EVALUATION OF SELECTED CROP – YIELD WATER USE MODELS FOR TOMATO (*LYCOPERSICON ESCULENTUM*) UNDER MOISTURE STRESS CONDITIONS.

BY

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DECLARATION

I hereby declare that this thesis has been written by me and that it is a record of my research work. It has not been submitted or accepted in any previous application for a Higher Degree. All sources of information have been duly specifically acknowledged by way of reference.

EMMANUEL SUNDAY OLORUNAIYE **DATE**

CERTIFICATION

This thesis, titled “Evaluation of selected crop-yield-water use models for tomato under moisture stress conditions” by E.S. Olorunaiye meets the regulations governing the award of the degree of Master of Science (Agricultural Engineering) of Ahmadu Bello University, Zaria and is approved to scientific/Technical knowledge and literary presentation.

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To God Almighty through our Saviour and Lord Jesus Christ and to my dear wife Florence Oladunni Olorunaiye.

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ABSTRACT

Two crop yield models, Jensen (1968) and Bras and Codova (1981), multiplicative and additive models respectfully were evaluated by developing a relationship between crop yields and seasonal evapotranspiration for tomato in Kaduna, Nigeria, under conditions of moisture stress caused by evapotranspiration deficits at three growth stages. Tomato (lycopersicon esculentum) TI539 variety was planted in the Kaduna Polytechnic farm, Nariya, Kaduna during the 2005/2006 irrigation season. Evapotranspiration deficits were created by withholding irrigation 3,5 and 7days in excess of the regular 7-days irrigation interval at each of the three stages of growth considered. The stress sensitivity factors for the two models were estimated for the three growth stages studied and their accuracy and predictability of crop yields were also tested. The result showed that strong linear relationships exist between fruit yield and seasonal evapotranspiration within the limits tested. A seasonal evapotranspiration of between 530 and 460mm was observed with a corresponding fruit yield of between 20 – 43t/ha. The two crop yield models evaluated were found to have adequately predicted crop yield with Jensen (1968) giving a better prediction. It was also found from the stress sensitivity factor determined that moisture stress at the vegetative growth stage of tomato will significantly reduce fruit yield.

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Chapter 1 INTRODUCTION

1.1. Background of the study

If irrigated agriculture is to accomplish its main objective of increased crop production through efficient and adequate management of irrigation water, efforts must be made to minimize unnecessary waste of water through proper scheduling, that is, by knowing when to irrigate and the right amount of water to apply. Generally, crop production is adversely affected when water requirement of a crop is not satisfactorily met. In order to forestall this situation, it is important to know the cost of additional water demand by crops and the corresponding increase in yield associated with it. Therefore, for proper evaluation of an irrigation system, knowledge of the relationship between water demand of crops and the subsequent yield is very vital. The water requirements of crop vary from crop to crop considering other factors that may affect it. Also, the way a crop responds to moisture stress in –terms of growth and yield varies with crop species, growth stage and the degree of stress (Kassam and Dooronbos, 1979).

The effect of moisture deficit on crop yield is related to the soil water retention characteristics and also to the climate as expressed by the potential evaporation (Mogensen, 1980). When a crop is exposed to drought for a given period of time, the stress intensity will differ depending largely on the evaporative demand and the crop actual evapotranspiriation at such a growth stage (Igbadun, 1997). For this reason, the intensity of stress imposed on the crop when moisture is withheld for a few days under a high evaporative demand may be higher thereby creating an adverse effect on the crop performance with regards to yield than a long period of withholding moisture under a low evaporative demand.

Therefore, for a better assessment of the effect of moisture stress at the various growth stages, the evaporation deficit and the resulting stress intensities should be considered. Efficient use of water in crop production can only be attained when the planning, design and operation of the water supply and distribution systems are tailored towards meeting in quantity and time, the crop water needs for optimum growth and yield.

In the arid and semi-arid regions where water must be carefully managed, an optimization approach applicable to the use of limited water supply is suggested. This approach is to increase water use efficiency by increasing crop yield and simultaneously applying water in amounts less than the actual evapotranspiration requirement (ET_a). Water management which employs the use of potential evapotranspiration (ET_p) as a guide to irrigation scheduling for high yield can be applicable where land is limited and water supply is unlimited. (Sing, 1981). Such management of a limited water supply results in an inevitable introduction of some evapotranspiration deficit (ET_d) during the cropping season. Thus, the optimal timing of the desired evapotranspiration deficit (ET_d) which results in definable minimum reduction in yield below the maximum becomes very important. This requires quantitative knowledge of the critical growth stages for the crop and the order of their relative sensitivity to water deficit. Therefore, the relationship between water use and crop yield is very important. When studying the question of economic optimal use of water, one needs to know the exact shape of the crop response function to different quantities of water use by the crop throughout the growth stages (Minhas and Parkh, 1974).

It is an established fact that certain growth stages in crops are more sensitive to water deficits than others. Therefore, in order to arrive at an optimal set of decisions, the knowledge of the marginal productivity of water allocated to each crop at different, stages of its growth is required. According to Minhas and Parkh (1974) and Stewart and Hagan (1983), this knowledge is also required in determining the command area of an irrigation system and also a production function for each crop in which yield is related to water input will provide the needed knowledge. They further stated that these functions can offer some extremely powerful tools for a rational design and effective production and management of irrigation systems.

Crop water production functions derived from experiment are usually valid only near the location where they are developed (Tsakiris, 1982). This is because the absolute quantity of water needed to produce a given yield differs greatly between locations. Moreso, when no crop-water production function is presently universally applicable to all crops, growing seasons and climates (Rhenals and Bras, 1981), it becomes necessary to formulate, validate or evaluate crop-yield models for different locations and crops.

Research studies related to the effects of moisture stress on yield and yield components of tomato *(lycopersicon esculentum)* have been carried out at the Institute for Agricultural Research (IAR) Samaru, Zaria, by some Investigators (Bodunde, 1998; Ibrahim et al, 1992; Oyinlola, 1994; and Akintoye, 2001) but no attempt was made in any of these works to relate the crop yield to evapotranspiration; a term considered a better predictor of crop yield (Rhenals and Bras, 1981). Thus, an area of research study in tomato production yet un-explored is the aspect of crop-yield-water use relationship by which crop yields and yield decrease due to water deficits can be quantified.

1.2. Statement of the Problems

If irrigated agriculture is to accomplished its main objective of increased crop production through efficient and adequate management of irrigation water, effort must be made to reduce unnecessary waste of water by knowing when to irrigate and the right amount of water to apply.

Crop production is usually adversely affected when water requirement of crop is not satisfactorily met (Itier, 1996).

In order to arrive at an optional set of decisions, the knowledge of the marginal productivity of water allocated to each crop at a given season or time is required.

When studying the question of economic optimal use of water, it is important to know the exact shape of the crop response function to different quantities of water used during the growing season. Allen et al (1996).

Presently, there is no crop-water use production function that is universally applicable to all crops (Pruitt, 1999). It becomes necessary therefore to formulate, calibrate and validate existing models for different locations and crops in order to ascertain their applicability and usefulness.

1.3 Justification of the study

The reason why irrigation farm operators are not greatly receptive to any particular irrigation scheduling despite their availability is that reduction caused by developed irrigation, improper fertilization and excess irrigation are not easily recognized or quantified by them.

The recognition and quantification are made possible and practicable by using crop water production functions. The result goes a long way in assisting in planning and designing of irrigation system and scheduling strategies under limited water supply or where it is desired that yield per unit of water use be maximized.

The results could also be used by extension workers to assist farmers to easily recognize and forecast yield that is expected from an irrigation scheduling method under limited water supply.

1.4 Objectives

The general objective of this work is to evaluate two selected crop-yield water use models to ascertain their applicability to tomato crop grown in Kaduna. The specific objectives include:-

1. To establish a relationship between tomato yield (Fruit) and its seasonal evapotranspiration.
2. To estimate the parameters associated with the selected models and test the models applicability and accuracy in simulating yield of tomato crop under moisture stress conditions

Chapter 2 REVIEW OF LITERATURE

Introduction

Tomato (*Lycopersicon esculentum*) is an important and popular vegetable crop grown in Nigeria. It was an obscure and little used fruit when first introduced to Europe from the Northern Andes in the early days of New World exploration. Today, tomato is a major World Food Plant , the production of which comes to about 18 million tonnes yearly, mostly in Europe and North America (Bodunde, 1998).

