WATER USE, GROWTH AND YIELD OF AMARANTHUS CAUDATUS (*Quinoa*) UNDER IRRIGATED CONDITION

BY

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CERTIFICATION

This is to certify that this work was carried out by **MR. ADEOSUN EMMANUEL OLUWATOYIN** (AGE/98/1237) in the Department of Agricultural Engineering, Federal University of Technology, Akure in partial fulfillment of the requirements for the award of Master of Engineering (M. Eg.) in Soil and Water Engineering option, Department of Agricultural Engineering, Federal University of Technology, Akure.

It has not been submitted elsewhere for the award of any other degree or diploma.

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Date:......23/1/2002......

DEDICATION

To the Holy Spirit whose divine guide has been the source of my success and for his immeasurable blessings and protection.

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SYMBOL	UNIT	NOMENCLATURE
DAE	day	Days after establishment
WAE	week	Weeks after establishment
WUE	Kg/ha-mm	Water use efficiency
W_{in}	mm	Amount of water added to soil
W_{out}	mm	Amount of water withdrawn from soil
ET	mm/day	Crop evapotranspiration
EP	mm/day	Potential evaporation
P	mm	Precipitation
R	mm	Runoff
ΔS	mm	Change in soil moisture storage
LAT	-	Leaf area index
D	mm	Capillary Drainage
F.U.T.A	-	Federal University of Technology Akure
PET	mm/day	Potential evapotranspiration
I	mm	Irrigation
Vio	Cm^3	Volume of water collected
A_c	m^2	Catchment Area
Wk	-	Week
Ds	-	Dry density
Db	-	Bulk density

ABSTRACT

Soil water is a major hinting factor to crop production particularly under dry season condition. Field experiments were conducted in the early and late season periods of year 2000 at the experimental farm of the Department of Agricultural Engineering, Federal University of Technology, Akure (F.U.T.A.). The aim was to evaluate the growth and yield of amaranthus under irrigated condition and to determine water use pattern of the crop with a view to developing a good water management strategy. The treatments were: irrigation at full pan evaporation (T_4), Irrigation at ¾ pan evaporation (T_3) and irrigation at ½ pan evaporation (T_2). Soil moisture content was measured weekly at 10cm, 20cm and 30cm soil depth using gravimetric methods. Biomass yield was determined weekly throughout the growing season until maturity. Other agronomic measurements include plant height, root depth and leaf area index (LAI). Meteorological data were taken at the experimental site.

It was observed that treatment T_4 had the best result in terms of plant height, LAI, and total biomass yield of 1.95 ton/ha during second planting season. crop water use (determined by water balance method) differed among treatments and the amount corresponded to the magnitude of total water applied. The highest amount of crop water use (ET) was 4.1 mm/day and 7.9 mm/day during the two seasons and was observed at 14 DAE at the 4^{th} WAE, the treatment T_4 gave the highest value of water use efficiency (WUE) of 0.5 kg/ha-mm of water. This was observed during the second planting season.

However, on considering the overall result, it is proposed that amaranths will yield maximum result when water is applied at the rate of ¾ pan evaporating during emergence, at full evaporation during the maximum vegetative cover and at ½ pan evaporation during the maturity stage.

Irrigation at full evaporation improved crop performance by increasing agronomic attributes such as plant height, leaf area and biomass yield. Crop water use (ET) differed among

treatments and it reflected an influence of irrigation water application and hence soil moisture availability for crop growth and yield. The highest water use (4.1 mm/day and 7.9 mm/day) was observed at 14 DAE during the first and second planting seasons. The highest WUE (0.5 kg/ha-mm of water) was obtained form irrigation at full pan evaporation at the 4th WAE during the second planting season.

It could be concluded that to obtain maximum yield, amaranths should be supplied with water at ¾ of pan evaporation during the emergence, at full pan evaporation during the maximum vegetative cover and at ½ pan evaporation during the maturity stage of the crop.

The results obtained in this study would be useful in water stress studies, which can be used for irrigation scheduling and yield prediction.

