3	2.7	3.5	3.8	4.2	4.4	5.0	5.7	4.5	2.6	1.7
V1,I75,Bpm	2.2	2.1	2.2	2.2	2.6	2.5	2.8	3.1	2.6	2.2	2.0	1.5
V1,I50,Bpm	2.2	2.3	2.5	2.1	2.0	2.1	2.2	2.5	3.1	2.2	1.5	1.2
V2,I100,Nm	2.3	2.3	2.6	3.8	3.9	4.2	4.5	4.8	5.3	4.8	3.1	1.8
V2,I75,Nm	2.2	2.4	2.6	3.0	3.2	3.4	3.7	4.0	4.6	3.6	2.3	1.7
V2,I50,Nm	2.3	2.4	2.5	2.2	2.4	2.2	2.4	2.6	3.0	2.3	1.6	1.2
V2,I100,Bpm	2.2	2.3	2.5	3.3	3.6	4.0	4.1	4.9	5.4	4.3	2.6	1.6
V2,I75,Bpm	2.3	2.3	2.1	2.2	2.3	2.5	2.7	2.9	2.6	2.2	2.1	1.3
V2,I50,Bpm	2.2	2.3	2.5	2.1	2.0	2.0	2.2	2.3	2.8	2.2	1.5	1.2

Appendix III Average weekly deep percolation for the various treatments

Treatments	WEEKS											
	1	2	3	4	5	6	7	8	9	10	11	12
V1,I100,Nm			0.6	1.0	1.3	1.6	1.7	1.8	2.1	1.5	1.3	1.1
V1,I75,Nm			0.5	0.7	1.0	1.3	1.5	1.5	1.6	1.4	1.0	1.0
V1,I50,Nm			0.4	0.6	0.7	0.9	1.1	1.1	1.4	1.2	0.8	0.8
V1,I100,Bpm		0.1	1.0	1.1	2.2	2.2	2.3	2.4	3.1	1.9	1.3	1.1
V1,I75,Bpm			0.6	0.8	1.3	2.1	2.1	2.1	2.7	1.9	1.3	1.0
V1,I50,Bpm			0.5	0.6	1.0	1.4	1.7	1.4	1.9	1.4	1.2	1.0
V2,I100,Nm			0.4	0.9	1.1	1.4	1.7	1.8	3.0	1.5	1.3	1.0
V2,I75,Nm			0.4	0.7	1.0	1.2	1.5	1.5	1.6	1.2	0.9	0.7
V2,I50,Nm			0.4	0.6	0.8	0.9	1.1	1.1	1.3	1.1	0.7	0.7
V2,I100,Bpm			1.0	1.2	2.1	2.2	2.3	2.4	3.0	1.9	1.3	1.0
V2,I75,Bpm			0.5	0.8	1.5	2.1	2.0	2.2	2.7	1.6	0.7	0.9
V2,I50,Bpm			0.4	0.5	1.0	1.3	0.5	1.5	1.5	1.3	0.9	0.7

Appendix IV Average weekly Kc for the various treatments

Treatments	WEEKS											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
V_1,I_{100},NM	0.44	0.29	0.29	0.61	0.62	0.65	0.70	0.73	0.75	0.75	0.47	0.25
V_1,I_{75},NM	0.50	0.30	0.26	0.48	0.46	0.45	0.50	0.53	0.56	0.53	0.41	0.27
V_1,I_{50},NM	0.44	0.30	0.26	0.36	0.35	0.33	0.34	0.36	0.36	0.37	0.24	0.20
V_1,I_{100},BPM	0.44	0.30	0.27	0.36	0.39	0.39	0.38	0.39	0.40	0.42	0.37	0.26
V_1,I_{75},BPM	0.44	0.30	0.27	0.36	0.40	0.40	0.40	0.40	0.41	0.41	0.36	0.23
V_1,I_{50},BPM	0.44	0.30	0.25	0.35	0.29	0.28	0.29	0.32	0.36	0.33	0.25	0.20
V_2,I_{100},NM	0.46	0.31	0.26	0.62	0.57	0.59	0.60	0.62	0.62	0.72	0.55	0.29
V_2,I_{75},NM	0.45	0.31	0.26	0.50	0.48	0.47	0.50	0.51	0.53	0.54	0.40	0.27
V_2,I_{50},NM	0.46	0.31	0.25	0.37	0.35	0.31	0.32	0.34	0.35	0.35	0.26	0.19
V_2,I_{100},BPM	0.45	0.31	0.25	0.36	0.38	0.38	0.38	0.38	0.38	0.44	0.36	0.26
V_2,I_{75},BPM	0.46	0.30	0.26	0.36	0.34	0.35	0.37	0.37	0.38	0.43	0.36	0.23
V_2,I_{50},BPM	0.45	0.30	0.25	0.36	0.33	0.31	0.30	0.32	0.33	0.34	0.27	0.20

Appendix V Calibration of the micro-lysimeter on the field.

Height (cm)	Weight(Kg)
18.40	0.00
22.00	7.00
25.90	13.85
29.00	20.05
32.70	26.25
36.30	33.25
39.30	39.25
43.30	46.15
46.20	52.95
48.80	59.55
52.00	65.95
54.70	72.55
58.00	79.55
60.50	86.15
61.20	92.35
62.30	98.75
62.60	105.15



Plate VI Digging of pits



Plate VII Micro-lysimetres installation



Plate VIII Experimental field after irrigation