OPTIMUM IRRIGATION SCHEDULES FOR TOMATO PRODUCTION UNDER *FADAMA* CONDITIONS IN THE GUINEA SAVANNAH REGION OF NIGERIA

BY

Sunusi Amin ABUBAKAR B.ENG (ATBU) 2008
MSc/ENG/02929/2010-2011

A THESIS SUBMITTED TO THE SCHOOL OF POST GRADUATE STUDIES, AHMADU BELLO UNIVERSITY, ZARIA

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTERS OF SCIENCE DEGREE IN AGRICULTURAL ENGINEERING

DEPARTMENT OF AGRICULTURAL ENGINEERING
FACULTY OF ENGINEERING
AHMADU BELLO UNIVERSITY, ZARIA, NIGERIA

DECEMBER, 2014

DECLARATION

I declare that the work in this thesis entitled Optimum Irrigation Water for Tomato Production under Fadama Conditions in Guinea Savannah Region has been carried out by me in the Department of Agricultural Engineering under the supervision of Prof. O.J. Mudiare and Dr M. K. Othman. 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 university.

Sunusi Amin ABUBAKAR	……	……..
M. Sc/ENG/02929/2010-2011	(Signature)	(Date)

CERTIFICATION

This thesis entitled OPTIMUM IRRIGATION SCHEDULES FOR TOMATO PRODUCTION UNDER *FADAMA* CONDITIONS IN THE GUINEA SAVANNAH REGION OF NIGERIA by Sunusi Amin ABUBAKAR meets the regulations governing the award of the degree of Masters in Agricultural Engineering of the Ahmadu Bello University, and is approved for its contribution to scientific knowledge and literary presentation.

Prof. O. J. Mudiare	……	……..
Chairman, Supervisory Committee	(Signature)	(Date)
Dr M. K. Othman	……	……..
Member, Supervisory Committee	(Signature)	(Date)
Prof. D. D. Yusuf	……	……..
Head of Department	(Signature)	(Date)
Prof. Z. A. Hassan	……	……..
Dean, School of Postgraduate Studies	(Signature)	(Date)

DEDICATION

This work is dedicated to my late father Alhaji Garba Uzum for his tireless effort to see me succeed in life. May Allah have mercy on him!

ACKNOWLEDGEMENTS

I express my deep gratitude to my supervisors Prof O. J. Mudiare and Dr M. K. Othman for their understanding, support, constructive criticism and sustained contributions throughout the conduct of this work. I also wish to express my appreciation to my lecturers in the Department of Agricultural Engineering, ABU, Zaria. I wish to express my profound gratitude to my colleagues particularly Dr A. L. E. Mofoke, Engr. A. U. Ibrahim, Engr. O. L. Akangbe and entire staff of the Department of Agricultural and Bioresource Engineering of the Abubukar Tafawa Balewa University, Bauchi. I also want to appreciate the support of my class mates. I acknowledge the support of my family, particularly my brothers K. A. Aminu and Sani Garba and my wife Salaha Muhammad. A great number of my family members and friends supported me in so many ways I cannot to mention, I appreciate them.

I say thank you to all.

ABSTRACT

An experiment was conducted to determine the optimum irrigation schedules for tomato production under fadama conditions in Guinea Savannah region. The experiment consisted of five (5) levels of soil moisture replacement (100%, 80%, 60%, 50% and 40%) and three (3) levels of irrigation interval (3 days, 5 days and 7 days). The treatments were replicated three times in a Randomized Complete Block Design. Water applied to each basin was measured using cutthroat flume. The soil moisture depletion was monitored using a gypsum block (watermark sensor). The crop was harvested at maturity and the weight of the product measured to determine the yield in tons per hectare. The yield obtained ranged from 10.90t/ha to 28.22t/ha. The least yield was obtained from the treatment with 40% replacement and 7 day irrigation interval, while the highest yield was obtained from the treatment with 60% replacement and 5 day irrigation interval. The highest crop water use efficiency (CWUE) and irrigation water use efficiency (IWUE) were 68.33 kg/ha-mm and 54.60kg/ha-mm at 60% level of replacement. The least CWUE and IWUE were 35.58kg/ha-mm and 28.23kg/ha-mm both at 100% replacement. An economic analysis employed to determine the optimum irrigation schedule revealed that the optimum irrigation intervals for 100%, 80%, 60%, 50% and 40% replacements were respectively 10days, 10days, 11days, 12 days and 19days. The optimum irrigation amount for the season were 759mm, 633mm, 450mm, 405mm and 315mm for 100%, 80%, 60%, 50% and 40% replacements, respectively. It is concluded that irrigation that replaces 60% of moisture depleted every 5 days gives better results in terms of yield and water use efficiencies. However for maximum economic return, the optimum irrigation schedules observed in this study could be used.

TABLE OF CONTENTS

Title Page i

Declaration iII

Certification III

Dedication IV

Acknowledgements v

Abstract VI

Table of Contents VII

List of Figures X

List of Tables XII

List of Plates XIV

List of Appendix XV

Chapter One 1

Introduction 1

1.1 Background Of The Study 1

1.2 Statement Of The Problem 4

1.3 Justification Of The Study 4

1.4 Objectives Of The Study 5

Chapter Two 6

Literature Review **6**

2.1 Irrigation Practices For Optimum Water Use **6**

2.2.1 Techniques Of Irrigation Scheduling 7

2.3 Crop Yield And Water Use **9**

2.4 Water Use Efficiency (Wue) **11**

2.5 Deficit Irrigation Concept **13**

2.6 Irrigation Water **15**

2.7 Soil Physical Properties **18**

2.7.1 Soil Texture 18

2.7.2 Total Available Water Capacity 18

2.8 Soil Moisture Content **19**

2.9 Evapotranspiration **20**

2.9.1 Reference Evapotranspiration 21

2.9.2 Crop Evapotranspiration 21

Chapter Three **23**

Materials And Methods **23**

3.1 Study Area **23**

3.2 Experimental Design **23**

3.3 Field Operation **23**

3.4 Determination Of Soil Physical Properties.....24

3.5 Determination Of Soil Moisture Content.....25

3.6 Measurement Of Irrigation Water.....25

3.7 Determination Of Crop Yield.....25

3.8 Determination Of Optimum Irrigation Practice.....25

3.9 Data Analysis.....30

Chapter Four.....31

Results And Discussions.....31

4.1 Tomato Yield.....31

4.2 Seasonal Water Applied And Seasonal Water Use.....34

4.3 Crop Water Use Efficiency (Cwue) And Irrigation Water Use Efficiency (Iwue)37

4.4 Economics Of Tomato Production.....40

4.4 Optimum Irrigation Schedules For Tomato.....41

Chapter Five.....43

Summary, Conclusion And Recomendations.....43

5.1 Summary.....43

5.2 Conclusion.....45

5.3 Recommendations.....46

References.....47

LIST OF FIGURES

Figure 2.1: General Form of The Relationship between Applied Water and Crop Yield 10

Figure 3.1: Model Used in the Analysis.....27

Figure C1: Yield of Tomato as Influenced by Percentage Replacement of Moisture Depleted and Irrigation Interval 54

Figure C2: Yield of Tomato for Percentage of Moisture Replacement 55

Figure C3: Means of Tomato Yield as Influenced by Irrigation Interval.....55

Figure C4: Means of Application Depth and Seasonal Water Use as Affected by Percentage Replacement of Soil Moisture Depleted 56

Figure C5: Means of Application Depth and Seasonal Water Use as Influenced by Irrigation Interval.....57

Figure C6: Crop Water Use Efficiency (CWUE) and Irrigation Water Use Efficiency (IWUE) as Influenced by Percentage Replacement of Soil Moisture Depleted.....58

Figure C7: Crop Water Use Efficiency (CWUE) and Irrigation Water Use Efficiency (IWUE) as Influenced by Irrigation Interval.....59

Figure C8: Revenue and Savings A Influenced by Percentage Replacement of Soil Moisture Depleted.....59

Figure D2: Revenue and Available Moisture Relationship for 100 % Level of Moisture Replacement 62

Figure D2: Revenue and Available Moisture Relationship for 80 % Level of Moisture Replacement 65

Figure D3: Revenue and Available Moisture Relationship for 60 % Level of Moisture Replacement 67

Figure D4: Revenue and Available Moisture Relationship for 50 % Level of Moisture Replacement 69

Figure D5: Revenue and Available Moisture Relationship for 40 % Level of Moisture Replacement 71

LIST OF TABLES

Table 4.1: Tomato Yield Obtained in Bauchi in 2012/2013 Dry Season 31

Table 4.2: Mean Tomato Yield for Percentage of Soil Moisture Replacement in Bauchi, 2012/2013 Dry Season.....32

Table 4.3: Mean Tomato Yield for Irrigation Interval in Bauchi, 2012/2013 Dry Season 33

Table 4.4: Effects of Replacement/Irrigation Interval Interaction on Tomato Yield in Bauchi, 2012/2013 Dry Season.....34

Table 4.5: Means of Application Depth and Seasonal Water Use as Affected by Moisture Replacement 35

Table 4.6: Means of Water Applied and Seasonal Water Use as Affected by Irrigation Interval 36

Table 4.7: Means of Application Depth and Seasonal Water Use as Affected by Moisture Replacement and Irrigation Interval 37

Table 4.8: Means of Crop Water Use Efficiency (CWUE) and Irrigation Water Use Efficiency (IWUE) as Affected by Moisture Replacement 38

Table 4.9: Means of CWUE and IWUE as Affected by Irrigation Interval in Bauchi, 2012/2013 Dry Season 39

Table 4.10: Effect of Replacement and Irrigation Interval Interaction on CWUE And IWUE in Bauchi, 2012/2013 Dry Season.....40

Table 4.11: Revenue Per Unit of Water Applied for the Various Levels of Moisture Replacement.....41

Table 4.12: Optimum Irrigation Schedules for Tomato in Bauchi, 2012/2013 Dry Season 42

Tableb1: Experimental Design and Treatments Combinations 52

Table B2: Physical Properties of Soil in the Experimental Site 53

Table D1: Revenue Versus Available Moisture for 100 % Moisture Replacement 61

Table D2: Revenue Versus Available Moisture for 80 % Moisture Replacement 64

Table D3: Revenue Versus Available Moisture for 60 % Moisture Replacement 66

Table D4: Revenue Versus Available Moisture for 50 % Moisture Replacement 68

Table D5 Revenue Versus Available Moisture for 40 % Moisture Replacement..... 70

LIST OF PLATES

Plate 1: Stream at Bayara Village in Bauchi State 73

Plate 2: Water being Pumped for Irrigation 74

Plate 3: Tomato Crop Growing in the Expiremental Field 75

Plate 4: Student taking Measurement for Soil Moisture 76

Plate 5: Flume used for Measuring Application Depth 77

Plate 6: An Assistant Harvesting Tomato Crop 78

Plate 7: Resistance Block (Water Mark Sensor) Used 79

LIST OF APPENDIX

Appendix A 51

Appendix B.....52

Appendix C.....54

Appendix D 60

Appendix E.....73

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Water is essential for socio-economic development and for maintaining healthy eco-systems. Properly managed water resources are critical components of economic growth, poverty reduction and equity. The livelihoods of the poorest nations are critically associated with access to water services. With higher rates of urbanization, increasing demand for drinking water will put stress on existing water sources. Feeding a planet of 8 billion by 2030 will require producing more food with less water and through improved water efficiency in agriculture (World Bank, 2011). Besides the needs for these human activities, it has to be ensured that the environmental water flows also maintain the ecosystems. Water Resources Management aims at optimizing the available natural water flows, including surface water and groundwater, to satisfy these competitive needs. Addition of uncertainty, climate change increases the complexity of water resources management. In some parts of the world, there are occurrences of floods while other parts, including the developing world, they experience draught. The mounting challenges posed by the changing demand for and supply of the resource highlight the importance of water in any development and growth agenda. The ability of developing countries to make more water available for domestic, agricultural, industrial and environmental uses depends on better management of water resources and more cross-sectoral planning and integration. With water security declining in many parts of the world, strengthening the resilience of the poorest countries and populations to climate change impacts becomes crucial, not only to ensure future water supply but also to combat food and energy price volatility (World

Bank, 2011). Among the massive water users agricultural sector uses more water than other sectors. The main driving force behind the use of water in agriculture is crop water requirement and irrigation water demand. The demand for irrigation water is increasing with increase in population and environmental degradation, and simultaneously other sectors are also expected to increase consumption in the near future. Non-agricultural sectors are using water more efficiently and they account for the lower share of the total abstraction. Therefore, it is generally agreed that the main changes in water management, to regulate water supply and demand, should take place in the irrigation sector, (Giannoccaro *et al*, 2009).

Conventional irrigation practices in most parts of the world are designed to avoid crop stress in order to maximize crop yield. During the next few decades, as the inevitable expansion of irrigated lands for increased food production comes into conflict with accelerating economic competition for water and rising environmental concerns, this fundamental precept of irrigation management might probably be abandoned. The new operational rule that replaces the conventional practice will be based on maximizing total benefits rather than only yields. This alternative approach, which might be referred to simply as 'optimization', is recognized by economists and a growing number of irrigation professionals as the most rational basis for irrigation management (English *et al*., 2002).

Optimal level of irrigation water for a particular situation is that which produces the maximum profit per unit of water applied. Maximization of profit is based on the hope that incremental value of water use generated, equals the incremental cost (Ali, 2010). When the optimum level of water application is known before hand, irrigators can make informed decision on the exact amount of water to apply for crop consumption.

Fadama are low lying lands subject to seasonal flooding or water logging along the banks of streams or depressions. It is a *Hausa* word meaning the seasonally flooded or floodable plains along major savannah rivers and or depressions or adjacent to seasonal or perennial streams and rivers. The enormous potentials of *Fadama* irrigated agriculture is indisputable. The *Fadama* lands have high potentials and agricultural values several times more than the adjacent upland (Oladoja and Adeokun, 2009). This is because of their high level of residual moisture during dry season. *Fadama* lands are also higher in organic matter and nutrients than adjacent uplands (Kyamu, 2001).