CHAPTER ONE

INTRODUCTION

Amaranthus, also known as vegetable amaranth is a popular vegetable in South Western Nigeria. Traditionally, it is grown either as a mono-crop or in mixed cropping system by broadcasting the seeds directly or by transplanting vigorousseedlings raised in a nursery (Grubben, 1976 and Enyi, 1965).

Lesander et al. (1970) reported that amaranthus Viridis and A Caudatus L are extensively cultivated in many parts of West Africa for human consumption. Cox and Jollif (1986) showed the various species of amaranthus which vary in time of maturity, colour of leaves, length of stem and other characteristics. Oke (1966) evaluated the proximate analysis and oxalic acid contents in A. Caudatus while Oyenuga (1968) reported on the levels of protein, fat, crude fibre, ash and cabohydrate in A. Caudatus and A. Spinosus. Martin and Telek (1979) reported that amaranthus grown in the tropics can be produced year round and for little effort they afford a nutritious dish with abundant provitamin A, a vitamin particularly necessary in the tropics for eye health.

Amaranthus Caudatus is known to be a short day species. Fuller (1949) stated that it usually flowers and sets seeds only when day length is less than 8 hours. Field observations indicate that amaranthus grows well on soils containing widely varying level of soil nutrients. Although the genus is not known for high salt tolerance, an apparent ability to withstand mild salinity and alkalinity is apparent in some species of amaranthus (Foy and Campbell, 1981). For seeds to germinate and establish roots, amaranthus requires well moistened soil, but once seedlings are established, vegetable amaranthus require moisture throughout the growing season.

Amaranthus is usually seeded directly into the field and on rare occasions, vegetable amaranthus are transplanted to the fields as seedlings when they reach the stage of bearing four true leaves. Once the stand is established, the erect leaves quickly create a closed canopy, making understory weeds only a minor problem. Although a few varieties of amaranthus selected can be harvested with a machine, most cannot be. According to Astorn (1984), selection and breeding of a new variety of amaranthus that is adaptable to mechanical harvesting is now in progress.

Amaranthus is grown during both wet and dry seasons, but irrigation is normally required for dry season cultivation since the rate of transpiration by the leaves is fairly high. Frequent applications of water are required, related to the stage of growth of the crop and the moisture retaining capacity of the soil. The importance of irrigation on the growth of crop is shown in an FAO (1980) statistics bulletin which revealed that irrigated agriculture constitutes about 13% of global arable land but 34% of the world food production. Grainger (1982) predicted that by the year 2000, approximately 84% of the world's total farm land will still be on rainfall and will yield just over half of all crops. It was also reported by Grainger (1982) that the vegetables and other crops in Niger fell from around 500 kg/ha in 1920 to 350 kg/ha in 1978. The prediction for the year 2000 is that yields might well be in the region of 200 kg/ha if nothing is done to reverse the decline.

Over large parts of developing countries like Nigeria, much work is required to be done to redeem falling crop yield, sustain and or diversify crops from rainfed cultivation. (Barrow 1987). Irrigation methods that are available today offer the potential, if all goes well, for doubling or even quadrupling the yields of amaranthus and for considerably reducing risks of crop failure. Kramer (1983) also said that irrigation can as well offer considerable indirect benefits like improving the sustainability of production.

According to Kozlowski (1981) and Heathcote (1983), about 50-60% of the increase in the growth of vegetables achieved over the last twenty years in developing countries has been from new or rehabilitated irrigated land. It should also be noted that for much of the last twenty years, development efforts has been directed at improving irrigation through the study of a soil water balance in the planning of irrigation system to be used for the growth of vegetables.

1.1 OBJECTIVES OF THE PROJECT

The following are the objectives of the project.

(i) To evaluate the growth and yield of amaranthus under irrigated condition.

(ii) To determine the water use pattern of the crop with an aim of developing a good water management strategy.

1.2 JUSTIFICATION

Leafy vegetables form an important part of human diet as they provide a cheap supplement to other sources of minerals, vitamins and proteins. It is thus important to study the conditions favouring increased production of such an important crop. Amaranthus is always very scarce at the peak of the dry season (around March) and sometimes almost as scarce at the peak of the wet season (around July). This suggests that low water status in the dry season is one of the limitations to its growth and also excess soil water condition inhibits its development.