The leading producing country is the United States, followed by Italy, Spain and the Arab countries. Brazil, Japan and Mexico are not far behind. Little commercial production occurs in the tomato's homeland, the Andes of Ecuador and Peru, although the species is locally grown. Tomato is available in a wide variety of sizes, shapes and colour. Hybrid varieties are becoming increasingly popular. Most tropical cultivars are relatively unselected and are neither as large fruited nor as uniform as varieties grown commercially in temperate regions (Alasiri and Odeleye, 2001)

In Nigeria, an annual total area of one million hectares is reportedly used for its cultivation (Anon and Katung, 1989). It is grown almost throughout the country but the most important areas lie in the Northern and South-western parts of Nigeria. In the Southern parts of the country, the crop is grown in small holdings under rain-fed conditions while it is grown extensively under irrigation in the Northern parts of the country. Tomato yields of between 18 and 52 tonnes/ha have been reported for northern savannah regions (Quinn, 1980) and between 12 and 24 tonnes/ha for southern rainforest areas of the country (Oyinlola and Akintoye, 2004). Much lower yields are obtained in local farms because of the use of low yielding varieties, diseases and pests problems and also inadequate cultural management (Simons and Sobulo, 1975) as well as reliance on rain-fed production and residual soil fertility.

2.1 Soil-Water-Plant-Atmospheric Relationships for Tomato Crop

Solar energy, in conjunction with the aerodynamic effects of air movement has been shown by Penman (1948, 1952, 1965) to be largely responsible for the consumptive use of water by plants. This concept of atmospheric demand has led to the development of equations to predict potential evapotranspiration. Several investigators have reviewed methods of estimating evapotranspiration (Levine, 1969; Ward, 1971). One equation which has received general acceptance is the Penman's equation which combines the aerodynamic and energy balance approaches of estimation. This equation has proven to be a reliable estimate of potential evapotranspiration from a rough vegetative surface (Tanner and Pelton, 1960) for periods as short as one day.

The Penman's (1965) estimate of potential evapotranspiration has been shown to be closely correlated with open water evaporation and especially with evaporation from the United States Weather Bureau Class A pan (Eagleman, 1967). The use of evapotranspiration estimates and pan evaporation modified by empirical crop coefficients has led to practical methods of determining the quantity of water and interval of irrigation in the United States of America (Jensen et al, 1972). Rijks and Walker (1968) have demonstrated the application of the method in the tropics. Potential evapotranspiration was defined by Penman (1965) for a well-watered close-growing grass crop that completely covered the ground. Crop factors that influence the actual evapotranspiration in relation to potential evapotranspiration include; the percentage of crop canopy as related to the stage of crop development and its height, and the total transpiring surface of the crop. A close growing crop of grass represents essentially two dimensional-vegetative surface. Tomato crop falls within this group.

Atmospheric demand is the primary determinant of consumptive use of water by plants. The soil condition of water availability and the crop condition of vegetative extent are important modifiers of potential rates to actual evapotranspiration rates. Shaw and Swezey (1972) obtained decreasing actual evapotranspiration with decreasing potential evapotranspiration, for corn crop. Shaw and Swezey (1972) found a range of soil tensions of 12 bars (1200k Pa) to 0.30 bar (30k Pa) as the point from which actual evapotranspiration declined from the potential rate. This corresponds to a range of potential evapotranspiration rates of 1.4 to 7mm per day, respectively.

The integration of factors influencing consumptive use of water by tomato to determine an irrigation requirement was discussed by Thompson (1970). The factors which determine the effectiveness of irrigation in increasing agricultural productivity were climate, soil factors, crop rooting characteristics and crop water requirements. The variability of climatic factors and especially rainfall from year to year and month to month and place to place was cited as one of the most important factors determining the need for irrigation.

2.2 Moisture Stress and Plant Growth

The physiological conditions of water in plants that are not favourable to optimal growth is referred to as moisture stress. It is a state when moisture supplied or available for the crop or plant use is not enough; a state when the water potential in the soil is sufficiently low to inhibit normal plant process (Craft, 1968).

This condition differs from plant to plant and may even be different within the same plant at different times or growth stages (Taylor, 1968). Moisture stress is influenced directly by plant water status and indirectly by soil water condition (Datiri, 1982). Water stress occurs as a result of the development of plant water deficit and not necessarily soil water deficit since with adequate soil moisture supply, plant water deficit can still occur as a result of high evaporative demand of the atmosphere. Thus, at any given soil water condition, the plant may show no symptom of stress if either the atmospheric desiccating conditions are low; in other words, high humidity, moderate to low temperature low wind; or if the internal solute concentration of the tissues is high (Taylor, 1968). Water deficit development in plant is said to be as a result of an inevitable consequence of water flow along a pathway (root, stem and leaf) in which frictional resistances and gravitational potentials have to be overcome (Javis, 1975).

However, stress due to high solute concentration of the plant tissue, that is, high salt concentration or high sugar content of the cells and tissues, causes the plant to develop thick and heavy cell walls and exhibit no visible symptoms. Stress due to water deficit or high evaporative demand may induce moderate to severe wilting symptoms in the plant. As water evaporates from the cells of the leaves, the water potential of the cell wall matrix adjacent to the liquid-air interface falls and water moves toward the interface from sources of higher water potentials distributed throughout the plant the soil. Consequently, a progressive reduction in the soil water content and soil water potential results (Begg and Turner, 1976).

Since there must be a potential gradient along the pathway, from the soil to the atmosphere to provide a driving force for water to flow, it follows that there is usually a concomitant water potential decline as evapotranspiration progresses which results in the development of an internal water deficit in the leaf, stem and root tissues (Slatyer, 1967). Slatyer further emphasized that the degree to which an internal water deficit develops in the leaves of a plant depends on the evaporative demand, the soil water potential at the root surface and the water potential gradients within the plant.

2.3 Water-Yield Relationships for Tomato

The optimal allocation of scarce resources to the production of an agricultural crop can be greatly enhanced with the knowledge of the production response surface for those resources. Production function estimates are made because economic criteria are available to put them to beneficial use in decision making (Heady and Dillon, 1961).

Water is important to tomato crop in its growth stages. Vegetative and flowering being critical stages where, water inputs are required to meet environmental evaporative demands. According to Stegman and Hanks (1980), growth limiting stress causes reduced leaf area and plant size if it occurs in the early vegetative period. This is because water stress at this stage affects the morphological processes by suppressing cells division and elongation hence reduction in yield.

Tomato crop has a fairly deep root system and in deep soils, roots penetrate down to about 1.5m. The maximum rooting depth is reached about 60 days after transplanting. Over 80 percent of the total water uptake occurs in the first 0.5 to 0.7m and 100 percent of the water uptake of a full gown crop occurs from the first 0.7m to 1.5m (Doorenbos and Kassam, 1979). The crop performance is sensitive to irrigation practice. In general, a prolonged severe water deficit limits growth and reduces yields which cannot be corrected by heavy watering at a later time. Highest demand for water is during flowering. However, withholding irrigation during his period is sometimes recommended to force less mature plants into flowering in order to obtain uniform flowering and ripening. Excessive watering during the flowering period has been shown to increase flower drop and reduce fruit set. This may cause excessive vegetative growth and a delay in ripening. (Doorenbos and Kassam, 1979).

El-Nadi (1969) stated that yield was not reduced if during the vegetative stage of growth a crop receives favourable water regime and after. However, Haise (1973) found that growth limiting stress in the early vegetative period causing reduced leaf area and plant size will often minimally affect yield of a reproductive organ because reduced leaf area can allow greater canopy light penetration to maintain assimilative capacity. This is consistent with the findings of Lehane and Staple (1962) that moisture stress at an early stage of growth does not appreciably affect yield.

Extensive reviews of literature on yield response to water deficit especially at the critical growth stage have shown differing opinions and findings. This may not be unconnected with the different definitions of length of growth stages and the degree of stress imposed. Other significant factors such as root development and water use efficiency are also important.

The description of the role of water inputs to tomato yield indicate the importance of the enumeration of dated inputs of water in the practical utilization of the production response surface. The term water-yield relationship or production response surface is an important decision making tool for management of water resources in crop production.

Boumol (1965) defined the production function as the summary of technological information which states the maximum amount of output resulting from a productive enterprise using exactly the stated amounts of the various inputs. It can be summarized as:

$$Y = g\,(U, V, W, X, \text{--------}) \qquad 2.1$$

where:

Y = output

U,V,W and X are inputs to the functional relation.

Heady and Dillon (1961) described the production function as a concept of physical and biological science. However, they cited the history of experimentation in which only a few treatments were used to provide point estimates of crop or livestock output, therefore not yielding production functions. Emphasis on the statistical determination of mathematically significant factor levels made it generally impossible to determine the most profitable combination of inputs for a specified level of output.