Tomato is a major crop grown in *fadama* areas in Nigeria. It is a rapidly growing crop with a growing period of 90 to 150 days. It is a day length neutral plant. Optimum mean daily temperature for growth ranges from 18 to 25^{o}C with night temperatures between 10 to 20^{o}C. Larger difference between day and night temperatures, however, adversely affect yield. Tomato can be grown on a wide range of soils, but well-drained, light loam soils with pH of 5 to 7 are preferred. The seed is generally sown in nursery plots and the emergence is within 10 days. Seedlings are transplanted in the field after 25 to 30 days. In the nursery the row distance is about 10 cm. In the field, spacing ranges from 0.3 by 0.6 m^2 × 0.6 by 1 m^2 with a population of about 40, 000 plants/ha. The crop is grown in rotation with crops such as maize, cabbage, cowpea, to reduce pest and disease infestations. Total water requirement (ETm) of a tomato crop in the field after transplanting for 90 to 120 days are 400 to 600 mm, depending on the climate (Doorenbos and Kassam, 1979) Water requirements related to Reference Evapotranspiration (ETo) in mm/period are given by the crop factor (Kc) for different crop development stages, or: during the initial stage from 0.4 to 0.5 (10 to 15 days), the development stage from 0.7 to 0.8 (20 to 30 days), the mid

season stage from 1.05 to 1.25 (30 to 40 days), the late season stage 0.8 to 0.9 (30 to 40 days) and at harvest 0.6 to 0.65. The cultural practices of growing the crop do not only vary but are generally characterized by indiscriminate use of fertilizer and injudicious use of water; both scarce resources. The day season growing however, has to be supported by irrigation, and a 7 day irrigation interval is a common practice in Semi Arid Savannah of Nigeria (Ramalan, 1994). However, Samail, *et al*., (2011) stated that 10 days irrigation interval produced best result in both tomato yield and quality in Samaru Zaria.

1.2 Statement of the Problem

Irrigation in *Fadama* areas is one of the major sources of income to the rural communities in Northern Nigeria. Despite its noticeable development, the practice is characterized with some operational problems. Typically, Mofoke *et al*., (2002) reported that water application is done based on farmers' judgment not based on scientific principles. Thus, farmers are not able to realize optimum production because they either under irrigate or over irrigate, either of which leads to a loss of revenue. This practice strongly militates against the famers' effort to achieve optimum production and thus, they are not able to escape from the present poverty cycle.

1.3 Justification of the Study

The current trend of agricultural production is centered at maximizing benefit per unit of water applied. This is of particular importance to the areas where water is scarce and becoming so expensive. Bauchi State is one of the states in Nigeria where large *Fadama* areas are put under irrigation to produce various crops with tomato playing a major role. Therefore, there is a need to optimize water utilization in the *Fadama* areas of the state.

1.4 Objectives of the Study

The general objective of the study is to determine the optimum irrigation water use that results to maximum yield of tomato grown in *Fadama* farms. The specific objectives are:

1. To determine the crop yield at different water application depths;
2. To evaluate the crop water use efficiencies;
3. To determine the optimum irrigation amount and interval at different levels of moisture replacement.

CHAPTER TWO

LITERATURE REVIEW

2.1 Irrigation Practices for Optimum Water Use

Conventional irrigation practices in most parts of the world are designed to avoid crop stress in order to maximize crop yields. During the next few decades, as the inevitable expansion of irrigated lands for increased food production comes into conflict with accelerating economic competition for water and rising environmental concerns, this fundamental precept of irrigation management might probably be abandoned reported that the new operational rule that replaces the conventional practice will be based on maximizing total benefits rather than yields. This alternative approach, which might be referred to simply as 'optimization', is recognized by economists and a growing number of irrigation professionals as the most rational basis for irrigation water management (English *et al*., 2002).

A number of strategies have been employed to assess and devise ways of maximizing irrigation water use and productivity. Shahbaz *et al*., (2007) used pick and mix strategies approach to optimize irrigation productivity and river health in the Murrumbidgee valley of New South Wales. Hassan *et al*., (2010) presented a mathematical model for simulating canal operation to optimize water allocation within a multiple irrigation canal in the wet and dry regions of Gezira Scheme – Sudan. The model capabilities to optimize water scheduling and allocation process can be used to save irrigation water during early stages of crop growth and to upgrade the operation of minor canals in the irrigated schemes in the Sudan. Roost (2002) developed a model: OASIS (Options Analysis in Surface Irrigation

Systems) for improving irrigation water use efficiency, productivity and equity. The model was developed from simulation experiments in the downstream yellow river basin in China. The model allowed proper quantification of water use efficiency, productivity and equity under actual and hypothetical conditions of land use, infrastructure and management.

2.2 Irrigation Scheduling

The problem of irrigation consists of how much water to apply and when to apply it. Irrigation scheduling means when to irrigate and how much water to apply. The objective of irrigation scheduling is maximization yield, irrigation efficiency and crop quality by applying exact amount of water to the crop or to replenish the soil moisture to a desired level. Some indices have been used by irrigators to determine the need of irrigation by crop. These indicators include plant leaf appearance, soil moisture status, soil-water potential, leaf water potential and leaf temperature. Strategy adopted by irrigator is one of the several factors influencing irrigation scheduling. Possible irrigation strategies adopted by farmers include maximizing yield per unit of land, water or energy and profit maximization. These strategies are affected by the existing land, water and labour resources conditions.

2.2.1 Techniques of Irrigation Scheduling

The common irrigation scheduling techniques as presented by Rijov *et al*. (1973) include:

a. Measurement or observation of water deficit in plants

b. Monitoring soil moisture content until the critical point is reached.

c. Irrigation scheduling based on evapotranspration rates.

d. Calculated irrigation schedules or irrigation guides.

Costly instrumentation and highly skilled man-power requirements strongly discourage the use of the first three of these techniques as routine field procedure. Calculated irrigation schedules are therefore the options adopted by many irrigators. With this approach, the timing of irrigation (Irrigation interval) is obtained based on soil, plant, climate characteristics as follows (Benami and Ofen, 1984):

$$Irrigation\ Interval\ (days) = NWR/(Average\ CU) \quad (2.1)$$

where:

NWR = net depth of application (mm)

CU_{peak} = peak average consumptive use (mm/day) but

$$NWR = (FC - WP) \times BD \times 10 \times DRZ \times MAD \quad (2.2)$$

In which

NWR is in mm,

FC = field capacity (weight basis), %

PWP = permanent wilting point (weight basis), %

BD = soil bulk density, g/cm^3

DRZ = design root zone depth, m

MAD = management allowable depletion.

Similarly, the net amount of water to apply can be estimated by the quantity depleted between successive irrigations. This is obtained as (Rijov *et al*., 1973):

$$d_n\ (mm) = \ CU \ \times \ irrigation\ interval \qquad (2.3)$$

where; d_n = adjusted net water requirement per application, mm

CU = consumptive use, mm/day

2.3 Crop Yield and Water Use

The relationship between crop yield and water use is represented by the production functions. These production functions can be used to estimate yield at particular crop water use. According to Doorenbos and Kassam, (1979), when economic conditions do not restrict crop production and in a constraint free condition, crop yield is at maximum when full water requirements are met. When water supply does not meet crop water demand, actual evapotranspiration (ET_a) will fall below maximum evapotransiration resulting to a water deficit in a plant which may develop to a point where crop growth and yield are adversely affected. However, according to Mofoke (2002), the fact that the relationship between yield and irrigation water applied is a diminishing return (Figure 2.1) function implies that, there exists a point beyond which further addition of irrigation water is not justified economically. This point represents the optimum level of irrigation.

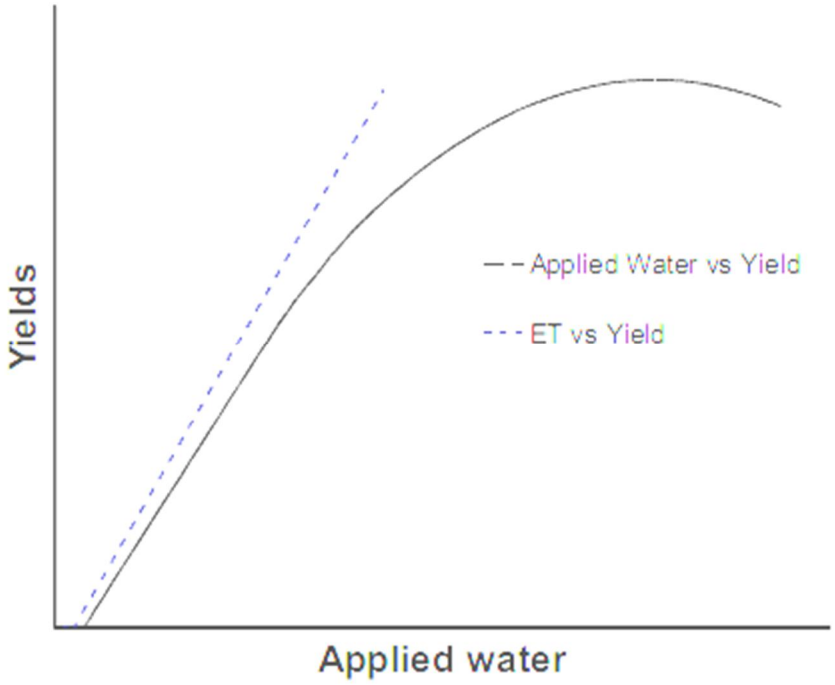


Figure 2.1: General form of the relationship between applied water and crop yield

Senyigit *et al* (2011) observed that when irrigation water and ET increased, yield also increased to a certain point; however, irrigation had a slightly more positive-effect on yield than ET. It was then concluded that there was a linear relationship between amount of irrigation water and the yield for the eggplant to a certain level, but after a certain level, the excessive water applied did not provide a significant increase, and on the contrary, caused a decrease in the yield.

The plot of the ratio of actual yield to maximum yield ( ) versus actual evapotranspiration to maximum evapotranspiration ( ) is a better way of generalizing the yield function since site-specific variable such as climate may produce different absolute evapotranspiration values for the same amount of growth (Stegman and Hanks ,1980).

2.4 Water Use Efficiency (WUE)

Water use efficiency is an important physiological characteristic that is related to the ability of crop to cope with water stress. In simple terms it is characterized by crop yield per unit of water used. WUE can be defined as a biomass produced per unit area per unit water evapo-transpired. The biomass is usually determined as dry weight rather than as fresh weight, therefore several methods are commonly used to determine water use efficiency. Water use efficiency is mainly relying on the economic yield of the crop rather than water use (Singh *et al.,* 2012). The increasing cost of irrigation water, as a result of an ever rising demand for food all over the world necessitates the need to reduce water losses from soils and maximize crop yield per unit of water applied. Water use efficiency (WUE) is an efficiency term that is used to judge how well crops can attain adequate yields at the least level of water consumption. Water use efficiency (WUE) is exprssed as the ratio of yield to the consumptive water use, that is,

$$WUE = \frac{Y}{ET} \tag{2.4}$$

in which Y is yield in t/ha and other terms as previously defined.

Michael (1978) identified that the term "water use" may either be field water use or actual crop evapotranspiration, hence differentiating field WUE from crop WUE. Burman *et al*., (1980) gave a more precise definition of WUE as a measure of the increase in the production of the marketable crop component relative to the increase in water consumed when irrigated over the simultaneous consumption under non-irrigated condition, that is

$$WUE = \frac{V_i - V_x}{ET_i - ET_x} \tag{2.5}$$

where;

Vi = mass of marketable crop produced with irrigation, t/ha

Vx = mass of marketable crop that could be produced simultaneously without irrigation, t/ha

ETi = amount of water used in ET by the irrigated crop

ETx = amount of water that could be used in ET by the same crop if not irrigated.

Eqn 2.4 suggests that WUE may be improved by either increasing the crop yield through improved production operations or by reducing ET. Extensive research summarized by Rosenberg *et al*. (1983), revealed that many attempts at increasing WUE through reduction of ET had limited success. It is therefore apparently more promising to increase WUE by augmenting crop yield rather than by decreasing ET (Hillel and Guron, 1973).

Benchmark water use efficiency is the total amount of water used to produce the yield and is expressed as (Irmak *et al*, 2011):

$$WUE_b = \frac{Y_i}{P_e+IR+\Delta SW} \quad (2.6)$$

Where:

WUE_b = Benchmark water use efficiency

Y_i = Yield of irrigated crop

IR = Irrigation applied

P_e = effective rainfall

ΔSW = change in water content in the root zone during the growing season.

2.5 Deficit Irrigation Concept

Deficit irrigation is the deliberate and systematic under-irrigation of a crop (English, 1990). Under deficit irrigation, crops are deliberately subjected to certain level of water deficit and yield reduction. Benefits of deficit irrigation may be achieved through increased irrigation efficiency, reduced costs of irrigation and the opportunity costs of water. The advantages of deficit irrigation are of particular importance in water limiting environments. English (2002) suggested that irrigation water productivity can be increased by simply applying less amount of water. This is done by simply irrigating at a lower point on the curve (Figure 2. 1), something less than the yield-maximizing level. In doing so, it could attain higher irrigation efficiency. The yield per unit of land would be less, since it would no longer be at the maximum yield point, but the yield per unit of applied water would be greater. Additionally, the costs of production and the environmental impacts of irrigation would also be reduced. At certain reduced level of irrigation the benefits derived from each unit of applied water would be maximized. Bergson (2012) reported that water use efficiency in irrigated agriculture can be improved through the adoption of a deficit irrigation strategy. He established that this strategy can result in increased water productivity. The use of Deficit Irrigation as a tool for agricultural water management was evaluated through simulations of the Soil-Water-Atmosphere-Plant (SWAP) model. The results indicate that with deficit irrigation it was able to increase water productivity of cotton in conditions of a semi arid land in Brazil, conforming to what was reported in the literature. However, deficit irrigation do not result in an increase of cotton yield per area used, but improved the relationship between yield and consumed water. A form of deficit

irrigation (limited irrigation-dry land) was tested (Stewart *et al*, 1983) on graded furrows and the limited irrigation dry-land was successful in the utilization efficiency of irrigation water. It tended to reduce losses other than transpiration. Deficit irrigation, by reducing irrigation water use, can aid in coping with situations where supply is restricted. In field crops, a well designed Deficit Irrigation regime can optimize water productivity (WP) over an area when full irrigation is not possible. In many horticultural crops, regulated deficit irrigation has been shown to improve not only WP but farmers' net income as well. It would be important to investigate the basis for the positive responses to water deficit observed in the cases where Regulated Deficit Irrigation is beneficial. While Deficit Irrigation can be used as a tactical measure to reduce irrigation water use when supplies are limited by droughts or other factors, it is not known whether it can be used over a long time period. It is imperative to investigate the sustainability of Deficit Irrigation via long-term experiments and modelling efforts to determine to what extent it can contribute to the permanent reduction of irrigation water use (Fereres and Soriano, 2007). Geerts and Raes (2009) concluded that in areas where the available water supply limits agricultural production, deficit irrigation gains importance over time as farmers strive to increase the productivity of their limited land and water resources. Farmers must choose crops and irrigation strategies carefully in order to maximize the value of their crop production activities, while ensuring the sustainability of agriculture. Deficit irrigation plays an important role in farm-level water management strategies, with consequent increases in the output generated per unit of water used in agriculture.