The aim of the project is to access the possibility of growing this crop under irrigation and also develop a good management of the irrigation water.

CHAPTER TWO

LITERATURE REVIEW

Irrigation water management is becoming critically important on farm lands worldwide because of improper water usage and increased competition for the limited water and energy supplies. Unfortunately, in many irrigation schemes, a lot of water is wasted on the farmer's field due to poor irrigation planning strategy. Irrigation planning are expressed in terms of frequency, rate and duration of water delivery to a farm unit. The methods may be simple or complicated.

Replogle and Merriam (1980) classified irrigation scheduling methods into three:

(i) Constant amount – Constant frequency, in which a fixed amount of water is applied at fixed intervals of days.

(ii) Constant amount – Variable frequency method, in which fixed amount of water is applied at varying days of irrigation intervals.

(iii) Varying amount – Constant frequency schedule, in which varying amount of water is applied at fixed irrigation intervals.

The first method is very common among irrigation farmers in Nigeria. This may be due to its ease of practice. The farmer knows the fixed day in a week or month when he has to irrigate. Some of the farmers just come on such fixed day and flood their fields. Unfortunately, this method of irrigation according to El-Nadi, (1969) leads to wastage of water especially at the early stage of the crop growth when the crop does not need all the water applied. This method of irrigation planning has led to waterlogging, rise of water table and consequently low crop yield.

2.1 WATER BEHAVIOUR IN THE SOIL

Water is not only of direct importance to plant, but also to soil, acting as solvent, hydrolyzing, reagent, temperature buffer, swelling agent and weaker of the soil fabric. Russells (1988) said further that high water content in the soil can also facilitates water and solute movement, as well as reducing the amount and rate of movement of oxygen in soil. Haines (1972) reported that there may be considerable residual water held at greater suctions than 1.5 MPa, especially in clay soils, and this is essentially unavailable to plants. In most clay soils the pores are not rigid and so there may be release of water from pores by their collapse rather than by capillary emptying and this is accompanied by shrinkage. The volumetric shrinkage is often equal to the volume of water lost and is then called normal shrinkage. Lawrence (1979) suggests that much of the plant available water in clay soils is held in pores narrower than 0.1μm which contract on drying, and in which suction in excess of 30 bar would be needed to remove water if the pores were rigid.

Soil normally receives water from precipitation and irrigation and deplete it by drainage, transpiration from the plant, direct evaporation from the soil as a result of high temperature and also through seepage into the ground water. The maximum or upper limit of amount of water retained in the soil is known as potential (full reservoir) water content of the root zone and is generally taken as equal to the field capacity, defined in practise as the water content of the specified volume of soil measurable two to three days after a thorough irrigation (Daniel, 1987). Michael (1978) reported that the value of field capacity were usually expressed in the past in terms of fractional volume or equivalent depth units. This is not a precise quantity, it only serves the useful purpose of providing an appropriate upper limit to the amount stored for subsequent use by plants, (Hillel 1982).

Table 1: Value of rooting depth and the fraction of the available water capacity of the root zone which is readily available.

Crop	Rooting dept (m)	Readily Available
Alfaifa	1.0 -2.0	0.55
Barley	1.0 – 1.5	0.55
Beans	0.5 – 0.7	0.45
Grass	0.5 – 0.7	0.45
Maize	1.0 – 1.7	0.60
Potatoes	0.4 – 0.6	0.25
Vegetable	0.3 – 0.6	0.20
Wheat	1.0 – 1.5	0.55
Ground nut	0.5 – 1.0	0.40

Source : Doorenboss and Pruit (1977)

The lower limit of soil moisture presumably available to crops was originally taken to be the "permanent wilting point". Irrigation management idea is to observe the moisture reserve of the root zone as it gradually diminishes following each irrigation so as to know when that reserve has been depleted to some level pre-determined to serve as the minimum allowable level (Maurya and Gupta 1989). The amount of water then required to restore the profile to field capacity is called the soil water deficit, often expressed according to Rowell (1996) as mm of water.

The typical values of rooting dept and the fraction of the available water capacity of the root zone which is readily available is shown in the Table 1 below.