2.3.1 Crop Yield as a function of water use

Numerous attempts have been made to develop production functions for irrigated crops. As reported by Barret and Skogerboe (1980), one of the most comprehensive studies of yield and transpiration relationship was that of Dewit (1958) who studied a wide range of data collected for common field crop grown in containers. In the few cases where the relationship deviated from linearity, he attributed such to poor aeration of the root system. Arkley (1963) plotted fruit yield versus transpiration corrected from mean relative atmospheric humidity during the period of the most active growth. All the graphs plotted from sites around the World for a wide range of crops showed linear relationships with high correlation coefficients.

In most cases, the line of best fit passed through the origin showing that dry matter yield was directly proportional to transpiration (Barret and Skogerboe, 1980). Similar relationships between dry matter yield and transpiration were obtained by Hanks and Gardner (1969) for grain crops at Akron and Colorado, United States of America. However, when the dry matter yield was plotted against evapotranspiration, the relationship, though linear did not pass through the origin but to the right. Hillel and Guron's (1973) experimental results showed that there appears to be a distinct intercept or threshold value of evapotranspiration below which crop yield is negligible. They concluded that crop yield is not proportional to evapotranspiration as it is often assumed, and that even if crop yield appears to be linear with evapotranspiration, the function does not pass through the origin. The threshold evapotranspiration value may be due largely to the loss caused by direct evaporation from the soil surface before the plant cover begins to accumulate measurable dry matter or grain yield and perhaps from senescing plant after the cessation of growth.

According to Stegman and Hanks (1980), plotting the ratio of actual yield to maximum yield (Y_a/Y_m) versus actual evapotranspiration to maximum evapotranspiration (ET_a/ET_m) is a better way of generalizing yield function since site-specific variable such as climate may produce different absolute evapotranspiration values for the same amount of growth. Thus, the use of relative evapotranspiration should permit some degree of site transferability for the production function.

The fitted curve of the relative relationship also does not pass through the origin but intersects the ET_a/ET_m axis at a value in the order of 0.05 – 0.10 (Hanks and Gardner, 1969) and could be as high as 0.25 – 0.50 (Stegman and Hanks 1980). The intercept tends to occur at the lower end of this range when the crops are stress tolerant or when stresses are ideally distributed between the vegetative, reproductive and fruiting stages and at the higher end of the range when stresses are extreme and/or occurred at the most sensitive growth stages of the crops (Stegman and Hanks 1980).

2.4 Water Use Efficiency (WUE)

Both crop yield and seasonal ET are influenced by a variety of factors, such as the crop type, atmospheric environment, cultivation practices and soil conditions, which include supplies of water, nutrients and others. Given that factors other than water are non-limiting Y and ET will both be functions of water supply. Thus, under the condition that only water supply changes, the function of Y can be described as follows:

$$Y = f\,(ET) \qquad 2.2$$

Where: Y = Yield in t/ha and ET = Evapotranspiration (mm)

The ratio of Y to ET describes the WUE for a given amount of seasonal ET. The first derivative of WUE, that is dY/dET the marginal product of the input (Hexem and Heady, 1978). Since the Y/ET is referred to as the WUE of a crop production system, dY/dET will be correspondingly called the marginal water use efficiency (MWUE) (Tanner and Pelton, 1960).

Water use efficiency can be increased either by increasing the numerator or decreasing the denominator (evapotranspiration). Hillel and Guron (1973) pointed out that it appears more promising to attempt to increase the water use efficiency (WUE) by increasing crop yield rather than decreasing evapotranspiration, since plant growing in the feld are subject to an externally imposed evaporative demand. Plant may curtail transpiration when the supply of soil water becomes limiting, but curtailing transpiration often entails restricting growth and subjecting the plants to stress during the growth period. The water stress may be temporary but can still reduce production, whereas the maintenance of a relatively moist root zone by frequent irrigation at a rate nearly commensurate with potential evapotranspiration can increase crop production, perhaps even disproportionately to the increased water use, thus increasing the water use efficiency, (WUE).

However, Howel and Hillel (1975) and Stewart and Hagan, (1983) argued that Hillel and Guron’s (1973) statement is valid only for well watered crop regimes but does not fully explore the possible implications of limited irrigation regimes of short intervals and the cost of water supplied. Limited irrigation will presumably decrease crop yield, therefore for an area where land is not limited but water is, emphasis should be given to developing systems that reduce all water losses other than transpiration which is possible with less frequent irrigation.

2.5 Soil Moisture Measurement

The measurement of soil water is required in order to determine when to irrigate, the amount of water needed when irrigating, to evaluate evapotranspiration, and to monitor soil water potential. For many years the standard method for measuring water content has been the gravimetric method. This method involves taking a soil sample from the field and determining the mass water content which is the ratio of mass of water to mass of dry soil. This approach is accurate and relatively free of operator's judgment. The gravimetric method was used in this study.

$$P_W = \frac{W_2 - W_3}{W_3 - W_1} \times 100$$

Where

P_w = Soil Water Content (%)

W_1 = Weight of container (g)

W_2 = weight of container + soil sample (g)

W_3 = weight of container + oven dry soil (g)

2.6 Determination of Evapotranspiration

Crop water use depends mainly on the climate and the soil of the area. The efficient use of evapotranspiration data in irrigation problems requires a satisfactory characterization of the effective soil moisture reservoir (Chang et al, 1975). Evapotranspiration is the sum total of water lost through transpiration by crop and evaporation from the soil or exterior portion of the plant where water may have accumulated from rainfall, dew or exudation from the interior of the plant. The word "consumptive" use for all practical purposes is identical with evapotranspiration. It may differ by the inclusion of water retained in the plant tissues, which is always significant when compared with evapotranspiration (Jensen, 1968).

The utilization of consumptive use data for tomato in order to predict irrigation quantity and timing must necessarily be modified for soil and plant conditions. The important crop parameters are the rooting depth and density, with regard to the root zone soil moisture capacity available to the plant. The second important crop factor which influences the irrigation requirement is the age of the crop as it affects the completeness of the crop leaf canopy and the proportion of the potential evapotranspition which the crop actually use.

Important soil parameters include the physical condition of the soil with regard to whether the rooting depth of the crop reaches its full potential. Also important is the rate at which water can be added to the soil without causing runoff, and the rate at which water is released by the soil and the quantity held in storage for plant use.

Potential evapotranspiration (ETp) is defined by Burman and Weiss (1983) as the maximum rate at which water, if fully available would be removed from the earth surface and transpired by the plant, expressed as the latent heat transfer per unit area or its equivalent depth of water per unit area. Thus, it is evapotranspiration that occurs when the vapour pressure at the evaporating surface is at the saturation point.

$$ET_a = K_C ET_p \qquad 2.3$$

where :

ET_P = Potential evapotranpiration

K_C = Crop coeffiecient

ET_a = actual evapotranspiration

Maximum evapotranspiration (ETm) as defined by Doorenbos and Kassam (1979) is the crop water requirement needed for unrestricted optimum growth and yield of the crop. It represents the rate of evaporation of a healthy crop, growing in a large field under optimum agronomic and irrigation management. This type of evapotranspiration has been shown to be related to the evaporative demand of atmosphere which is the potential evapotranspiration (ETp). For a given climate, crop and crop growth stage, the maximum evapotranspirtation (ETm) in mm/day of the period considered is (Doorenbos and Kassam 1979):

$$ET_m = K_c \text{ x } ET_p \qquad 2.4$$

where Kc is an empirically determined crop coefficient.

The actual evapotranspiration (ET_a) refers to the actual crop water used at a given time. The demand for water by the crop must be met by the soil water through the plant root system. The actual rate of water uptake by the crop from the soil at a given time in relation to its maximum evapotranspiration is determined by the amount of water in the soil (Doorenbos and Kassam, 1979). Therefore, in order to determine the actual evapotranspiration, the level of the available soil water must be considered. Actual evapotranspiration (ET_a) will be equal to maximum evapotranspiration when the available soil water is unlimited. Maximum evapotranspiration will be maintained when a field is irrigated and as a fraction of the available water is depleted, the actual evapotranspiration becomes increasingly smaller than the maximum until the next irrigation or heavy rain. The magnitude of ETa will now depend on the remaining available water in the soil and the evaporative demand of the atmosphere.

2.7 Evapotranspiration Measurement

There are numerous approaches to estimation or measurement of evapotranspiration, none of which is generally applicable for all purposes. (Linsley, 1975). The type of data required depends on the intended use.

The water budget approach adopted in this work is a direct method of measuring evapotranspiration which is suitable for areas where soil is fairly uniform and the depth of ground water is such that it will not influence the changes in soil moisture fluctuation within the root zone (Michael 1978). It involves monitoring the changes in soil moisture content between irrigations in the major root zone depth.