Water deficit in crops and the resulting water stress on the plant have effects on the crop evapotranspiration and subsequently the crop yield. Doorenbos and Kassam (1979)

reported that when crop water requirements are fully met from available water supply the actual evapotranspiration is equal to maximum evapotranspiration, and when water supply is limited, actual evapotranspiration is less than maximum evapotranspiration. Actual yield is equated to the maximum yield with full irrigation; otherwise actual yield is less than maximum. To quantify the effect of water stress on crop yield, it is necessary to derive a relationship between the relative crop yield decrease and relative evapotranspiration deficit. This is given as (Doorenbos and Kassam 1979):

$$\left(1 - \frac{Y_a}{Y_m}\right) = K_y\left(1 - \frac{ET_a}{ET_m}\right) \quad (2.7)$$

In which Y_a and Y_m are the actual and maximum yield, respectively.

Et_a and ET_m are the actual and maximum evapotranspiration and K_y is the crop response factor representing the effect of a reduction in evapotranspiration on yield. Values of K_y vary over the growing season according to the crop growth stage. If $K_y > 1$ the response is very sensitive to water deficit with proportional larger yield decrease, if $K_y < 1$ the crop is more tolerant to water deficit and exhibits less than proportional reduction in yield and if Ky = 1 yield reduction is directly proportional to reduced water used.

2.6 Irrigation Water

One of the major problems in surface irrigation system is the low efficiency of irrigation water. A measure that is essential for reducing waste and ensuring more efficient use among farmers is measuring the volumes of water supplied to the field. The amount of water that moves or passes a point in a given time period is termed water flow rate. Measurement and determination of flow rates is a critical component of irrigation water

management. Various techniques and tools are available to measure the flow rate. These range from simple indigenous methods to high-tech automated systems. Each of these methods has some advantages over the others as well as limitations.

The methods used to measure water supplies can be broadly categorized as Volumetric or direct measurement method, Area-velocity method and Tracer measurement method. In the area-velocity method, the volume of water flowing per unit time is determined with the area of flow and velocity of flow. But in the volumetric method, the discharge rate can be measured directly, the area of flow need not be determined and only the height of water over the particular section of the instrument is essential. Automated flow meters are available for different types of flow measurements, and especially for pipe flow, it is common.

The tools or devices used for measuring water flow can be categorized as follows:

a. Volumetric flow measuring devices (weirs, flumes, V-notch, venture meter, orifice meter, magnetic meter, ultrasonic meter, amongst others)
b. Velocity measuring devices (current meter, pitot tube, float, etc).
c. Water level (height) measuring devices (staff gauge, meter scale, water level sensor, ultrasonic water level sensor, etc.)

Flow rate through a small opening can be measured simply by collecting the outflow for a particular time period, and then by measuring the volume of the collected water. Alternatively, a stop watch may be used to record the time required to fill in a large container of known volume. Then the flow rate, Q would be:

Discharge rate, Q = $\frac{V}{t}$ (2.8)

Where: v = volume of the container (L)

t = Time to fill the container (s)

However, this approach is not suitable for large discharge or open channel flow.

Upon measuring the flow rate (Q) and application time (t), the total quantity of water applied during irrigation (IRR) may be estimated from Eqn. 2.9 James (1988)

$$IRR = Q.t \quad (2.9)$$

When Q is in m^3/s, and t in sec, IRR would be in m^3. It is often preferable and more convenient to express IRR on a depth basis rather than volume basis as given by Eqn 2.9. This could be done again according to James (1988).

$$IRR = \frac{Q.t}{A}.1000 \quad (2.10)$$

Where:

IRR = irrigation water applied in equivalent average depth, mm

A = average farm area, m^2.

The volumetric flow measuring devices are referred to as primary devices as water flow can be known from their measured data. On the other hand, velocity and water-height measuring devices are referred to as secondary devices as water flow cannot be determined directly from these readings.

2.7 Soil Physical Properties

2.7.1 Soil Texture

Soil texture is the relative proportion of sand, silt and clay contained within a particular soil mass (Benami and Ofen, 1984). Soil texture together with soil structure collectively form the basic soil matrix and geometry of voids created within the matrix. It is therefore, conventionally taken as one way of classifying agricultural soils, and from which other soil physical properties such as infiltration capacity, total available water capacity among others are estimated or determined.

Earlier work by Owonubi *et al*. (1994) reveals that, the Fadama soils are generally medium - textured (predominantly barns), but still display great textural variability even within the same microtopography

2.7.2 Total Available Water Capacity

The major role of soils in supporting agriculture is their function as a reservoir of water and nutrient for plant use. The amount of water which an agricultural soil can store and the extent to which it can make the water available to growing plants depends on the total available water capacity of the soil which is significantly influenced by the soil texture, organic matter, presence of cementing agents and salts, type of clay minerals, among other factors.

Total Available Water Capacity (TAWC) otherwise referred to as Total Available Water, Water Holding Capacity, or Available Water is the amount of moisture held between field capacity, FC and permanent wilting point, PWP. Total Available Water Capacity could be calculated from eq. 2.11 below (Benami and Ofen, 1984):

$$TAWC/_{1m} = \left(FC_{weight} - PWP_{weight}\right) \times BD \times \text{DRZ} \quad (2.11)$$

in which all the terms are as previously defined.

TAWC represents soil moisture that is held in the soil by the action of capillary forces. Therefore, sandy soils generally have a smaller TAWC than clayey soils because they release most of their water within a narrow range of suction due to predominance of non-capillary macropores. Values of TAWC vary very roughly from 80 mm/m depth of soil for sandy soils to 230 mm/m for clayey soils (James, 1988).

The range between FC and CP (critical point) – The level below which available water is not allowed to drop – is often termed the management allowable deficit (MAD), and it can be expressed as a percentage of TAWC. Generally MAD varies between 30 and 70% of the TAWC, with a value 50% being rather common (Benemi and Ofen, 1984)

2.8 Soil Moisture Content

Soil water is important in agriculture because of its strong influence on plant growth and crop production. Most studies related to the soil - plant - atmosphere continuum are invariably pivoted about accurate measurement of soil moisture. Typical studies requiring the determination of soil moisture content include; estimation of the Total Available Water Capacity, Measurement of actual Crop Evapotranspiration using the soil moisture depletion method, determination of Water Application Efficiencies, among others.

The gravimetric method is apparently the most prevalent technique in vogue for determination of soil moisture content. This technique is often preferred not simply

because it is the recommended standard, but also because of its minimal technical and financial implications. It involves weighing a sample of moist soil, drying it to a constant weight at a temperature of 105 to 110°C and reweighing to determine the amount of water lost upon drying. Soil moisture content is then calculated as follows (Skaggs *et al*., 1980):

$$\theta_{dw} = \frac{Wt_{ms} - Wt_{ds}}{Wt_{ds}} \times 100\% \quad (2.12)$$

Where:

θ_{dW} = soil moisture content, % dry weight basis

Wt_{ms} = weight of moist soil,

Wt_{ds} = weight of dry soil, g

Although the drying time depends on a number of factors such as soil texture, soil wetness, loading of oven, including others. Skaggs *et al*., (1980) however, reported the 24-hour drying period to be sufficiently accurate for most experimental works.

2.9 Evapotranspiration

Evapotranspiration (ET) is a term describing water loss from soil and plant surface to the atmosphere in a cropped land. The quantity of water depleted from the soil reservoir through ET is important in irrigation planning because, in the absence of rainfall, irrigation has to provide this water in order to secure good crop growth and yield.

2.9.1 Reference Evapotranspiration

The concept of reference evapotranspiration (ET_o) is an attempt to characterize the micrometeorological environment of a field in terms of an evaporative demand indepenedently of crop type, crop development and management practice. Burman *et al*., (1980) defined reference evapotranspiration as the maximum rate at which water if fully available, would be removed from the earth's surface, and transpired by plants.

Extensive review of numerous models to estimate ET_o are contained in literature (Burman *et al*., 1980; Doorenbos and Pruitt, 1977). Burman *et al*. (1983), however, identified that the energy combination method is apparently the most preferred approach of calculating ET_o for a wide range of climatic conditions due to its strong theoretical basis. This suggests that, in the absence of a locally calibrated ET_o model, the combination method may be reliably adopted.

2.9.2 Crop Evapotranspiration

The term crop evapotranspiration (under standard conditions) refers to the rate of evapotranspiration of a disease-free crop growing in a large field (one or more) under optimal soil conditions; including sufficient water and fertilizer, and achieving full production potential of that crop under the given growing environment (Doorenbos and Pruitt, 1977). If the standard conditions are not satisfied, then the rate of water loss from the cropped land through ET is termed actual crop evapotranspiration. Actual crop evapotranspiration (ETa) is therefore, the rate of evapotranspiration as affected by the level of available soil water, salinity, fleld size and/or other factors (Doorenbos and Pruitt, 1977).

ETa is obtained from the change in soil water content in successive soil sampling intervals as follows (Rijov *et al*., 1973);

$$ET_a = \sum_{i=1}^{n} \frac{M_{1i} - M_{2i}}{100} . Bd_i . D_i \qquad (2.13)$$

where:

ETa = actual crop evapotranspiration from the root zone in mm, for a sampling period within one irrigation cycle.

M_{1i} = moisture percentage on oven-dry basis at the first sampling in the i-th layer

M_{2i} = moisture percentage on oven-dry basis at the second sampling in the i-th layer

Bd_i = Bulk density of the i - th layer of soil

D_i = Depth of soil in mm of the i - th layer

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

The experimental site is located at Bayara, 11km away from Abubakar Tafawa University (Yelwa Campus), Bauchi. Bauchi falls within the Northern Guinea Savannah Ecological Zone of Nigeria. The location lies at latitude $10^{o}17$□N and longitude 09^{o} 49□E and on an altitude of 609.3 m above mean sea level. The dry season in this region starts from late October and extends to April, and sometimes May. These months are characterised with dry hamattan wind especially from November to February. Ambient temperatures during the period are between 10^{o} C and 37^{o} C which favours the growth of cold weather crops such as potato and carrot among others (Mofoke, 2006). The soil of the experimental site is predominantly sandy loam with the physical properties shown in Appendix A

3.2 Experimental Design

The experimental crop is tomato. The treatments are five levels of water replacement (100 %, 80 %, 60 %, 50 % and 40 %) combined with three different irrigation intervals (3-day, 5-day and 7-day) replicated three times. Randomized Complete Block Design (RCBD) was used. Therefore, there were forty five (45) basins (2 m × 2 m) separated by 2 m (buffer zone) each. The total area of the field was 0.1 ha (see Appendix A).

3.3 Field Operation

The experimental field was ploughed and harrowed for better root development. The tomato seedlings were transplanted after thirty days of nursery. The

seedlings were planted at 40 cm row spacing. One seedling was planted in each hole making a total of 25 plants per basin. The size of each basin was 2 m by 2 m. This size was selected based on the topography of the field and soil type and the common practice by the farmers. Uniform quantity of water was applied to all the basins for three weeks to allow for crop establishment before the treatments were imposed. Fertilizer application was done twice for the period of the experiment. The first application was done two weeks after transplanting while the second application was done six weeks after transplanting. Combination of both NPK and Urea was used at the rate 110 kg/ha of N, 30 kg/ha of P and 150 kg/ha of K as recommended by FAO (2007). Weeding was done as the need arose. Harvesting was started 90 days after transplanting and lasted for a period of 25 days. There was an incidence of disease, which was adequately controlled through consultation with the Pest Control Unit of the Bauchi State Agricultural Development Project (BSADP)

3.4 Determination of Soil Physical Properties

In order to know the type and relevant physical properties (such as water holding capacity, particle size, bulk density, etc) of the soil, samples were collected from five points in the farm. The samples were taken at the depth 0-20cm, 20-40 and 40-60cm considering the effective crop rooting depth. Particle size analysis was conducted using the hydrometer method as detailed by Loveday (1974). The core sampling method was used for the determination of soil bulk density.

3.5 Determination of Soil Moisture Content

The amount of water depleted from the soil between successive irrigations was determined through the use of resistance blocks (watermark sensors). Measurement of the soil moisture suction was done at the depths of 0-30 cm and 30-60 cm.

3.6 Measurement of Irrigation Water

The irrigation water applied (IRR) was measured with a calibrated cutthroat flume. Irrigation was done at intervals of three days, five days and seven days in accordance with the experimental treatments.

3.7 Determination of Crop Yield

The yield of the crop was determined by measuring the weight of the tomato fruits harvested from each basin. So the weight of tomato fruits to fill an average marketable basket was also determined for the basins.

3.8 Determination of Optimum Irrigation Practice

Optimum irrigation practice was determined based on the method reported by Wu and Liang (1972) as summarized by Benemi and Ofen (1984), using this method:

Yield in ₦ per hectare was plotted against available soil water (mm) held in the root zone prior to irrigation and from the plot; the optimum available water was obtained at the point when yield is at maximum.

Cost (C_1) incurred when available water (M_a)> optimum (M_o) and cost (C_2) incurred when available water < optimum (M_o) was determined from the results as follows:

$$C_1 = \frac{R_3 - R_1}{(m_1 - m_0) \times D} \quad (3.1)$$

$$C_2 = \frac{R_3 - R_2}{(m_0 - m_2) \times D} \quad (3.2)$$

where:

R_1 = Revenue in ₦/ha at 3 days irrigation interval

R_2= Revenue in ₦/ha for 5 days irrigation interval

R_3 = Revenue in ₦/ha for 7 days irrigation interval

m_0 = Available moisture for optimum revenue (mm)

m_1 = Available moisture for 3 days irrigation interval (mm)

m_2 = Available moisture for seven days irrigation interval (mm)

D = number of days of an irrigation season (days)

C_1 and C_2 are constants.