2.2 THE MOISTURE CHARACTERISTIC CURVE

Soil moisture tension is a measure of the tenacity with which water is retained in the soil. It shows the force per unit area that must be exerted to remove water from a soil. Soil moisture tension is not necessarily an indication of the moisture content of the soil nor the amount of water available for plant use at any particular tension. The relationship between water content and water suction is a very important property of a soil and is simply called the moisture characteristic curve.

2.3 SOIL-WATER-PLANT RELATIONSHIP

2.3.1 Water Potential

In the physiology of vegetable, it is customary to express the free energy content of water in terms of water potential (Ψ). Although derivation of water potential from strict thermodynamic principles can be found in Slatyer (1967) and Meidner and Sheriff (1976); however for the present purposes, water potential according to Fitter and Hay (1989) can be defined as the free energy per unit volume of water, assuming the potential of pure water to be zero under standard conditions.

2.3.2 Availability of Water of Crops

The water available to the crop is the amount of water in the soil at any time in excess of the wilting point and it is expressed as the percentage by weight of dry soil or as equivalent of water per units depth of soil. The result of experiment on the effect of water stress on plant growth conducted by Hsiao (1973) suggests that the period on reduced leaf water potential during which growth is stopped do not necessarily reduce net growth if they are not too long. Michael (1978) reported that the knowledge of available water to crops has helped to reduced waste and damage to irrigated land. The effect of water movement on availability has received less attention than the effect of suction. This is because root searches out for water in the soil and movement of liquid water virtually ceases when soil is dried beyond permanent willing point.

Therefore vegetables depend on root system for water reserves. By the time the situation approaches the permanent wilting point, cell expansion has long ceased and the tightly closed stomata, severely restrict carbon dioxide entry as well as water loss. (Hsiao 1973). A typical soil moisture quantities in percentage by weight of dry soil shown below in table 2.

Table 2: Typical soil moisture quantities in percentage by weight of dry soil.

Soil Type	Saturation (%)	Field Capacity (%)	Permanent Wilting Point (%)	Available Water (%)
Fine Soil	15 – 20	3 – 6	1- 3	2- 3
Sandy loam	20 – 40	6 – 14	3 – 8	3 – 6
Silt loam	30 – 50	12 – 18	6 – 10	6 – 8
Clay loam	40 – 60	15 – 30	7 – 16	8 – 14
Clay	40 – 70	25 – 45	12 – 20	13 - 20

Source: Peter H. S. (1980)

Jackson et al; (1981) reported that when plant are stressed and transpiration is curtailed even temporarily, (e.g. as a result of stomata closure at noon) canopy temperature tend to rise appreciable due to reduction of evaporating cooling. This is the basis for modern techniques of sensing crop water stress by monitoring canopy temperature with infra-red radiation thermometer.

2.3.3 Influence of Water Stress on Vegetable Cells

Levitt (1980) defined stress as any environmental factor capable of inducing a potentially injurious strain in plant. Because of the complexity of plants/water relations, there is no single index of water supply by the environment such as soil water content, bulk air humidity etc which can be used to express the degree of water deficit stress normally called water stress to which a plant is subjected. As a result, it has become convectional to use plant rather than environmental indices of water stress.

According to Hsiao (1973), it is convenient to use three classification rather than loosely defined degree of water stress.

These are:

(i) Mild Stress: cell slightly lowered, typically down to – 0.5Mpa at most.

(ii) Moderate stress: cell lowered to values in the range –0.5 to -1.2 or -1.5 Mpa.

(iii) Severe stress: cell below – 1.5Mpa

Cell and leaf expansion are the process most sensitive to water stress because of their dependence upon turgor. The relative rate of volume increase of a cell is described by Fitter and Hay (1989).

Tyree and Jarvis (1982) reported that most studies of cell expansion have relied upon whole tissue measurements, although it is clear that each three characteristic (Q, P and δ) can vary amongst the cell of a leaf, particularly between mature and expanding cell

2.3.4 The Supply of Water by the Soil

Geiger (1965) said that the quantity of water held by a soil depends primarily on the climate and in particular on the excess of precipitation over evapotranspiration. The amount of soil- water which is available for uptake by a plant depends primarily upon the size distribution of the soil pores;

However the assumption based on field measurements of soils in winter and spring in U.K made by Webster and Beckett (1972) is that only those pores wider than 60 µm drain under the influence of gravity. Plant do not draw water only from the immediate vicinity of their actively- absorbing roots. An extraction of the water adjacent to a root proceeds, a depletion zone similar to those for mobile ions develops causing water to flow over distances of at least several mm from the bulk soil to the root surface (Hainsworth and Aylmore, 1986).