Evapotranspiration is regarded as the changes in moisture depth between two successive measurement dates. The expression is:

$$ET = \sum_{I=1}^{n} \frac{M_{i-1} - M_i}{100} \times A_{sj} \times D_j \quad \text{----------} \; 2.5$$

where:

ET = evapotranspiration in the entire root zone depth.

M_i = Gravimetric moisture content on day i

M_{i-1} = Gravimetric moisture content on day i > 1.

Asj = Apparent Specific gravity of soil layer j

Dj = Thickness of layer j.

n = number of layers within the profile under consideration.

The soil water budget method of estimating evapotranspiration (Eq.2.4) is based on the assumption that drainage losses are negligible so that evapotranspiration is the only depletion mechanism of the soil moisture content of the soil profile. Soil moisture content determination is therefore advised to be taken some two or three days after each heavy irrigation so as to give enough time for free drainage if any within the crop root zone, following the assumption that soil moisture content will assume field capacity since the soil is silty clay to clay loan (James, 1988; Michael, 1999). This method is cheap and easy but changes in moisture content within the soil profile depth are greatly influenced by movement of water within the profile.

2.8 Crop Yield – Water Use Models

Quite a lot of expressions have been suggested in an attempt to relate crop yield to water use. Yields have been related to transpiration or evapotranspiration and some to factors such as soil moisture depletion, climatic and cultural factors. Vaux and Pruitt (1983) broadly classified these functions into what they called “agronomic formulations” and “economic formulations”. The formulated economic models are based on the premise of conventional economic theories which provide an adequate framework for analyzing crop-water production relation. The Agronomic formulations are those derived empirically from irrigation experiments designed to determine crop sensitivity factors to water deficits at specified periods of growth which usually coincide with the characteristic growth stages of the crop. Only the agronomic formulated models are considered in this work. The three stages considered were; vegetative, flowering, yield formation/ripening. These growth stages were selected because according to (Singh, 1981), in planning strategies for efficient use of limited water supplies, the crop response to an evapotranspiration deficit at each of these stages are important since stress at these stages could cause significant reduction in crop yields.

The crop water deficits in each growth stage have some unique effects on crop yield and the effect of water deficit at one growth stage is independent of the others, but they have a multiplicative or additive effect on the total crop yield. That is, crop water deficit in two or more growth stages may reduce yield in a multiplicative or additive manner (Taskiris, 1982).

In this study, two crop yield models were evaluated to ascertain their applicability and accuracy for tomato grown in Kaduna - a multiplicative model (Jensen, 1968) and an additive model (Cordova, 1981).

The function expresses the relative yield, as a function of relative evapotranspiration. Thus, the expression is given as:

$$Y_a/Y_m = \prod_{i=1}^{n} (ET_a/ET_m)_i^{\lambda_1} \qquad 2.6$$

where: λ = the relative sensitivity of the crop to water stress in the growth stage which is a parameter to be estimated.

n = the number of growth stages considered,

$\prod$ = the multiplicative sign.

y_a = the actual yield

y_m = maximum yield

ET_a = actual evapotranspiration

ET_m = maximum evapotranspiration

For the multiplicative expression, the crop yield becomes zero if evapotranspiration becomes zero at any growth stage. Brass and Cordova (1981) model

The additive model, is given by the expression given by Bras and Cordova (1981):

$$Y_a/Y_m = \sum_{i=1}^{n} A_i (ET_a/ET_m)_i \qquad 2.7$$

where A_i is the crop sensitivity parameter to be estimated while other terms are as previously defined.

Equation 2.7 is used for fruit yield prediction. However, Hanks and Hill (1980) suggested that, Eq. 2.6, can be used for fruit yield prediction as well.

In this work, Eqs. 2.6 and 2.7 were studied for prediction of fruit yield of tomato crop.

Chapter 3 MATERIALS AND METHODS

3.1 Experimental Site

The study was carried out at the Kaduna Polytechnic School Farm, Nariya which is on latitude 10^o 16 ‘N and longitude 7^o 27 ’E at an altitude of 600m above the mean sea level, during the dry season, Nov. 2005 to May 2006. (fig 3.1)

3.2 Climatic Conditions of Experimental Site

The region falls within the Sudan Savanah with dry, sub-humid with severe deficit in rainfall from October to May each year and a surplus from June to September with an average annual rainfall of 1200mm. The average incoming solar radiation range from 15.6 MJ/m^2/day in August to 21.0 MJ/m^2/day in March (Water Resource Meteorological Record, 1998). The range in solar radiation implies that light and temperature do not greatly limit potential crop production at any time of the year. The mean daily temperature from November to Mid-February is generally low and ranges from 19^o to 25^{o}C, while for the remaining months of the year, the mean daily temperature ranges between 25^o and 32^{o}C. This temperature regime throughout the year is suitable for growing most tropical crops under rain-fed agriculture and subtropical crops such as wheat, tomato, onion, cabbage and others during the irrigation season of November to May (Igbadun, 1997).

The meteorological data for the period of the study was obtained from the Federal Meteorological Department, Kaduna, and presented in Table 3.1. The average monthly values for previous five years are also included to show that there were little variations in weather conditions for the growing season.

3.3 Soil Condition of the Experimental Site

The soil of the experimental site was silty clay loam. Classified as belonging to the alluvial fans, flood plains or secondary deposits having undeveloped profiles which are deep and readily pervious to roots and water. (Brentte and Skegoboe, 1979). It has a water holding capacity in the upper 120cm of a little greater than 12% with effective depth of about 100cm, enough to allow necessary crop root development and provides adequate storage for moisture and permits drainage.

Tables 3.2 and 3.3 show some physical and chemical properties of the soil of the experimental site respectively.

Table 3.1 – Meteorological data for the Growing Season (2005/2006).

	Nov	**Dec**	**Jan**	**Feb**	**March**	**April**	**May**
Maximum temperature (^{o}C)	23.4	22.6	23.2	29.5	30.5	32.0	33.2
	(22.6)	(23.5)	(25.1)	(28.1)	(31.2)	(33.0)	(31.4)
Minimum temperature (^{o}C)	14.2	14.6	15.6	16.5	18.2	19.0	19.5
	(13.0)	(14.4)	(16.2)	(16.0)	(17.0)	(19.5)	(18)
Wind Speed (Km/hr)	180.6	125.6	130	132.5	125	126	127
	(175.2)	(119.4)	(135)	(130.1)	(128)	(125)	(124)
Relative humidity (%)	38.0	28.2	19.5	17.6	16.0	25.6	40
	(37.2)	(25.6)	(17.2)	(18.2)	(14.5)	(22.4)	(38.0)
Monthly Pan evaporation	8.8	8.2	9.2	10.5	9.5	10.2	11.5
	(9.6)	(10.1)	(8.0)	(9.1)	(8.0)	(9.2)	(10.2)

The figures in parenthesis are the average for a five-year period (1999 – 2005).

Table 3.2: Physical Properties of Soil in the Experimental Plot* (Nov 2005)

Depth (mm)	Moisture Content (% weight)	Bulk Density(g/cm^3)	Textural Class [a]
0 – 150	6.37	1.55	Silt loam
150 – 300	8.36	1.62	Clay loam
300 – 400	8.96	1.60	Clay loam
400 – 600	12.75	1.61	Clay

a USDA Classification.

Table 3.3 Chemical Properties of Soil in the Experimental Plot *

pH in water	6.2
pH in 0.01 ml C_aCl_2	4.9
% organic carbon	0.92
Available phosphorus (mg/kg^{-1})	26.8
% Total Nitrogen (T.N)	0.0

Exchangeable Cation	**(C mol Kg^{-1}) ***
N_a^+	0.89
K^+	0.38
Mg^{++}	1.40
Ca^{2+}	4.83
CEC	8.20

* Samples were analyzed using standard procedures described by Agbenin (1995).

3.4 Experimental Approach

The growing season is divided into three stages – vegetative, flowering, and yield formation/ripening. Water stress is imposed at a given period by withholding irrigation either entirely or to a quantified stress level before relief. Irrigation maintains a non or low stress level before or after the stress period. Irrigation treatment therefore, may range from full irrigation, that is, maintenance of maximum evapotranspiration rate, in all the growth stages to a non-irrigated or all growth stages stress treatment and all the combinations of such. Stress imposed is normally limited to one growth period with irrigation withheld either entirely or until a quantified degree of moisture deficit occurs, usually measured as the evapotranspiration deficit relative to the evapotranspiration of the non-stress treatment, and the maximum seasonal yield (Y_m) is usually associated with the scheduling treatment that satisfies maximum evapotranspiration rate in all stages of growth, which also accumulates the maximum seasonal evapotranspiration (Et_m) (Stegman and Hanks, 1980; Stegman, 1983; Bungwon, 1993).