Optimum irrigation water applied and optimum irrigation interval were determined following the model used by Wu and Liang as depicted by Figure 3.1

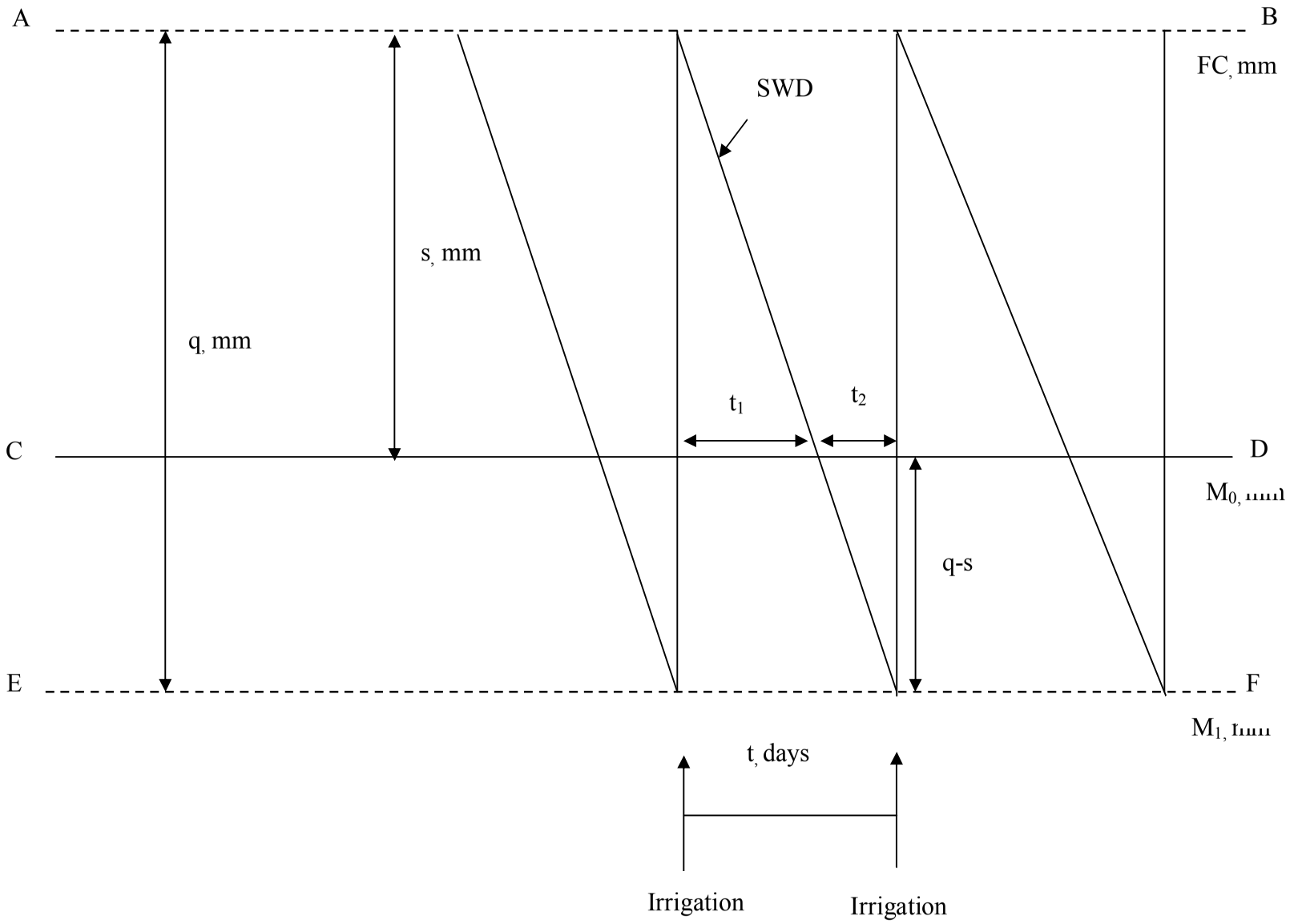


Figure 3.1: Model used in the analysis

From Figure 3.1:

SWD represents Soil Water Depletion

AB represents moisture content at field capacity (FC)

CD is an imaginary line between AB and EF representing optimum existing moisture (M_o) – simply the critical point

EF represents available moisture prior to any irrigation (M_i)

From the Figure 3.1 the following relationships are observed based on similar triangles

$$\frac{t_1}{t} = \frac{s}{q}; \quad t_1 = \frac{s}{q}t \tag{3.3}$$

$$\frac{t_2}{t} = \frac{q-s}{q}; t_2 = \frac{q-s}{q}t \tag{3.4}$$

Where:

t_1 = the number of days during an irrigation interval that the available soil water exceeds optimum (M_o). Number of days the SWD reaches CD

t_2 = the number of days during an irrigation interval that the available soil water is exceeded by optimum (M_o). Number of days SWD reaches EF

s = quantity of irrigation applied when available water is at optimum in mm

q = quantity of irrigation in mm

The area of the triangle having a base t_1 and height s depicts the available soil-water in excess of M_o in mm-days, during an irrigation interval of t days. This area is computed from:

$$\frac{s}{q}t \times \frac{s}{2} = \frac{s^2 t}{2q} \quad (3.5)$$

The available soil moisture (in mm) exceeding optimum (M_o) each day is derived by dividing Eqn. (3.3) by the number of interval-days, t. Thus

$$M_e = \frac{s^2 t}{2q \times t} = \frac{S^2}{2q} \quad (3.6)$$

Cost incurred due to loss of yield when available water (M_a) > optimum, M_o is derived when eq 3.6 is multiplied by C_1

$$K_1 = C_1 \frac{S^2}{2q} \quad (3.7)$$

Cost incurred due to loss of yield when available water (M_a) < optimum, M_o the triangle having the base t_2 and height (q-s) is considered. then following the same as before:

$$K_2 = C_2 \frac{(q-s)^2}{2q} \quad (3.8)$$

Cost of labour and water is given by

$$K_3 = C_3 \frac{ET}{q} \quad (3.9)$$

where; $\boldsymbol{C_3}$ = cost of water + cost of labour for each application

ET = evapotranspiration in mm/day

Total cost:

$$K_t = C_1 \frac{S^2}{2q} + C_2 \frac{(q-s)^2}{2q} + C_3 \frac{ET}{q} \quad (3.10)$$

Optimum irrigation practice is obtained by differentiating Eqn 3.10 with respect to s and q and the derivatives set equal to zero. This results to

$$q_o = \sqrt{2ETC_3}\sqrt{\frac{C_1+C_2}{C_1C_2}} \quad (3.11)$$

$$S_O = \frac{q_o C_2}{C_1+C_2} \quad (3.12)$$

where: q_o = optimum quantity of irrigation water in mm

Initial soil water at which irrigations are to be started is given by

$$M_i = M_o + S_o - q_O \quad (3.13)$$

Optimum irrigation interval is given by

$$t_o = \frac{q_o}{ET} \quad (3.14)$$

The method proposed by Wu and Liang could, no doubt, be helpful to planners in areas where data from field experiment are available. With q_O, t_o, and M_i known, both the design and operation of irrigation systems become more efficient, and can be expected to result in maximum crop yields at minimum system costs (Benemi and Ofen, 1984).

3.9 Data Analysis

The data collected was analysed using the statistical analysis of variance using a software Mstat-c

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Tomato Yield

The effects of the treatments (percentage levels of replacement of soil moisture depleted and irrigation intervals) on the yield of tomato in Bauchi, 2012/2013 dry season are shown in Table 4.1. The least yield was obtained from the plot treated with 40 % replacement of moisture depleted and 7 days irrigation interval ($A_{40}I_7$). The highest value of the tomato yield was obtained from the plot treated with 60 % replacement of moisture depleted and 3 days irrigation interval ($A_{60}I_3$). The yield obtained from this study ranges from 10.90 t/ha to 28.22 t/ha. These values are a bit higher than what is obtained in Bauchi. A range of 5 t/ha to 13 t/ha was reported by (BSADP, 2012).

Table 4.1: Tomato yield obtained in Bauchi in 2012/2013 dry season

Treatment	Replacement (%)	Irrigation Interval (Days)	Yield (t/ha)
$A_{100}I_3$	100	3	23.52
$A_{100}I_5$	100	5	25.52
$A_{100}I_7$	100	7	16.04
$A_{80}I_3$	80	3	25.07
$A_{80}I_5$	80	5	26.6
$A_{80}I_7$	80	7	17.67
$A_{60}I_3$	60	3	27.3
$A_{60}I_5$	60	5	28.22
$A_{60}I_7$	60	7	18.67
$A_{50}I_3$	50	3	20.51

Treatment	Replacement (%)	Irrigation Interval (Days)	Yield (t/ha)
$A_{50}I_5$	50	5	21.21
$A_{50}I_7$	50	7	13.68
$A_{40}I_3$	40	3	16.80
$A_{40}I_5$	40	5	16.34
$A_{40}I_7$	40	7	10.90

A= percentage replacement of soil moisture depleted I = Irrigation Interval

Table 4.2 shows the statistical means of tomato yield at 5 % level of probability with respect to different levels of replacement of moisture depleted. The highest yield of 24.74 t/ha was obtained at 60 % level of replacement of moisture depleted. This value was statistically similar to 23.11 t/ha at 80 %. The lowest yield of 14.68 t/ha was obtained from 40 % level of moisture replacement. The results indicated that high yield could be achieved by replacing 60 % of the water used by the crop.

Table 4.2: Mean Tomato yield for percentage of soil moisture replacement in Bauchi, 2012/2013 dry season

Replacement	Yield (t/ha)
A_{100}	21.56b
A_{80}	23.11a
A_{60}	24.74a
A_{50}	18.47c
A_{40}	14.68d
S.E	0.7

Means followed by the same letter are statistically similar at 5% level of significance

Table 4.3 shows that the highest yield was obtained when the irrigation interval was 5 days (23.50 t/ha) which is statistically similar to 22.65 t/ha obtained when the irrigation interval was 3 days. The lowest yield of 15.39 t/ha was obtained when the irrigation interval was 7 days.

Table 4.3: Mean Tomato yield for irrigation interval in Bauchi, 2012/2013 dry season

Irrigation Interval	Yield (t/ha)
I_3	22.65a
I_5	23.50a
I_7	15.39b
S.E	0.54

The results of the effects of the interaction between moisture replacement and irrigation interval on the yield of tomato are shown in Table 4.4. The results indicate that across all levels of irrigation interval, replacement levels of 80 % and 60 % recorded highest yield (similar) of tomato. The results revealed that good yield of tomato can be obtained by replacing only 60 % of the water used by the crop when irrigation interval is kept at 5 days.

Table 4.4: Effects of replacement/irrigation interval interaction on Tomato yield in Bauchi, 2012/2013 dry season

	Yield (t/ha)		
Treatments	I_3	I_5	I_7
A_{100}	23.52b	25.11a	16.04f
A_{80}	25.07a	26.60a	17.67d
A_{60}	27.34a	28.22a	18.66d
A_{50}	20.51c	21.21c	13.68g
A_{40}	16.79e	16.34f	10.9h
S.E	1.212		

4.2 Seasonal Water Applied and Seasonal Water Use

The effects of moisture replacement on seasonal water applied and seasonal water use is shown in Table 4.5. The results showed that application depth and seasonal water use decrease with decrease in percentage replacement of moisture depleted. The range of the application depth was 775 mm for 100 % level of moisture replacement to 310 mm for 40 % level of moisture replacement. Similarly, seasonal water use decreased with decrease in moisture replacement. For 100 % level of moisture replacement, the seasonal water use was 611 mm, while for 40 % level of moisture replacement it was found to be 242 mm.

Table 4.5: Means of application depth and seasonal water use as affected by moisture replacement

Replacement	Application depth	Seasonal water use
A_{100}	774.7a	611a
A_{80}	619.7b	491b
A_{60}	464.7c	371c
A_{50}	387.7d	304d
A_{40}	310e	242e
S.E	17.55	17.07

Table 4.6 shows the results of application depth and seasonal water use as affected by irrigation interval. The highest application depth of 537 mm was obtained when the irrigation interval was 7 days (I_7), followed by a statistically similar value of 508 mm at 5 days (I_5) irrigation interval. The lowest value of the application depth was 490 mm at irrigation interval of 3 days (I_3). The seasonal ET (water use) was found to be 427 mm at irrigation interval of 7 days. For 5 days irrigation interval, the ET was 404 mm which is similar to that of 7 days. The lowest seasonal water use was 381 mm at 3 days irrigation interval.

Table 4.6: Means of water applied and seasonal water use as affected by irrigation interval

Treatments	Application depth	Seasonal water use
I_3	489.8b	308.7b
I_5	507.6a	404.0a
I_7	536.6a	426.9a
S.E	13.60	13.22

The effect of moisture replacement and irrigation interval interaction on the application depth and water use of tomato was observed and the result presented in Table 4.7. From the results, it was found that when moisture replacement is given at 100% throughout the three levels of irrigation interval (3, 5 and 7 days), the values of application depth for the season where found to be 742 mm, 769 mm and 813 mm, respectively. These values are statistically similar. When moisture replacement was kept at 40% percent, the values of depth of water applied were 297 mm, 308 mm and 325 mm at irrigation intervals of 3, 5 and 7 days, respectively. For seasonal water use (ET), the results were that at 3 days irrigation interval the ET was 230 mm, at 5 days it was 216 mm and at 7 days it was 279 mm.

Table 4.7: Means of application depth and seasonal water use as affected by moisture replacement and irrigation interval

Treatment	Application Depth (mm)		
	I_3	I_5	I_7
A_{100}	742a	769a	813a
A_{80}	594b	615b	650b
A_{60}	445c	461c	488c
A_{50}	371d	341d	325c
A_{40}	297f	308f	325e
S.E	30.40		
	Seasonal water use (mm)		
A_{100}	587.3a	615a	631.3a
A_{80}	467c	478.7c	527.3b
A_{60}	356.7e	369e	387e
A_{50}	267g	341.3e	309e
A_{40}	230.7h	216h	279.3f
S.E	29.57		

4.3 Crop Water Use Efficiency (CWUE) and Irrigation Water Use Efficiency (IWUE)

The results of the effects of moisture replacements on CWUE and IWUE are presented on Table 4.8. The highest value of CWUE was found to be 68.33 kg/ha-mm at 60 % level of moisture replacement. The lowest value of CWUE was 35.58 kg/ha-mm at 100 % level of moisture replacement. Similarly, the highest value of IWUE of 54.60 kg/ha-mm was found at 60 % level of moisture replacement with lowest value of 28.23 kg/ha-

mm at 100 % level of moisture replacement. Sixty percent (60 %), 50 % and 40 % recorded similar values of CWUE. Doorenbos and Kasam (1986) reported that the FAO range of CWUE for Tomato was 100 to 120 kg/ha-mm. However, Othman (2001) reported a CWUE of 71.16 kg/ha-mm in Bauchi and Mofoke (2000) reported a range of 27 to 123 kg/ha-mm for eight *Fadama* farms in Samaru, Zaria. The results revealed that replacing 100 % of soil moisture depleted gives poor water use efficiency as against replacing certain percentage (e.g 60 %) of the moisture depleted. This implies that efficient use of water resources was ensured with deficit irrigation.