2.3.5 Water Movement in Vegetables

According to Spanswick, (1976), water evaporates in a freely-transpiring plant from the cell wall of epidermal and mesophyll cell in the interior of leaves and is lost to the atmosphere. The pathway of water movement from the root surface to the site of evaporation in the leaf is predominantly extracellular. Following Vanden Honert (1948) a number of workers have estimated the relative sizes of the resistance to water flow offered by different section of the water pathway from root surface to leaf mesophyll, by treating the plant as a hydraulic system made up of a simple series or catena of hydraulic resistance through which water flows in response to a gradient in water potential.

2.4 EVAPOTRANSPIRATION

Evapotranspiration or consumptive use denotes the quantity of water transpired by plants during their growth, or retained in the plant tissue, plus the moisture evaporated from the surface of the soil and the vegetation.

Potential Evapotranspiration (PET) concept was suggested by Thornthwaite (1948) who defined it as the Evapotranspiration from a large vegetation covered land surface with adequate moisture at all times. Penman (1948) also defined PET as the ET from an actively growing short green vegetation completely shading the ground and never short of moisture. Jensen (1973) assumed PET as the upper limit of ET that would occur with a well watered agricultural crop having an aerodynamically rough surface such as lucern with 30 to 50 cm of top growth.

Singh (1988) report that in irrigated areas, the soil may be adequate supplied with water, yet the plant surface may appears dry. In this case the canopy resistance is probably not zero (van Bavel and Ehrler 1968), but has a value that will be called the canopy resistance at potential evapotranspiration, rcp. The value of rcp will probably be different for different crops, and may change with environmental condition during a single day.

In planning the cropping pattern for an area, it may be possible to have such crop combinations which have their peak consumptive use rates spread out in such a way as to use the available supply in the most efficient manner. Table 3 below presents some typical values of the peak of soil moisture removal by crop under different climate condition for precise estimates, however the peak use rates of different crops should be established on the basic of experimental data from the concerned or similar agro climatic region.

Water extraction:

On root system morphology and distribution, Lange et al (1982) reported that vegetables do not required deep and widely – spreading root in humid zones for water uptake because soil water is plentiful and all the water required for transpiration can in theory be supplied by a relative small volume of soil. In drier tropical zones, the proportion rises to 30-40% whereas the root system of some desert plant which grow to great depths can be up to 60-90%. For example, in a review of woody species native to Mediterranean and desert areas of Israel and the Americans, Kummerow (1980) found maximum rooting depths of up to 9 m for a plant growing in south African desert and 30 m for another plant grow near the suez canal.

Von Willert (1985), reported that, some cases of deep rooting can be achieved when a large quantity of seeds are released. A very few of which may germinate extends their root rapidly to make contact with store water while the surface layer remain moist.

Table 3: Maximum rates of soil moisture use rates by crops under different conditions.

Climate Condition	Peak rate of soil moisture removal (mm/ day)
Cool, humid	3
Cool, dry	4
Moderate, humid	4
Moderate, dry	5
Hot humid	5
Hot dry	8

Source: Michael and Ogha (1987)

2.5 The Estimation of Water use by Crops using water balance method.

The actual evapo-transmission from a crop normally falls well short of the Potential evaporation as a result of insufficient rainfall during the growing season.

The water balance of a field is an itemized statement of all gains, losses, and change of storage of water occurring in a given field within specified boundaries during a specified period of time. The task of monitoring and controlling the field water balance is vital to the efficient management of water and soil.