This framework was adopted in this study with the growing season of tomato divided into three main stages: vegetative, flowering, yield formation/ripening.

Generally two approaches of estimates of crop-water production function are available in literature. One approach synthesizes production functions from theoretical and empirical models of individual components of the crop water process (Maas and Hoffman, 1977; Letey and Dinar, 1986). The second approach estimates production functions by statistical inference from observations of the effect of different water applications on crop yield (Dinar and Knapp, 1986; Dinar et al, 1985; Knapp et al, 1990; Letey et al, 1990 and others).

The first set of approach is quite useful but due to the implicit assumptions, their applications are restricted. Moreover, the production functions generated by this approach are not verified by actual field data whereas the second set of approach estimates direct relationships. By using the second approach, many production functions can be estimated under various conditions. These are reviewed by Hexem and Heady (1978) and Vanx and Pruitt (1983).

The approach used in this study is based on the assumption that crop yields are directly influenced by quantity of the irrigation water used (ET). Other factors that may affect the yields such as quality of irrigation water are considered constant.

3.5 Field Layout & Experimental Design

A total of about $300m^2$ (18m x 16m) land area was prepared and divided into three blocks laid along the general slope of the field in order to ensure as much homogeneous soil conditions as possible within the block (plate 3.1).

Each block was divided into eleven (2m x 2m) basins. The basins were spaced 1.0m apart and the blocks (replications) were 1.5m apart to allow for a buffer zone between basins and blocks in order to reduce possible seepage of water from one basin to another as a result of lateral movement of water within the soil. Each row of basins was served with water through a field ditch running along the slope adjacent to the basins each of which were opened at a midpoint to allow water to flow in until it was adequately ponded, after which it was closed. The field layout is as shown in Fig. 3.2. A randomized complete design was adopted with eleven treatment one of which was a dry treatment and replicated three times (fig 3.2).

Table 3.4 Description of Growth Stages

Growth Stage	**Description**	**DAT**[a]
I	Vegetative	14 - 39
II	Flowering	40 - 64
III	Yield formation/ripening	65 - 77

[a] DAT = Days after transplanting.

Tomato seedlings were established in the nursery for a period of 25-30 days before transplanting. The description of the growth stages are closely related to those suggested by Zadok (1974) and Yayock and Kumar (1980).

The treatment pattern followed the experimental design approach discussed in Section 3.5. It involved irrigating at 7-day interval after transplanting; this is the recommended irrigation interval for tomato for the type of soil of the experimental site (silty loam) (Quinn, 1980) for all the growth stages except at the particular growth stage at which stress treatment was imposed. This is existing practice by farmers in the study area especially when irrigating during the vegetative and flowering stages of growth. (Plate 3.2)

Stress was imposed by withholding irrigation for additional days in excess of the regular 7-day irrigation interval. It was expected that by withholding irrigation from the crop at any of the stages for a given number of days in excess of the regular irrigation intervals, while the control treatment was irrigated, an evapotranspiration deficit would occur in the stressed plots due to moisture stress, which could affect the yield. Three levels of moisture stress were considered for each of the three stages of growth. Irrigation withheld 3 days, 5 days and 7 days in excess of the 7-day regular irrigation interval, labeled X_1. X_2 and X_3, respectively at the growth stages I, II and III. The dry treatment labeled 11 was stressed to level X_2 in all the three stages of growth to allow for comparison of the effect of single stress and the stress throughout the growing season on the yield. Table 3.5 shows the description of the treatments.

After the stress period, the plots that underwent the stress were thereafter irrigated at the regular 7-day interval for the rest of the season. Each treatment was stressed once except treatment 11 that was treated to level X_2 at all the three stages of growth studied. The control treatment labeled 1 was irrigated at 7-day interval for the entire season.

3.6 Irrigation Method

A petrol engine 80mm water pump was used to deliver ($60m^3$/hr) about 17 l/s water taken from Kaduna River directly for the surface irrigation method. (Check basin). Each basin to be irrigated was irrigated through a portable weir box installed in the embankment and about 4.0l/s of water was allowed in until the basin was ponded to a level of 5.0cm read from an erected graduated stake used to measure water depth in each basin. It takes about 48-50 seconds to accomplish this. Hence the quantity of water applied was monitored. This approach was similar to that used by Wynn and Skogerboe (1982) in evaluating check basin irrigation methods at Utah State University, United State of America. The approximate water requirement for tomato is 50mm per irrigation (Oyinlola and Akintoye, 2004). At each irrigation, the approximate volume of water applied is known through this approach. However, the soil moisture was monitored to ascertain how much of the applied water had been used by the crop.

Test on irrigation water revealed that the exchangeable cations, a measure of its salinity was 2.25 dS/m (mmho/cm) with a boron content of 1.53 mg/l, both showing good usage range for irrigation. No degree of restriction for such range (Ayers and Westcot, 1994).

Table 3.5 Treatment Description of the Experimental Treatments for 2006 Season

Treatment Number		Description
1 (T1)	All satges	Irrigation weekly throughout the season (Reference treatment).
2 (T2)	Stage 1	Irrigation was skipped 3 days in excess of the 7-day irrigation interval at stage 1 only.
3 (T3)		Irrigation was skipped 5 days in excess of the 7-day irrigation interval at stage 1 only.
4 (T4)		Irrigation was skipped 7 days in excess of the 7-day irrigation interval for stage 1 only
5 (T5)	Stage 2	Irrigation was skipped 3 days in excess of the 7-day irrigation interval at stage 2 only
6 (T6)		Irrigation was skipped 5 days in excess of the 7-day irrigation interval at stage 2 only.
7 (T7)		Irrigation was skipped 7 days in excess of the 7-day irrigation interval for stage 2 only.
8 (T8)	Stage 3	Irrigation was skipped 3 days in excess of the 7-day irrigation interval at stage 3 only.
9 (T9)		Irrigation was skipped 5 days ins excess of the 7-day irrigation interval at stage 3 only.
10 (T10)		Irrigation was skipped 7 days in excess of the 7-day irrigation interval at stage 3 only.
11 (T11)	All stages	A 12-day interval of irrigation was observed throughout the Season.

3.7 Soil Moisture Determination

Soil moisture was measured throughout the period of the study. Soil sample were taken at incremental depth of 150mm down to 600mm for the determination of the moisture content in 2 replications for each treatment using soil auger. As earlier assumed, soil moisture content would attain field capacity in two days since the soil is silty clay to clay loam (James 1988, Michael 1999). The samples were taken two days after and just before the next irrigation. The difference in moisture content between the two sampling periods was taken to be the moisture used. That is, the evapotranspiration by the crop for that period in line with the water budget method. Since it was assumed that drainage was negligible (no drainage), the moisture change was principally attributed to evapotranspiration.

3.9 Models Parameters Determination

The parameters to be estimated in each of the models studied are the stress sensitivity factors for the three growth stages considered in this study. The relative yield (Y_a/Y_m) and the relative evapotranspiration (ET_a/ET_m) terms of the model expressions were obtained from the yields and evapotranspiration data measured in Sections 3.8. The stress sensitivity factors for each of the growth stages for each model (that is, Jensen, 1968; Bras and Cordova, 1981) was obtained by using multiple linear regression technique. The multiplicative model (Jensen, 1968) equations were first transformed to logarithmic equations before the regression analysis was done.

The relative yield reduction, ($1-Y_a/Y_m$) versus relative evapotranspiration deficit, ($1-ET_a/ET_m$) were plotted on a linear graph paper and using the least squares approach, the line of best fit was established. The slope of the fitted line is the yield response factor (Doorenbos and Kassam, 1979). In the same manner, the sensitivity parameters of the other model was also determined and the results so obtained were tested using the relative evapotranspiration deficit terms of the other treatments to see how closely the expression can predict relative fruit yields. Field measured relative yields were then compared with calculated values at 5% confidence interval using the t-test statistic to see how closely the expression can predict the relative yields.

3.10 Determination of Water Use Efficiency (WUE)

Water use efficiencies were calculated for fruit production by computing the ratio of seasonal yield to the seasonal evapotranspiration. Fruit yields were expressed in t/ha while the seasonal evapotranspiration expressed in mm, (Table 3.6)

Evaluation of Models' Performance

The parameters estimated in each of the models under study were three stress sensitivity factors for the three growth stages considered in this study. The relative yield (Y_a/Y_m) and the relative evapotranspiration (ET_a/ET_m) terms of the model expressions were obtained from the yields and evapotranspiration data measured as explained in Sections 3,7 and 3.8. The stress sensitivity factor for each of the growth stages for each model was obtained by using multiple linear regression technique.