Table 4.8: Means of crop water use efficiency (CWUE) and irrigation water use efficiency (IWUE) as affected by moisture replacement

Replacement	CWUE (Kg/ha-mm)	IWUE (Kg/ha-mm)
A_{100}	35.58c	28.23d
A_{80}	47.65b	37.48c
A_{60}	68.33a	54.60a
A_{50}	61.98a	48.19b
A_{40}	62.90a	47.69b
S.E	2.43	1.751

CWUE = Crop Water Use Efficiency; IWUE = Irrigation Water Use Efficiency

The effect of irrigation interval on CWUE and IWUE is presented in Table 4.9. The highest value of CWUE of 64.57 kg/ha-mm was found at irrigation interval of 3 days. This value was similar to 62.87 kg/ha-mm at 5 days irrigation interval. The lowest value of CWUE was 38.43 kg/ha-mm at 7 days irrigation interval. At 3 days irrigation interval, IWUE was 49.51 kg/ha-mm and at 5 days interval it was 49.58 kg/ha-mm. These values

are statistically similar. The lowest value of IWUE was 30.62 kg/ha-mm. Water Use Efficiencies are high with lower irrigation intervals because higher yields are obtained here than with longer irrigation intervals. Lower values of water use efficiencies at high irrigation intervals is an indication of the lower yields realized from such treatments.

Table 4.9: Means of CWUE and IWUE as affected by irrigation interval in Bauchi, 2012/2013 dry season

Treatments	CWUE (Kg/ha-mm)	IWUE (Kg/ha-mm)
I_3	64.57a	49.51a
I_5	62.87a	49.58a
I_7	38.43b	30.62b
S.E	1.882	1.356

Table 4.10 shows the results of the effects of moisture replacement and irrigation interval interaction on CWUE and IWUE. From the table, the CWUE of 25.3 kg/ha-mm for 7 days irrigation interval was lower than 41.3 kg/ha-mm for 5 days irrigation interval which is statistically similar to 40.1 kg/ha-mm for 3 days irrigation interval when irrigation is given at 100 % replacement of soil moisture depleted. Similar trait was observed when irrigation was kept at any particular level of moisture replacement from 80 % to 40 %. When irrigation was kept at any level starting from 100 % to 40 %, irrigation intervals of 3 days and 5 days recorded higher IWUE than 7 days irrigation interval. It was observed that, across the three levels of irrigation intervals, 60 % level of moisture replacement (i.e A_{60}) recorded the highest value of IWUE.

Table 4.10: Effect of replacement and irrigation interval interaction on CWUE and IWUE in Bauchi, 2012/2013 dry season

	CWUE (kg/ha-mm)		
Treatment	I_3	I_5	I_7
A_{100}	40.1f	41.3e	25.3f
A_{80}	53.7c	55.6c	33.6g
A_{60}	76.7a	79.3a	49.0d
A_{50}	79.1a	62.5b	44.3d
A_{40}	73.2a	75.7a	39.9f
S.E	4.21		
	IWUE (Kg/ha-mm)		
A_{100}	31.74e	33.23d	19.71g
A_{80}	42.03c	43.23c	27.17f
A_{60}	61.72a	63.22a	38.86c
A_{50}	55.53a	55.17c	33.87c
A_{40}	56.53a	53.03b	33.49d
S.E	3.03		

4.4 Economics of Tomato Production

Table 4.11 shows the economics of production which includes cost of water application and savings from reduction in the quantity of water applied for the various levels of moisture replacements. The result shows that there was savings in cost of water application when quantity of moisture replacement was reduced. The highest savings was achieved with 40 % level of moisture replacement. However, 60 % level of moisture of replacement

justified the savings with the highest net revenue. It is therefore noted that replacing maximum quantity of water used does not necessarily leads to obtaining maximum economic benefit.

Table 4.11: Revenue per unit of water applied for the various levels of moisture replacement

Replacement (%)	Yield (t/ha)	Irrigation Amount (mm)	COW (N/mm)	Net Revenue (N/ha/mm)	Savings (N/ha/mm)
100	21.56	775	21	1117	0
80	23.11	620	21	1376	3255
60	24.74	465	21	1974	6510
50	18.47	389	20	1761	8106
40	14.68	310	21	1754	9765

COW=Cost of Water Application

4.4 Optimum Irrigation Schedules for Tomato

Table 4.11 presents the results of the economic analysis (Section 3.8) performed to determine optimum schedules for irrigated tomato in Bauchi in 2012/2013 dry season. The results included the values of optimum irrigation quantity, available moisture prior to irrigation and the optimum irrigation interval for various levels of moisture replacement. The optimum irrigation was higher, 759 mm per season, when the replacement was 100 %. It therefore decreased with decrease in percentage moisture replacement. The optimum irrigation interval ranges from 10 to 19 days for 100 % through 40 % of moisture replacements as shown in Table 4.12. Samail *et al.,* (2011) reported that irrigation interval

of 10 days gives best result. This agrees with the optimum irrigation interval recorded for 100 % and 80 % level of moisture replacements. However, it is reported by Ramalan, (1994) that the common practice in the semi arid region is 7 days. Optimum irrigation interval increases with decrease in percentage replacement. This is because minimum cost of water application is targeted by the economic analysis so that maximum net revenue could be obtained. Since lower percentages of moisture replacements produced lower yields, the analysis reduces the frequency of irrigation so that farmers can recover their investments. The economic analysis showed that maximum net revenue could only be obtained by using the optimum schedules. The optimum schedules imply that when percentage moisture replacement is reduced, which leads to reduced yield, irrigation interval should be increased.

Table 4.12: Optimum irrigation schedules for tomato in Bauchi, 2012/2013 dry season

	Replacement (%)				
Scheduling Parameters	100	80	60	50	40
Optimum irrigation (q_o) per season, mm	759	633	450	405	315
Optimum irrigation depth per application , mm	66	55	43	42	52
Available Moisture (M_i), mm	15	20	16	27	32
Irrigation (S_o), @ M_o per season, mm	518	449	335	306	280
Optimum Irrigation Interval (t_o), days	10	10	11	12	19

Details of the procedure for calculating the above optimum scheduling values is presented in Appendix C

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMENDATIONS

5.1 Summary

A field experiment was conducted in Bayara village, Bauchi local government area of Bauchi State, Nigeria. The experiment was aimed at determining the optimum water use of tomato grown under *Fadama* conditions. The effects of various levels of moisture replacement and irrigation interval on the crop yield, seasonal water use, water application and water use efficiency were determined. Optimum irrigation schedules were also determined. The crop yield realized ranges from 10.9 t/ha for $A_{40}I_7$ to 28.22 t/ha for $A_{60}I_5$. The highest value of irrigation water applied of 774 mm was recorded at 100 % level of moisture replacement, while the lowest was 310 mm at 40 % level of moisture replacement. Crop water use was 611 mm at 100 % level of moisture replacement and 242 mm at 40 % level of moisture replacement. The highest irrigation water use was 536.6 mm when the irrigation interval was 7 days. Crop Water Use Efficiency (CWUE) was 68.33 kg/ha-mm at 60 % level of moisture replacement and 35.58 kg/ha-mm at 100 % which was the lowest. Irrigation Water Use Efficiency (IWUE) was 54.60 kg/ha-mm at 60 % moisture replacement and 28.23 kg/ha-mm at 100 %. When the irrigation interval was 3 days the CWUE and IWUE were 64.57 kg/ha-mm and 49.58 kg/ha-mm, for 5 days irrigation interval they were 62.87 kg/ha-mm and 49.58 kg/ha-mm and for 7 days irrigation interval they were 38.43 kg/ha-mm and 30.62 kg/ha-mm, respectively. The economic analysis revealed that the highest optimum irrigation water was 759 mm per season for 100 % level of moisture replacement and the lowest is 315 mm per season for 40 % level of moisture

replacement. The optimum irrigation interval was 10 days for 100 %, 10days for 80 %, 11 days for 60 %, 12 days for 50 %, and 19 days for 40 % levels of soil moisture replacement.

5.2 Conclusion

The results of the study revealed that tomato yield is influenced by varying the level of replacement of soil moisture depleted. It was observed that replacing maximum water used by the crop does not necessarily produce the maximum yield. The highest yield was obtained from the plots irrigated by replacing 60 % percent of moisture depleted every 5 days.

The water use efficiencies were evaluated and it was observed that efficient use of water is ensured by deficit irrigation. The lowest water use efficiencies were observed from plot treated by replacing 100 % of soil moisture depleted, while the highest water use efficiency was recorded for plots irrigated with 60 % replacement.

Optimum irrigation schedules were determined for tomato production in Bauchi. It was observed that the optimum application depth for 100 % replacement was 759 mm per season. The depth of water for an irrigation event was 66 mm. This amount should be applied through an optimum irrigation interval of 10 days. In order to achieve maximum net revenue, the optimum scheduling tends to minimize the cost of production by reducing either the depth of water applied or its frequency.

5.3 Recommendations

The following recommendations were drawn from this study

1. A similar study could be conducted in different parts of the country to obtain adequate information so that general conclusion could be drawn on water utilization for tomato production in Nigeria.
2. Since other important crops are also being produced by the farmers, these crops should also be considered by researchers as far as optimum utilization of water resources is concerned.
3. Mulching can be tried together with the procedure used in this study to determine the effect of mulch on the optimum water use of tomato for even longer irrigation intervals

REFERENCES

Ali, M. H. (2010). *Fundamentals of Irrigation and on Farm Water Management*. Springer Science and Business Media, LLC. London.

Benemi, A. S and Ofen, A. (1984). *Irrigation Engineering. Irrigation Engineering* Seintific Publications, Israel.

Bergson, G. B. (2012). Crop Evapotranspiration and Water Use Efficiency, Irrigation Systems and Practices. In: Challenging Environments, Teang S. (Ed.), Retrieved on 2nd may, 2013

From http://www.intechopen.com/books/irrigation- systems-and-practices-in-challengingenvironments

BSADP. (2012). Agricultural Production Survey of Bauchi State Agricultural Development Project. Unpublished. BSADP, Bauchi, Nigeria.

Burman, R. D., Cuenca, R. H. and Weiss A. (1983). Techniques for Estimating Irrigation Water Requirements. In: D. Hillel, (Ed.) *Advances in Irrigation* Vol. 2 Academic Press, New York, 336-391.

Burman, R. D., Nixon P. R., Wright J. L. and Pruitt, W. (1980). Water Requirements In: M. E. Jensen (Ed) *Design and operation of farm irrigation systems*. ASAE Monograph 3: 189-225

Doorenbos and Kassam (1979). Yield Response to water. FAO Irrigation and Drainage paper 33. Rome, Italy.

Doorenbos, J. and Pruitt, W. (1977). Guidelines for predicting crop water requirements. FAO Irrigation and Drainge Paper 24. Rome, Italy.

English M. J., Kenneth H. S., and Glenn, J. H. (2002). A Paradigm Shift in Irrigation Management. *Journal of Irrigation and Drainage Engineering,* 128(5): 267-277

English, M. (2002). Irrigation advisory services for optimum use of limited Water. *Irrigation Advisory Services and Participatory Extension in Irrigation Management*. FAO-ICID Workshop. Montreal, Canada.

English, M. (1990). Deficit irrigation. I . Analytical framework. *J. Irrig. Drain E. ASCE* 116, 399–412.

FAO (2007). Fertilizer Recommendations. Retrived, 12th August, 2012

from www.fao.org/docrep

Fereres, E and Soriano, M. A (2007). Deficit Irrigation for Reducing Agricultural Water Use. *Journal of Experimental Botany, Vol. 58, No.2, pp. 147–159.* Retrieved, 8th May, 2013

from http://www.riegoyfertirriego.com/IV_Jornadas/Conferencias

Geerts, S. and Raes, D. (2009). Deficit Irrigation as an on-farm strategy to maximize crop water productivity in dry areas. *Agricultural Water Management*, 96 pp 1275-1284.Retrieved, 6th May, 2013

from www.elsevier.com/locate/agwat

Giannoccaro, G., J. M. Piston, S. Kolberg and J. Berbel (2009). Comperative analysis of water saving policies: pricing versus Quatas Retrieved, 6th May, 2013 from **http://ressources.ciheam.org/om/pdf/a88/00801198.pdf**

Hassan I. M, Elsadig E. A., Omran M. A. and Abdel Moneim E. M. (2010). Water Allocation and Optimization of Minor Canal Operation. *Agriculture and Biology Journal of North America,*1(5): 1031-1043

Hillel, D. and Guron, Y. (1973). Relationship between evapotranspiration rate and maize yield. Water resources res. Vol. 8. Springer-Verlang, Berlin.

Irmak, S.,Odhiambo, O. L., Kranz, W. L (2011). Irrigation Efficiency and Uniformity and Water Use Efficiency. Retrieved, 2nd May, 2013

From *http://extension.unl.edu/publications*

James, L. G. (1988). *Principles of farm irrigation design*. John Wiley and Sons, New York

Kyamu, K. (2001). Ecological Sustainability of Pady Soils. Internal Seminar on Appropriate use of Fertilizer. In: Ahmed, Freny, Kyamu and Mutert (Eds), Taiwan R. D. C. 6th to 14th August 2001.

Loveday, J. (1974). Methods of Analysis of Irrigated Soils. *Technical Communication of the Commonwealth Bureau of Soils.* No. 54. Australia.

Michael, A. M. (1978). *Irrigation, Theory and Practice*. Vani Education books, India.

Mofoke A.L.E., Ahmed A. and Mudiare O.J. (2002). Eevaluation of Fadamam Irrigation Efficiencies around Samaru, Zaria, Nigeria. *Journal of Agriculture and Environment*. 3(2): 319-329, Faculty of Agriculture, Usaman Danfodio University, Sokoto Nigeria.

Mofoke, A. L. E (2002). Performance Evaluation of Fadama Irrigation Practice. Unpublished M.ScThesis. Submitted to the Department of Agricultural Enineering, Ahmadu Bello University, Zaria, Nigeria

Mofoke, A. L. E. (2006). Design, Construction and Evaluation of Continuous Flow Drip Irrigation System. Unpublished PhD Thesis.Submitted to the Department of Agricultural Enineering, Ahmadu Bello University, Zaria, Nigeria.

Oladoja, M. A. and Adeokun, O. A. (2009). An Appraisal of National Fadama Development Project (NFDP) in Ogun State, Nigeria. Retrieved, 14th April, 2013 from www.medwelljournals.com.

Othman, M. K., (2001). Effects of mulch on water use for some common vegetables *Fadama* crop in Bauchi. Unpublished MSc Thesis. Ahmadu Bello University, Zaria

Owonubi, J. J., Malgwi, W. B. and Kparmwang. T (1994). Utilzation and sustainabillty of *Fadama* in Northern Nigeria: Soil fertility and water conservation practices. In: Kolawole, A., Scoones I., Awogbade, M.O and Voh, J. P. (Eds). *Strategies for the Sustainable Use of Fadama Lands in Nigeria*. IIED and CSER Zaria: 123-137

Ramalan, A. A. (1994). Irrigation and Environment: The State of Research a Development at the Institute of Agricultural Research,IAR,Samaru. NOMA Magazine, (II): 16-19.

Rijov, S. N., Hagan, R.M and Aston, M. J. (1973). Water, Plant Growth and Crop Irrigation Requirements. In: Kovda, V. A., Berg C. V. and Hagan R. M (Eds). *Irrigation, Drainage and Salinity*. Hutchinson and Co. Ltd: 206-251.

Roost, N. (2002). Strategic Options Analysis in Surface Irrigation Systems: Integrated Modelling for Efficient, Productive and Equitable Water Use. PhD dissertation. Lausanne, Switzerland: Swiss Federal Institute of Technology (EPFL).

Rosenberg, N. J., Blad, B. L. and Verma S. B. (1983). Microclimate: The Biological Environment. John Wiley and Sons, New York.

Samaila, A. A., Amans, E. B., and Babaji, B. A., (2011). Yield and Fruit Quality of Tomato (*lycorpersiconesculentum mill*)asInfluenced by Mulching, Nitrogen and Irrigation interval.*International Research Jouranal of Agriculture and Soil Science*. 1(3): 99-95

Senyigit, U., Kadayifci, A., Ozdemir, F. O., Oz, H. and Atilgan, A. (2011). Effects of Different Irrigation Programs on Yield and QualityParametersof Eggplant (*Solanum melongena L.*) under greenhouse conditions. *African Journal ofBiotechnology, 10(34), 6497-6503.* Retrieved on 6th May, 2013 from http://www.academicjournals.org/AJB

Shahbaz K., Hector M., Brian D., Aftab A., Shahbaz M and Catherine A. (2007). Optimised Irrigation Productivity and River Health through Pick and Mix Strategies. *CRC for Irrigation Futures, Technical Report* No. 03/07.

Singh, A., Aggarwal, N., Aulakh, G. S. and Hundal, R. K (2012). Ways to Maximize the Water Use Efficiency in Field Crops. A review. *Greener Journal of Agricultural Sciences 2(4), 108-129*. Retrieved, 2nd May, 2013 From http://www.gjournals.org/GJAS

Skaggs, R. W., Miller D. E and Brooks H. R (1980). Soil water. In: (M.E. Jensen, ed). *Desing and Operation of farm Irrigation Systems*, ASAE Monograph, Vol. 3: 77-135

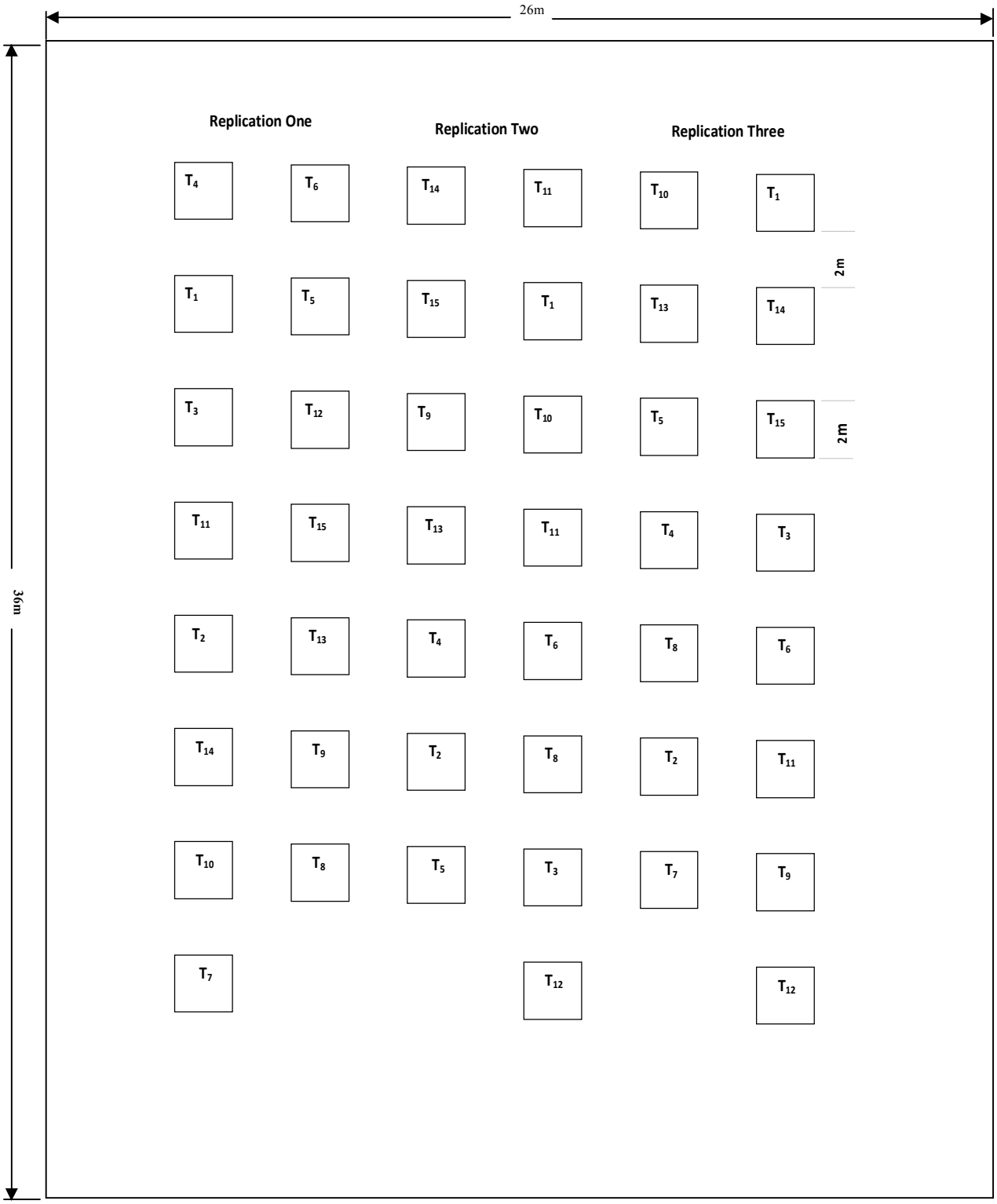
Stegman E.C. and. Hanks R.J. (1980) Irrigation water management. In: Design and Operation of Farm Irrigation System. ASAE monograph 3:763– 816.

Stewart. B. A., Musick, T. J. and Dusek, D. A. (1983). Yield and Water Use Efficiency of Grain Sorghum in a Limited Irrigation-Dryland Farming System. *Agronomy Journal,* vol. 75 pp 629-634.

World Bank, (2011). *Water Resources Management.* Retrieved, 5th October, 2011 from http//water.worldbank.org/water/topics/agricultural water management

Wu, I and Liang, T. (1972). Optimal Irrigation Quantity and Frequency. *Journal of Irrigation and Drainage Division*. ASCE 98(IR 1) pp 117-133

Appendix A: FIELD LAYOUT



Appendix B

TableB1: Experimental Design and Treatments Combinations

Treatment No.	Treatment Code	Treatment combinations	Description of treatment combinations
1	T_1	$A_{100}I3$	100 % replacement @ 3 days interval
2	T_2	$A_{100}I5$	100 % replacement @ 5 days interval
3	T_3	$A_{100}I_7$	100 % replacement @ 7 days interval
4	T_4	$A_{80}I_3$	80 % replacement @ 3 days interval
5	T_5	$A_{80}I_5$	80 % replacement @ 5 days interval
6	T_6	$A_{80}I_7$	80 % replacement @ 7 days interval
7	T_7	$A_{60}I_3$	60 % replacement @ 3 days interval
8	T_8	$A_{60}I_5$	60 % replacement @ 5 days interval
9	T_9	$A_{60}I_7$	60 % replacement @ 7 days interval
10	T_{10}	$A_{50}I_3$	50 % replacement @ 3 days interval
11	T_{11}	$A_{50}I_5$	50 % replacement @ 5 days interval
12	T_{12}	$A_{50}I_7$	50 % replacement @ 7 days interval
13	T_{13}	$A_{40}I_3$	40 % replacement @ 3 days interval
14	T_{14}	$A_{40}I_5$	40 % replacement @ 5 days interval
15	T_{15}	$A_{40}I_7$	40 % replacement @ 7 days interval

Table B2: Physical Properties of Soil in the Experimental Site

Depth (cm)	Bulk Density (g/cm^3)	FC (%) (vol. basis)	PWP (%) (vol. basis)	% Sand	% Silt	% Clay	Soil Texture
0-20	1.55	19	10	74.4	13.28	12.32	Sandy loam
20-40	1.53	20	10	66.4	21.28	12.32	Sandy loam
40-60	1.37	28	17	52.4	27.26	20.32	Sandyclay loam

Appendix C

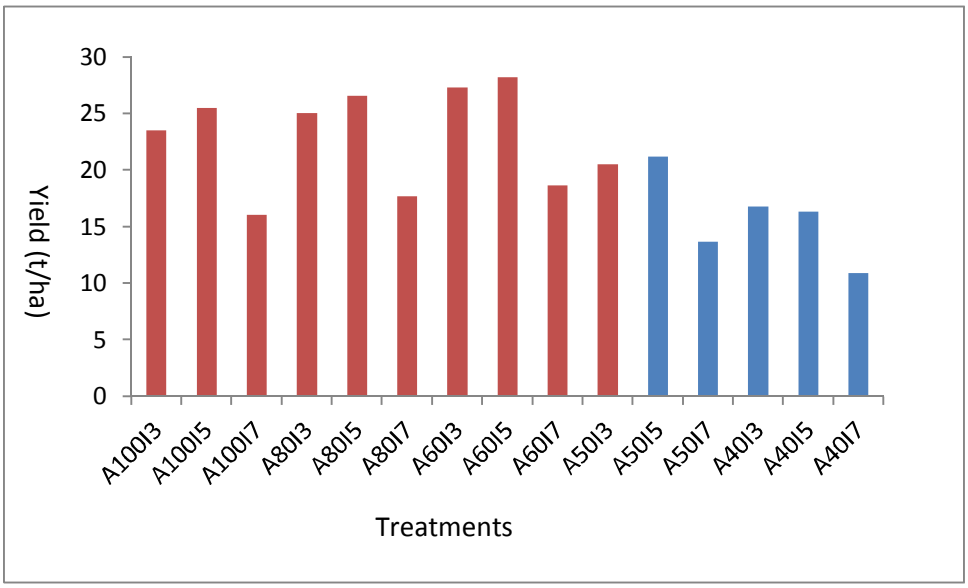


Figure C1: Yield of tomato as influenced by percentage replacement of moisture depleted and irrigation interval