Table 3.6: Water use Efficiency

Treatment	SET (mm)	Yield t/ha	WUE t/ha-mm
1	530	42.58	0.08
2	486	24.33	0.05
3	484	23.08	0.05
4	470	20.10	0.04
5	478	21.74	0.05
6	469	19.44	0.04
7	456	22.08	0.05
8	470	18.11	0.04
9	465	21.04	0.05
10	454	21.63	0.05
11	446	23.00	0.05

WUE = Water use efficiency

SET = Seasonal evapotranspiration

Table 3.8: Percent yield, yield reduction and seasonal evapotranspiration deficit as measured from the experimental plot for 2006 season.

Treatment		Yield t/ha	% SET_d*	%Yield reduct.
Control	1	42.58		
S1fq10	2	24.33	8.0	43
S1fq12	3	23.08	8.6	46
S1fq14	4	20.10	11.3	53
SIIfq10	5	21.74	9.8	45
SIIfq12	6	19.44	11.5	44
SIIfq14	7	22.08	13.9	48
SIIIfq10	8	18.11	9.8	43
SIIIfq12	9	21.04	12.3	45
SIIIfq14	10	21.63	14.3	49
ASfq10	11	23	15.80	44

*% seasonal evapotranspiration

Chapter 4 RESULTS AND DISCUSSIONS

4.1 Introduction

The relationship between crop yield and water use is a unique one. When climatic and agronomic conditions are adequate, crop yield completely depends on the amount of water available for use by the crops (Igbadun 1997). When agronomic conditions do not restrict crop production, and in a constraint – free environment, that is, when water quality or salty soil are not inhibiting yield crop yields is at maximum when full water requirements are met. (Doorenbos and Kassam 1979).

Whenever water supply does not meet crop water requirement, actual evapotranspiration (ET_a) will fall below maximum (ET_m) resulting in water deficit in crop and can develop to a point where crop growth and yield are adversely affected.

The effect of the magnitude and timing of the occurrence of water deficit on crop growth and yield is therefore of major importance in irrigation scheduling under limited supply of water and in determining the priority of water supply among different crops during the growing season.

4.2 Crop Yield and Evapotranspiration

In order to understand the economic optimal use of water by crops, it is necessary to know the nature or behaviour of the crop response to different amounts of water the crop used throughout the growing season. Certain growth stages of crop are more sensitive to water deficits than others. Therefore, knowledge of marginal productivity of water allocated to each crop at different stages of growth is required in order to arrive at an optimal set of decision making with regard to irrigation water management. According to (Stewart et al 1973) and (Minhas and Parkh 1974), crop water use function (also known as crop yield water use models) in which crop yield is related to water inputs will provide the needed information for scheduling irrigation that promises a high economic return.

In this study, two crop water production functions were evaluated for tomato crop grown in Kaduna, Nigeria. The crop water production functions derived from experiments are usually valid only near the location of such experiments; this is because the quantity of water to produce a given yield differs greatly from location to location and no crop water production function is universally applicable to all crops, growing season and climate (Rhenals and Bras, 1981).

Table 4.1 shows the yield of tomato in Kg/m^2 for the experimental field for the 2006 season. It can generally be observed that tomato yield increased with a corresponding increase in seasonal evapotranspiration. The highest yield was obtained from the reference treatment (Treatment 1) which was subjected to weekly irrigation schedule. Treatment 8 (T8), irrigated at 10 days interval throughout stage three indicated the least yield. This may be attributed to the fact that the fruit formation (stage III) was sensitive to water deficit and hence reacted to the stress imposed during that period. Treatment 7 (T7) that was exposed to identical stress period but in stage II (flowering) also indicated an appreciable reduction in yield. But treatment 4 (T4) that was exposed to the same stress but at stage I (vegetative) showed a little higher yield compared to (T4) and (T7) but still relatively low as compared to treatment 1 (T1) yield, that was irrigated weekly through out the season. It can be observed that treatments 2 (T2), 3(T3), 4 (T4), 5 (T5), 6(T6), 8(T8) that had a range of 3 – 5 days in excess of weekly irrigation showed significant yield reduction when compared to treatment 1(T1). The vegetative and flowering stages showed appreciable sensitivity to water deficit. This agrees with findings reported by Doorenbos and Kassam (1999) and Stegman (1982).

The relationship between crop yield and water use is a unique one. Crop yield completely depends on the available moisture to the crops if climatic and agronomic conditions are adequate. According to Doorenbos and Kassam (1979), under normal condition, when economic conditions do not restrict crop production, crop yield is at maximum when the crop water requirement is met.

Table 4.1: Yield of Tomato in Kg/m^2 from the Experimental Plot in 2006 Season

Treatment		Replication	Replication 2	Replication 3	Average	
1	Control	4.60(4.50)	4.20(42.00)	4.03(40.25)	4.26(42.58)	2
	S1Fq10	2.60(25.50)	2.13(21.25)	2.63(26.25)	2.43(24.33)	
3	S1Fq12	1.80(18.05)	2.63(26.25)	2.50(25.00)	2.30(23.08)	
4	S1Fq14	1.80(18.05)	1.78(17.75)	2.45(24.50)	2.00(20.10)	
5	SIIIFq10	1.97(19.73)	2.73(27.25)	1.83(18.25)	2.17(21.74)	
6	SIIIFq12	2.10(21.00)	2.10(21.00)	1.63(16.33)	1.94(19.44)	
7	SIIIFq14	2.40(24.00)	2.65(26.50)	1.58(15.75)	2.20(22.08)	
8	SIIIFq10	1.80(18.13)	1.37(13.70)	2.23(22.50)	1.81(18.11)	
9	SIIIFq12	1.60(15.63)	2.40(24.00)	2.35(23.50)	2.10(21.04)	
10	SIIIFq14	1.68(16.75)	2.14(21.38)	2.68(26.75)	2.63(21.63)	
11	ASFq10	1.45(14.50)	2.65(26.50)	2.80(28.00)	2.30(23.00)	

Figures in parenthesis are in t/ha.

4.3 Crop Water Use

Table 4.2 shows the seasonal crop water use for 2006 season in (mm) in the field using the water budget method for the growth stages under consideration and those of the entire season (SET). It varied between 446 and 530mm. The highest seasonal evapotranspirations were recorded in the reference treatment (1) while the least was recorded in the treatment 11. This was expected since the reference treatment was exposed to regular irrigation as against (T10) with limited irrigation. The recorded seasonal evapotranspiration in the reference treatment and in treatments in which irrigation was withheld three days in excess of the regular 7-day interval (T2, T5, T8) at a growth stage only was within the range of seasonal water consumption for tomato given by Dane et al (1991) as 480 – 530mm. The treatments in which irrigation was withheld in excess of 7 days over the regular interval (T4, T7, T10) was lower than Danes et al's (1991) range. This was indicative of the fact that in those treatments, crops had less water than their requirement and hence lower yields. Treatment 3 had the highest measured evapotranspiration values at growth stage I and II while the control treatment (T1) had the highest evapotranspiration values at stages I and II as can be observed from Table 4.2. On irrigation scheduling basis, treatments on an average 10-day irrigation intervals, indicated the highest evapotranspiration in stages I and III, respectively while those on 12-day intervals had the highest in stage II only. The control, with a regular irrigation interval of 7 days had the highest evapotranspiration rate in stages I and II only.

The analysis of variance for water use efficiency (WUE) shows a high correlation between water use and yield of tomato with $R^2 = 0.937$

Table 4.2: Growth Stages and Seasonal Evapotranspiration (mm) as Measured from the Experimental Plot in 2006 Season.

Stages of Growth

Treatment	Treatment No.	Stage 1 (14-39 DAT)	Stage 2 (40-63 DAT)	Stage 3 (64-80 DAT)	Seasonal ET (mm)
Control	T1	190	184	156	530
SIFq10	T2	166	173	148	486
SIFq12	T3	158	180	146	484
SIFq14	T4	158	163	149	470
SIIFq10	T5	157	165	155	478
SIIFq12	T6	156	160	154	469
SIIFq14	T7	165	156	135	456
SIIIFq10	T8	160	164	146	470
SIIIFq12	T9	160	166	139	465
SIIIFq14	T10	159	163	132	454
ASFq10	T11	163	146	137	446

SIFq = Stage 1 frequency

SIIFq = Stage 2 frequency

SIIIFq = Stage 3 frequency

ASFq = All stages frequency.