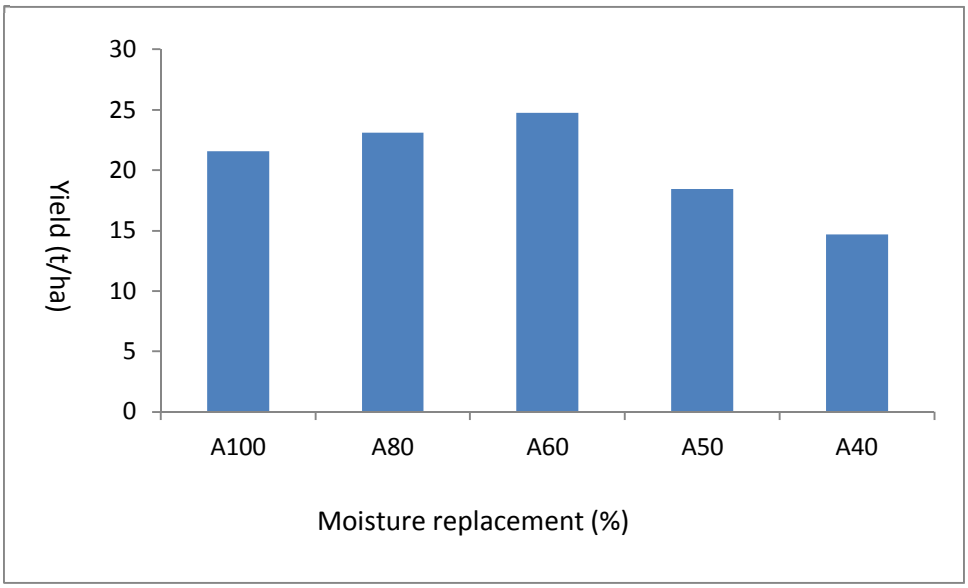


Figure C2: Yield of tomato for percentage of moisture Replacement

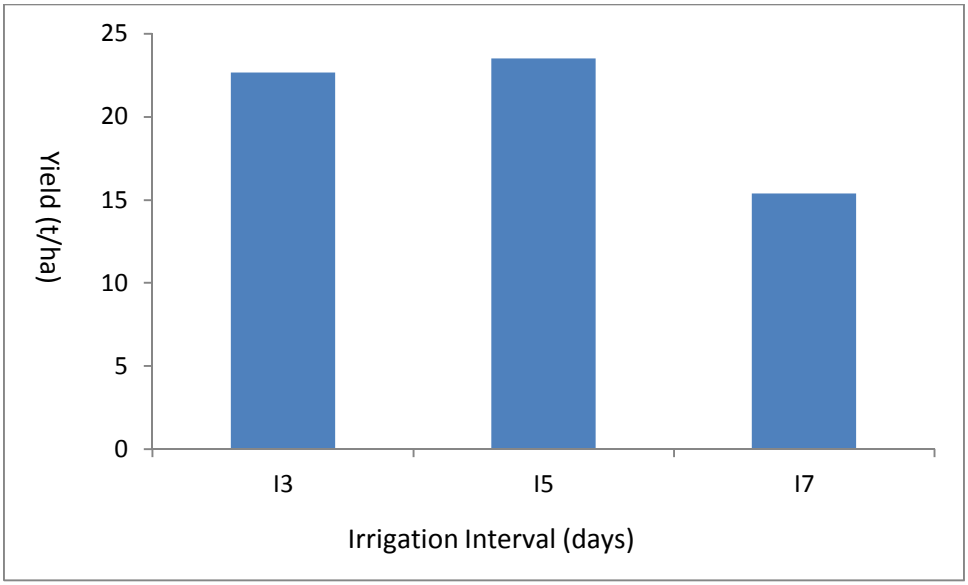


Figure C3: Means of tomato yield as influenced by irrigation interval

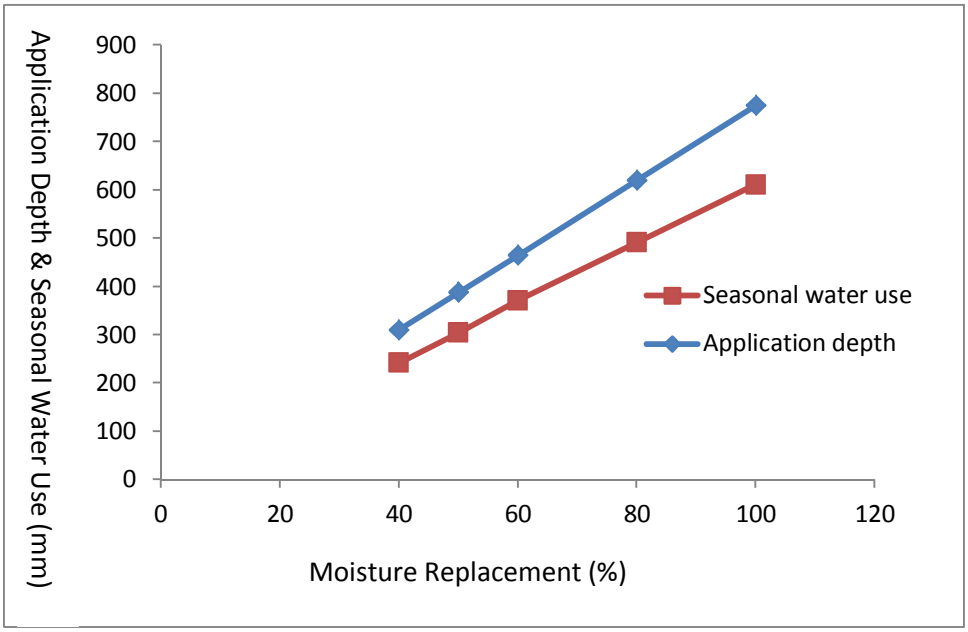


Figure C4: Means of application depth and seasonal water use as affected by percentage replacement of soil moisture depleted

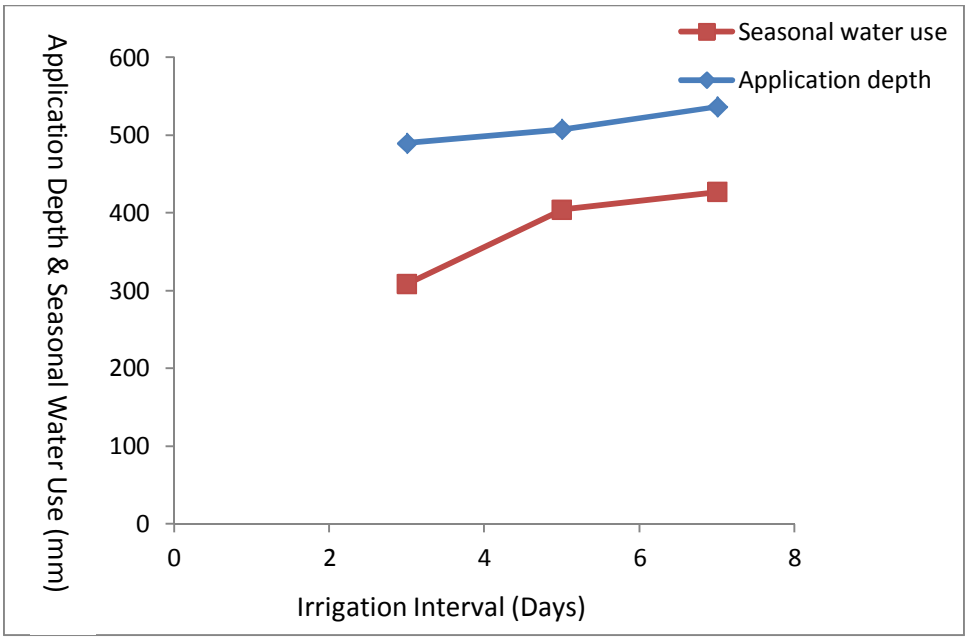


Figure C5: Means of application depth and seasonal water use as influenced by irrigation interval

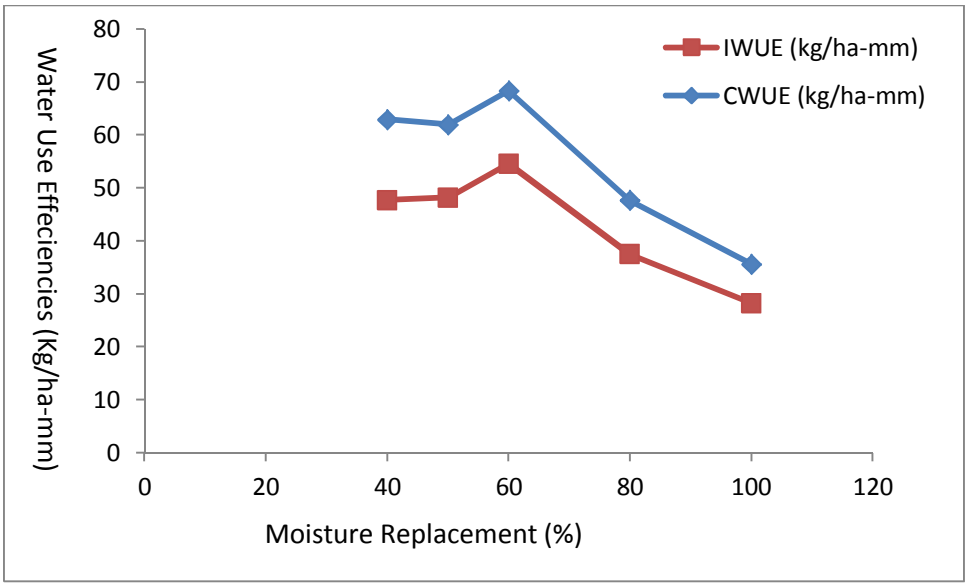


Figure C6: Crop Water Use Efficiency (CWUE) and Irrigation Water Use Efficiency (IWUE) as influenced by percentage replacement of soil moisture depleted

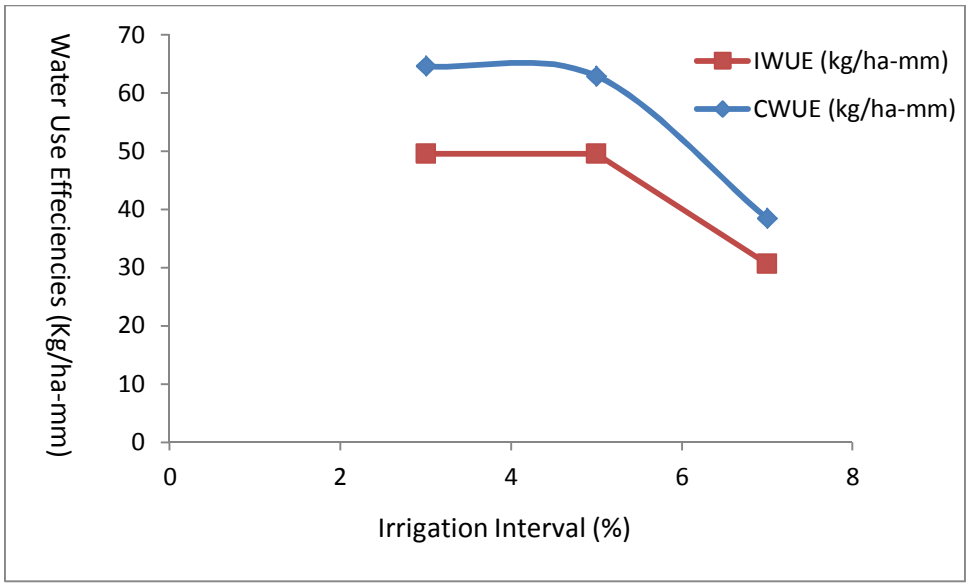


Figure C7: Crop Water Use Efficiency (CWUE) and Irrigation Water Use Efficiency (IWUE) as influenced by irrigation interval

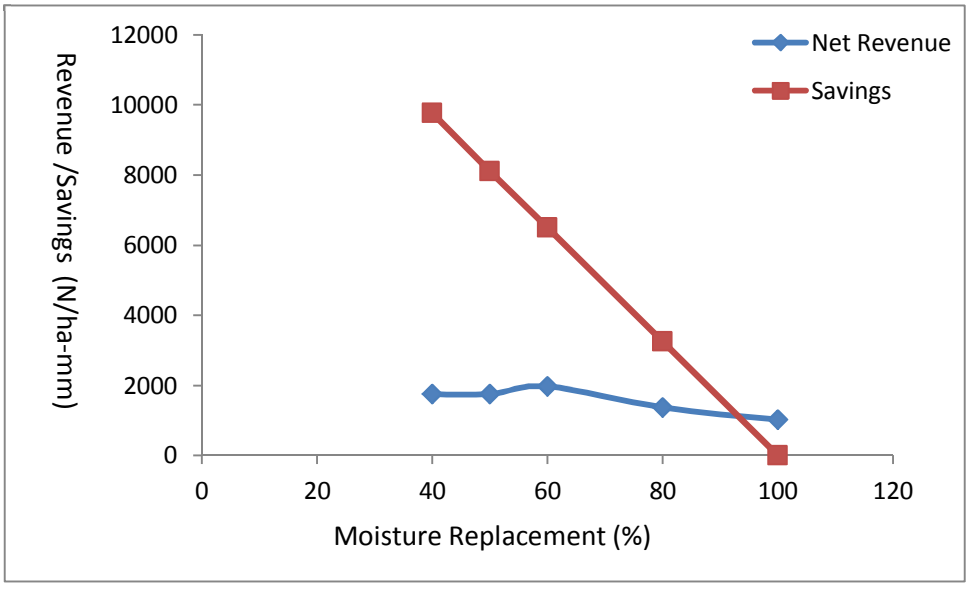


Figure C8: Revenue and savings a influenced by percentage replacement of soil moisture depleted

Appendix D

PROCEDURE FOR CACULATING OPTIMUM IRRIGATION SCHEDULES

Calculating the available soil moisture prior to irrigation:

FC = 22 % volume basis

PW = 12 % volume basis

$TAWC/m = (FC - PW) \times 10$

$= (22 - 12) \times 10$

$= 100mm/m$

FOR DRZ = $0.6m$

$TAWC = 0.6 \times 100$

$= 60mm$

For 7 days irrigation interval

average $ET = 43mm$

$MAD = 43/60 \times 100\ \% = 67\ \%$

$Available\ moisture\ content = 60 - 43 = 17mm$

This value is for 7 days irrigation interval

Similar procedure was followed to calculate available moisture content for 5days and 3days irrigation intervals:

For 5 days irrigation interval available moisture = 33 mm

For 3 days irrigation interval available moisture = 45 mm

Determination of optimum schedules for 100 % moisture replacement

Table D1: Revenue versus available moisture for 100 % moisture replacement

I (Days)	AMC (mm)			YIELD (t/ha)			REVENUE (₦/ha)		
	R1	R2	R3	R1	R2	R3	R1	R2	R3
3	45	44	45	24	23.7	22.87	900000	888750	857625
5	31	33	34	26.1	21.44	27.8	978750	804000	1042500
7	17	19	16	15.58	18.55	13.98	584250	695625	524250

Plot revenue against available moisture to determine the optimum revenue

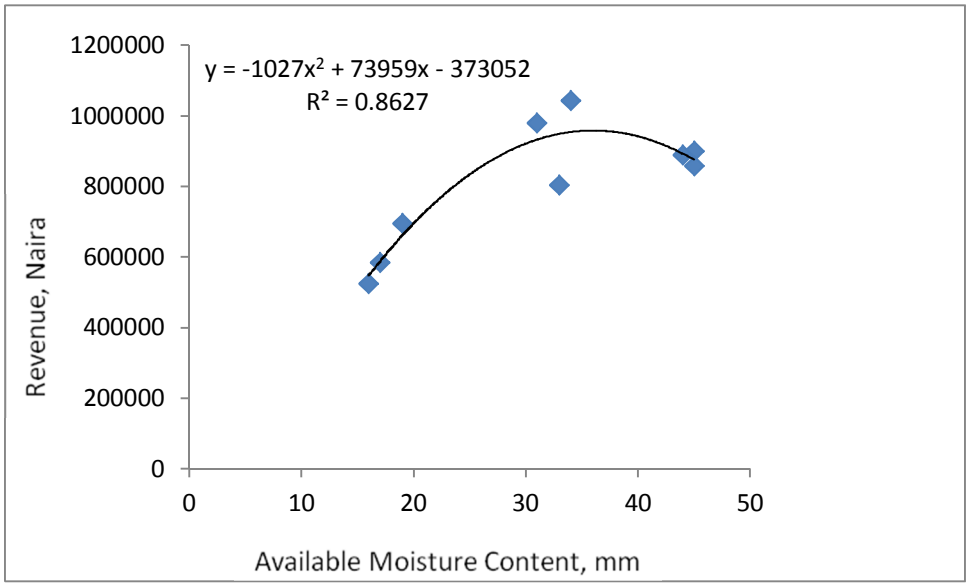


Figure D2: Revenue and available moisture relationship for 100 % level of moisture replacement

From the plot

—

Therefore, M_o=36 mm

Now optimum revenue:

$= ₦958,480\ per\ hectare$

$C_1 = \frac{958,480 - 882,125}{(45 - 36) \times 115} = ₦74\ per\ mm - day - ha$

$C_2 = \frac{958,480 - 601,375}{(36 - 17) \times 115} = ₦163\ per\ mm - day - ha$

$C_3 =$ cost of labour and water

$C_3 = ₦16,500\ per\ hechare$

$ET = \frac{q}{t} = \frac{775}{115} = 6.7\ mmper\ day$

This value is assumed to be constant throughout the season for 100 % replacement

The optimum quantity of irrigation, q is determined as:

$q_o = \sqrt{2ETC_3}\sqrt{\frac{C_1 + C_2}{C_1 C_2}}$

$q_o = \sqrt{2 \times 6.7 \times 16500}\sqrt{\frac{74+163}{74 \times 163}} = 66mm$

The quantity of irrigation applied when available moisture is at optimum;

$S_o = \frac{q_o C_2}{C_1 + C_2}$

$S_o = \frac{47 \times 163}{74+163} = 45mm$

The available moisture content prior to irrigation;

$M_i = M_0 + S_o - q_o$

$M_i = 36 + 56 - 66$

$M_i = 15mm$

The optimum irrigation interval;

$t_o = \frac{q_o}{ET}$

$t_o = \frac{66}{6.7} = 10\ days$

Determination of optimum schedules for 80 % moisture replacement

Table D2: Revenue versus available moisture for 80 % moisture replacement

I (Days)	AMC (mm)			YIELD (t/ha)			REVENUE (N/ha)		
	R1	R2	R3	R1	R2	R3	R1	R2	R3
3	45	44	45	25.6	28.8	20.8	960000	1080000	780000
5	31	33	34	29.8	23.78	26.23	1117500	891750	983625
7	17	19	16	18.8	16.76	17.44	705000	628500	654000

Plot revenue against available moisture to determine the optimum revenue

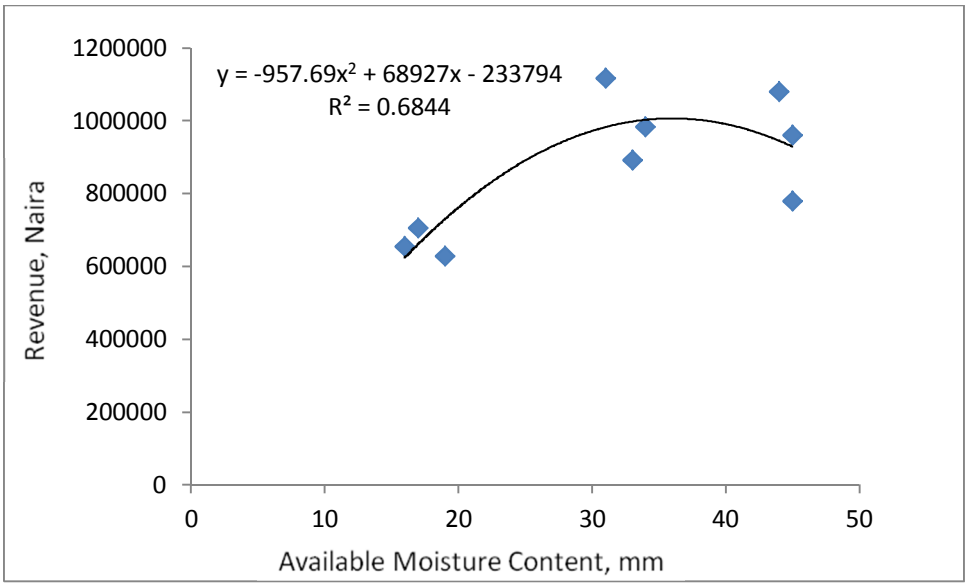


Figure D2: Revenue and available moisture relationship for 80 % level of moisture replacement

From the plot

From the same procedure as for 100 % replacement;

The optimum moisture content,

The optimum revenue was, =

=

=

=

The optimum quantity of irrigation;

$q_o = 55mm$

The quantity of irrigation when the available moisture content is at optimum;

$S_o = 39mm$

The available moisture content;

$M_i = 20mm$

The optimum irrigation interval;

$t_o = 10\ days$

Determination of optimum schedules for 60 % moisture replacement

Table D3: Revenue versus available moisture for 60 % moisture replacement

I (Days)	AMC (mm)			YIELD (t/ha)			REVENUE (N/ha)		
	R1	R2	R3	R1	R2	R3	R1	R2	R3
3	45	44	45	28.64	27.33	26.04	1074000	1024875	976500
5	31	33	34	27.4	29.33	28.03	1027500	1096125	1051125
7	17	19	16	16.6	20.5	18.89	622500	768750	708375

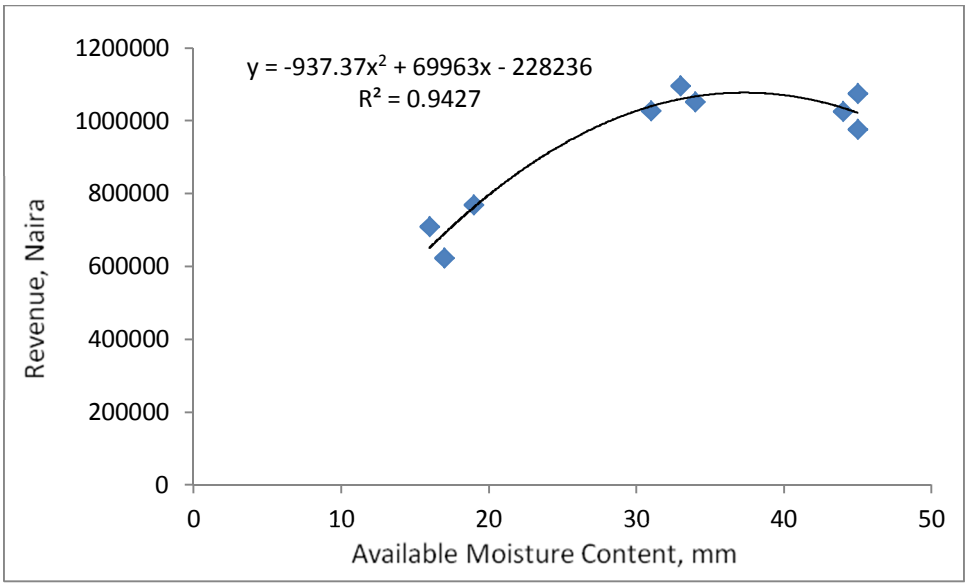


Figure D3: Revenue and available moisture relationship for 60 % level of moisture replacement

From the plot

From the same procedure as for 100 % replacement;

The optimum moisture content,

The optimum revenue was, –

–

–

–

The optimum quantity of irrigation;

$q_o = 43mm$

The quantity of irrigation when the available moisture content is at optimum;

$S_o = 32mm$

The available moisture content;

$M_i = 16mm$

The optimum irrigation interval;

$t_o = 11\ days$

Determination of optimum schedules for 50 % moisture replacement

Table D4: Revenue versus available moisture for 50 % moisture replacement

I (Days)	AMC (mm)			YIELD (t/ha)			REVENUE (n/ha)		
	R1	R2	R3	R1	R2	R3	R1	R2	R3
3	45	44	45	19.44	21.8	20.3	729000	817500	761250
5	31	33	34	23.22	20.08	20.33	870750	753000	762375
7	17	19	16	13.8	12.7	14.54	517500	476250	545250

I=Irrigation Interval

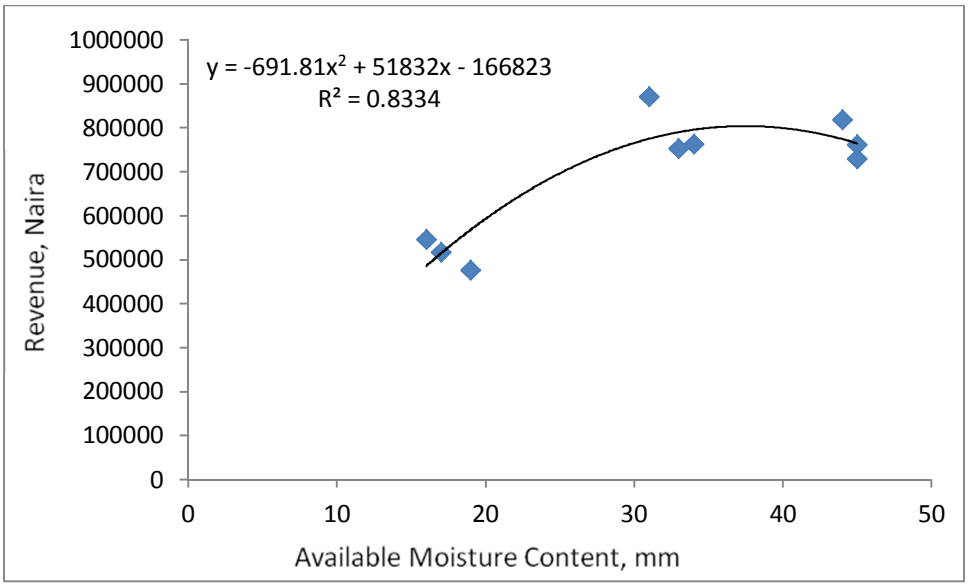


Figure D4: Revenue and available moisture relationship for 50 % level of moisture replacement

From the plot

From the same procedure as for 100 % replacement;

The optimum moisture content,

The optimum revenue was, –

–

–

–

The optimum quantity of irrigation;

$q_o = 42mm$

The quantity of irrigation when the available moisture content is at optimum;

$S_o = 32mm$

The available moisture content;

$M_i = 27mm$

The optimum irrigation interval;

$t_o = 12\ days$

Determination of optimum schedules for 40 % moisture replacement

Table D5 Revenue versus available moisture for 40 % moisture replacement

I (Days)	AMC (mm)			YIELD (t/ha)			REVENUE (N/ha)		
	R1	R2	R3	R1	R2	R3	R1	R2	R3
3	45	44	45	16.3	19.78	14.3	611250	741750	536250
5	31	33	34	16.01	17.76	15.24	600375	666000	571500
7	17	19	16	10.6	9.9	12.2	397500	371250	457500

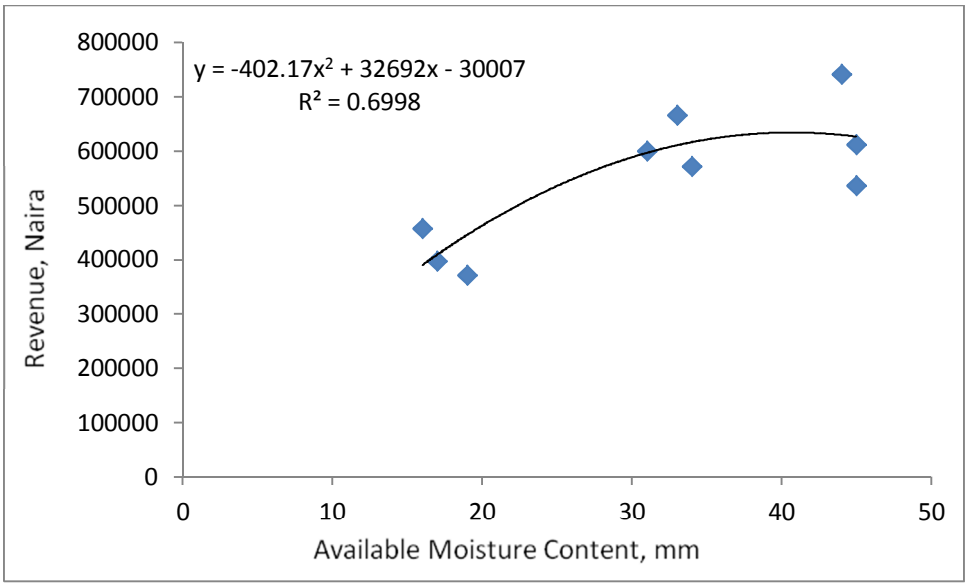


Figure D5: Revenue and Available Moisture Relationship for 40 % level of moisture replacement

From the plot

From the same procedure as for 100 % replacement;

The optimum moisture content,

The optimum revenue was, –

–

–

–

The optimum quantity of irrigation;

$q_o = 50mm$

The quantity of irrigation when the available moisture content is at optimum;

$S_o = 41mm$

The available moisture content;

$M_i = 33mm$

The optimum irrigation interval; $t_o = 19\ days$

Appendix E



Plate 1: Stream at Bayara Village in Bauchi State



Plate 2: Water being pumped for irrigation



Plate 3: Tomato crop growing in the expiremental field



Plate 4: Student taking measurement for soil moisture



Plate 5: Flume used for measuring application depth

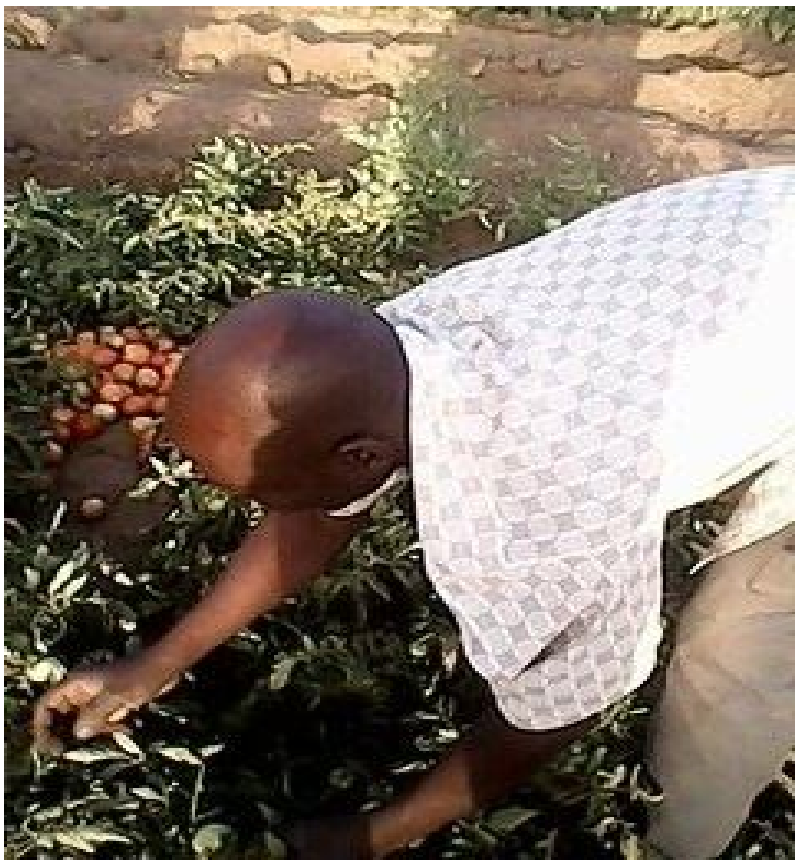


Plate 6: An assistant harvesting tomato crop



Plate 7: Resistance block (water mark sensor) used.