DAT = Days after transplanting

The generally high evapotranspiration observed in stage II may be as a result of crops attaining their full vegetative cover and hence the use of more water. This equally explains the drop in stage III when the majority of the tomato crops have started dropping their leaves because of age.

It can be seen from Table 4.1 that tomato yield increased with increase in seasonal evapotranspiration. The relationship between relative yield decrease ($1 - Y_a/Y_m$)

and relative evapotranspiration decrease ($1 – ET_a/ET_m$) is as shown in Fig. 4.2. The yield response factor for tomato for this study was found to be 3.574, which agrees with the findings of Datta et al (1997) of 2.06-3.86 range for soil conditions identical with that of the study area. The application of the yield response factor for planning, design and operation of irrigation projects allow quantification of water supply and water use in terms of crop yield and total production for the project area. Under conditions of limited water distribution equally over the total growing season, involving crops with different yield response factor values, the crop with the higher response values will suffer a greater yield loss than that with a lower value. The yield response to water deficit of different crops is of major importance in production planning. It is also important in the scheduling of available but limited water supply in order to obtain highest yields Doorenbos and Kassam (1979). The relationship between crop yield and water use is called water production function (Fig 4.1 and fig 4.2).

4.4 Seasonal Yield Reduction – Evapotranspiration Deficit Relationship

Crop water production functions are very useful in determining irrigation strategies when water supply is limited. It is often linear and varies among varieties of crops and climate zones. The determination of crop water production function for a specific location is usually required. (Kipkovir et al, 2002). A useful way to express the crop water production function is on a relative basis where actual yield (Y_a) is divided by maximum yield under a given management condition (Y_m) and actual evaportanspiration (ET_a) is divided by crop evapotranspiration for non-limiting water condition (ET_m). In order to quantify the effect of water stress on yield, it is necessary to derive the relationship between relative yield decrease and the relative evapotranspiration deficit given by the empirically derived yield response factor (k_y). The application of the yield response factor (K_y) for planning, design and operation of irrigation projects allows for quantification of water supply and water use in terms of crop yield and total production for the project area. The relationship between evapotranspiration deficits [$1 - (ET_a/ET_m)$] and yield depression, ($1 - (Y_a/Y_m)$ is always linear with a slope called yield response factor (K_y). The expression is given in Eq. 4.1

$$(1 - Y_a/Y_m) = \qquad K_y\,(1 - ET_a/ET_m) \qquad 4.1$$

Reported K_y values for several crops, for individual growth stage and also for the total growing season are based on the effect of water deficit for the period under consideration. In this study, water stress was spread over three growth stages to cover the entire growing season for tomato, therefore; seasonal K_y could be obtained. The water production function for tomato was obtained by plotting the observed yield versus seasonal evapotranspiration.

The relationship between seasonal fruit yield and water use with that of yield reduction and evapotranspiration deficit are shown in Fig. 4.3 and 4.4, respectively. Strong linear relationships were found to exist between yield and evapotranspiration, so also is that between yield reduction and evapotranspiration deficit. These findings are in agreement with those of Igbadun (2001), and Datta (1997). The fruit yield (Fy) versus SET function was obtained as:

$$Fy = 0.2872\ SET - 113.16 \qquad 4.2$$

$R^2 = 0.8935$

Where:

Fy = Fruit yield (t/ha)

SET = Seasonal evapotranspiration (mm)

R^2 = Coefficient of determination.

The yield reduction versus evapotranspiration deficit function was obtained as:

$$(1 - Ya/Ym) = 3.5743(1 - ETa/ETm) + 0.0832 \text{ -------------------------} \qquad 4.3$$

$R^2 = 0.8935$

It would be observed that equations 4.2 and 4.3 are not exactly the same as equation 4.1 which shows direct proportionality between relative yield and relative seasonal evapotranspiration.

The relationship between relative yield and relative seasonal evapotranspiration is not strictly or entirely proportionate as to give a 1:1 fit graph that would have passed through the origin hence the intercept of 0.0832 which for practical purposes can be considered very small and real zero. This supports Hillel and Guron (1973); Hanks and Gardner's (1969) argument on yield and evapotranspiration relationship.

Table 4.3 Moisture Stress Sensitivity Indices for the Models Evaluated

MODEL	(Jensen)					Bras and Cordova				
Growth stage	λ_1	λ_2	λ_3	R^2	SEE	A_1	A_2	A_3	SEE*	Constant
Indices	2.42	0.91	1.92	0.99	0.02	2.14	0.63	1.16	0.023	2.94

* standard error estimate

AE = 0.04 = Average error of bias

CV% = 8.51 = Coefficient of variation

RMSE = 0.04 = Root mean square error

CRM = - 0.08 = Coefficient of residual mass

R^2 0.9035 = Coefficient of determination

Table 4.4: Models Expressions with their sensitivity factors

Jensen (1968) $\mathbf{Y_a/Y_m} = \mathbf{(Z)}_1^{2.42} \times \mathbf{(Z)}_2^{0.91} \times \mathbf{(Z)}_3^{1.92}$

Bras and Cordova (1981) $\mathbf{Y_a/Y_m} = 2.14\,\mathbf{(Z)}_1 + 0.63\,\mathbf{(Z)}_2 + 1.16\,\mathbf{(Z)}_3 - 2.941$

Where:

$Z = (ET_a/ET_m)$

4.5 Model Validation

In order to validate the models under consideration, some randomly selected treatments, T4, T5, T8, T9 and T11 were used to simulate the relative yield. The results were then compared to see how well the models predicted the actual yield. Table 4.5 shows the field data used to test the accuracy and predictability of the sensitivity indices of the models. The measured relative yield and model calculated relative yield results for each model are also shown. It can be observed that each yield model simulated the field results closely well.

Table 4.6 shows the statistical performance indicators for the comparison of the model simulated and the field measured relative yields.

The average error of bias (AE) was 0.04. The coefficient of residual mass (CRM), which indicates the degree of over or under prediction of the models, shows that both models slightly over predicted the field-measured values (Brass and Cordova by 8%, while Jensen by 17%). The coefficient of variation (cv) for both models were below 10%. This coefficient is a measure of the degree of precision between the two quantities that are being compared. The degree of closeness between the quantities under comparison reduces as the values of coefficient of variation increases. This trend implies that the models are acceptable for the area were this study was carried out.

Table 4.5 Measured Relative Yield and Calculated Relative Yield using model equations.

Treatment	Measured Relative Yield (t/ha)	Simulated Relative Yield (t/ha)	
		Jensen	Bras & Cordova
T4	0.47	0.52	0.50
T5	0.52	0.57	0.55
T8	0.49	0.52	0.51
T9	0.45	0.48	0.47
T11	0.43	0.44	0.41

Plot predicted $(Y_a/Y_m)_p$ vs $(Y_a/Y_m)_m$

Table 4.6 Statistical Comparison of field measured and model predicted relative fruit yield

	Log values				
Treatment	Stage 1	Stage 2	Stage 3	Fruit yield	
T1	0.00	0.00	0.00	0.00	
T2	-0.06	-0.03	-0.02	-0.24	
T3	-0.08	-0.01	-0.03	-0.27	
T6	-0.09	-0.06	-0.01	-0.29	
T7	-0.06	-0.07	-0.06	-0.34	
T10	-0.08	-0.05	-0.07	-0.37	
	Relative values				$(\text{Meas-Mn})^{2*}$
T4	0.83	0.89	0.95	0.47	0.00
T5	0.83	0.90	0.99	0.52	0.002
T8	0.84	0.89	0.93	0.49	0.001
T9	0.85	0.90	0.89	0.45	0.001
T11	0.86	0.79	0.88	0.43	0.002

*****measured Fy

AE = 0.04 (Average error of bias)

CV% = 8.51 (Coefficient of variation)

RMSE = 0.04 (Root mean square error)

CRM = 0.08 (Coefficient of residual mass)

R^2 = 0.9035 (Coefficient of determination)

Figure 4.3 shows the relationship between the measured relative and predicted relative yields. A strong linear relationship exists with a correlation coefficient of 0.8924 while the regression equation is given as:

$$(Y_a/Y_m)_m = 0.170 + 0.68\,(Y_a/Y_m)_p$$

a statistical t – test show the values of a = 0.17 which is close to zero, and that of b = 0.68 also close to unity.

Therefore the equation can be accepted to closely describe the relationship between measured and predicted relative yields.

Chapter 5 SUMMARY,CONCLUSION & RECOMMENDATIONS

5.1 Summary

A farm land of 300m^2 was prepared into check basins of size 2.0m x 2.0m during the 2005/2006 irrigation season at the Kaduna Polytechnic farm, Kaduna. Tomato seedlings were transplanted after 28 days of establishment in a nursery.

Three levels of moisture stress were imposed for each of the three stages of growth; vegetative, flowering and fruit formation/ripening by withholding irrigation for 3, 5 and 7 days in excess of the regular 7-day irrigation interval for tomato (Quinn, 1980). Water use was monitored throughout the growing season. The study was used to evaluate and validate two crop yield-water use models for tomato crop- Jensen (1968), a multiplicative model and Bras and Cordova (1981), additive model.

5.2 Conclusion

The following conclusions were made from the results of this study:-

1. A strong linear relationship exists between crop yields and seasonal evapotranspiration. Seasonal evapotranspiration values in the range 530 – 446mm were obtained which are in agreement with the findings of Doorenbos and Kassam (1979), Alasiri and Odeleye (2001), and Bodunde (1998).
2. The two crop yield models evaluated were found to have adequately predicted crop yield. Jensen's (1968) model was found to be better than that of Bras and Cordova (1981). The stress sensitivity factors for the three

stages of growth studied showed that moisture stress at vegetative and fruit formation stages had significant yield reduction effect on tomato.

5.3 Recommendations

The following recommendations are therefore made from the results of this study:-

1. While crop yield models and their stress sensitivity factors estimated have been found to adequately predict crop yields in Kaduna, more information will be required including application of other models for optimal water allocation for irrigation of tomato crop.
2. More time and information are needed about the nature of the critical period characteristic of commercial crops like tomato and the magnitude of the adverse effects of the associated soil – moisture deficiencies and for it to be reasonably universal such data should be gathered in dimensionless form.

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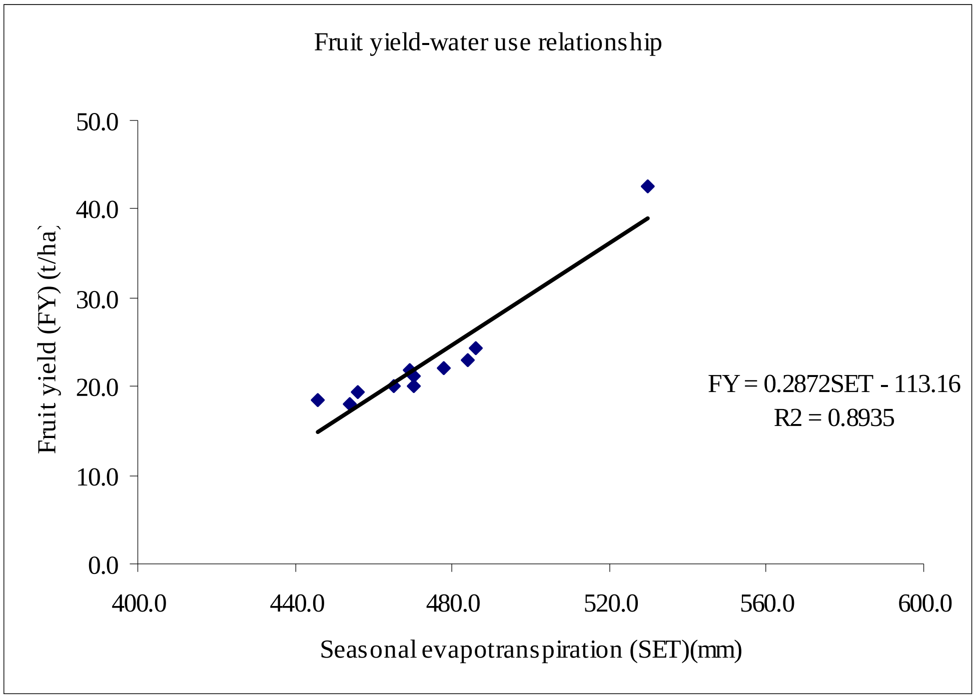
Seasonal evapotranspiration for the tomato crop in 2005 season

Treatment Description	Treatment	Growth Stages ET			Seasonal ET
		Stage I (14-39 DATP)	Stage II (40-63 DATP)	Stage III (64-80 DATP)	
Control	T1	189.5	184.2	156.2	529.9
SIFq10	T2	165.5	172.9	147.6	486.0
SIFq12	T3	158.0	180.2	146.0	484.2
SIFq14	T4	157.7	163.3	149.0	470.0
SIIFq10	T5	157.4	165.4	155.2	478.0
SIIFq12	T6	155.7	159.7	153.6	469.0
SIIFq14	T7	164.6	156.2	135.2	456.0
SIIIFq10	T8	160.0	164.2	145.8	470.0
SIIIFq12	T9	160.4	165.6	139.0	465.0
SIIIFq14	T10	158.7	163.1	132.2	454.0
ASFq10	T11	162.8	146.2	137.0	446.0

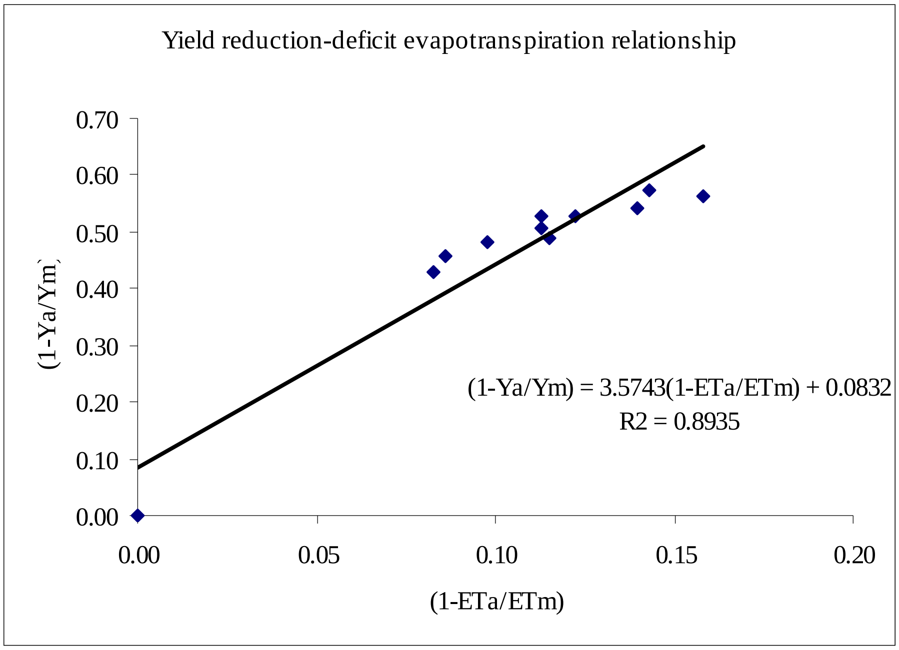
Yield of Tomato in t/ha from the experimental field in 2005 season

Treatment Description	Treatment	Replication 1	Replication 2	Replication 3	Average
Control	T1	45.5	42.0	40.3	42.6
SIFq10	T2	25.5	21.3	26.3	24.3
SIFq12	T3	18.0	26.3	25.0	23.1
SIFq14	T4	18.1	17.8	24.5	20.1
SIIFq10	T5	19.7	27.3	18.3	22.1
SIIFq12	T6	21.0	21.0	16.3	21.7
SIIFq14	T7	24.0	26.5	15.8	19.4
SIIIFq10	T8	18.1	13.7	22.5	21.1
SIIIFq12	T9	15.6	24.0	23.5	20.0
SIIIFq14	T10	16.8	21.4	26.8	18.1
ASFq10	T11	14.5	26.5	28.0	18.6

Tomato yield –water use relationship



Seasonal yield reduction-evapotranspiration deficit relationship



Model		Stage 1	Stage 2	Stage 3	R2	SEE
Jensen		**λ1**	**λ2**	**λ3**		
		2.42	**0.91**	**1.92**	**0.991**	**0.02**
Bras-Cordova	**Constant**	**β1**	**β2**	**β3**		
	-2.941	**2.14**	**0.63**	**1.16**	**0.992**	**0.029**

Treatment	**Measured Rel. Yield**	**Simulated Rel. Yield**	
		Jensen	Bras Cordava
T4	**0.47**	**0.52**	**0.50**
T5	**0.52**	**0.57**	**0.55**
T8	**0.49**	**0.52**	**0.51**
T9	**0.45**	**0.48**	**0.47**
T11	**0.43**	**0.44**	**0.41**

Statistical performance indicators	Jensen	Bras-Cordova
AE	0.04	0.02
CV %	8.51	5.42
RMSE	0.04	0.03
CRM	-0.08	-0.04
r^2	0.9035	0.8894

AE = Average error of bias
CV= Coefficient of variation
RMSE = Root mean square error
CRM= coefficient of residual mass
r^2= coefficient of determination