The water balance equation according to Stegman et al (1980) is written as:

$$P + I = ET \pm R \pm D \pm \Delta S \ldots\ldots\ldots\ldots (1)$$

Where P = Precipitation (rainfall) (mm)

I = Irrigation (mm)

ET = Crop evapotranspiration (consumptive use) (mm)

R = Surface run off into or out of the field in

question (mm)

D = Capillary drainage toward the surface or into the subsurface (mm)

ΔS = Residual moisture in soil (mm)

Rearranging (2); the ET is derived as follows.

$$ET = P + I \pm R \pm D \pm \Delta S \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

he data were obtained as follows:

(i) Potential ET. Evapotranspiration was obtained by Doorenbos and Pruitt (1977) from meteorological information

(ii) The crop factor takes into account the limited evaporation from bare soil between plant and is based on the extent to which the crop covers the ground. This can also be obtained from a published table.

(iii) Estimate ET. Evapotranspiration was obtained by multiling the potential evaporation by the crop factor.

(iv) Rainfall was measured on site.

(v) Soil water deficit; The previous record showed that the deficit had reached

23 mm by the beginning of day 1, on day 1, 3.6 mm of water was lost and the deficit rose to 26.6 mm. On day 2, the deficit rose to 31.4 mm. On day 3, evaporation was only 0.6 mm more than the rainfall and so the deficit rose to 32.0. On day 5, the limiting deficit of 40 mm was exceeded and so during the evening, irrigation was applied which brought the soil to field capacity and added extra water for controlling salinity by leaching. On day 9, rainfall was in excess of that required to bring the soil back to field capacity and 3.5 mm of water must have drained through the root zone.

The data illustrated the use of soil water balance sheet as a bases for planning irrigation. Water applied when the deficit reaches the limiting value, although not necessarily in amounts to bring the il back to the field capacity.

Table 4; A soil water balance sheet for a crop of groundnut grown in central India.

Day	1	2	3	4	5	6	7	8	9	10
Potential Evap. (mm)	4.5	6.0	7.2	5.4	6.6	3.2	6.6	7.2	6.5	5.5
Crop factor	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9
Estimated Evap.(mm)	3.6	5.8	5.8	4.3	5.9	2.9	5.9	6.5	5.9	5.0
Rainfall (mm)	0	5.2	5.2	0	0	0	0	0	25.0	0
Soil water deficit at the Beginning of day(mm)	23.0	31.4	31.4	32.0	36.3	0	2.9	8.8	15.3	0
Soil water deficit at the End of the (mm)	26.0	32.0	32.0	36.3	42.2	2.9	8.8	15.3	0	5.0
Irrigation (mm)	0	0	0	0	50. 0	0	0	0	0	0
Drainage (mm)	0	0	0	0	7.8	0	0	0	3.8	0

Source: Rowell (1996)

CHAPTER THREE

MATERIALS AND METHODS

3.1 THE STUDY AREA

The experiment was conducted at the Department of Agricultural Engineering Experimental Farm, Federal University of Technology, Akure (FUTA). It is located in the lowland rainforest area of Nigeria. The annual rainfall ranges between 1000-1500 mm. There are two growing seasons due to the bimodal character of rainfall distribution. The first starts from late March to late July ending in a dry spell of approximately two weeks and a shorter second season from late August to early November.

3.2 THE CROP AND LAND PREPARATION

Amaranthus caudatus (*quinoa*) is usually short-lived annual crop up to 1 m in height. The stem is usually erect, often tick and fleshy, sometimes grooved. The leaves varies in shape, green or purple, normally alternate, petiolate and entire tips often obtuse.

Amaranthus grow rapidly and may be harvested 30-50 days from sowing when they are 15-20 cm high. Either the whole plant may be uprooted, or established plants may be cut back to within 15 cm of the base to encourage lateral growths which will provide successive harvests.

The soil was tilled to form seed beds Seeds of Amaranths Caudatus (*Quinoa)* commonly known as African spinach were broadcasted on the field at the rate of 8 g/m^2. Thinning was done two weeks after planting at a spacing of 1 m x 0.8 m thereby, giving a plant population of 15 stands per plot. Same procedures were repeated during the second experiment which was carried out between September and October 2000. Fertilizer was not applied to the soil during the experiment.

SYSTEM LAYOUT

Water was applied using sprinklers arranged in 12 m X 12 m triangle. The layout of the field plot is as shown in fig. 1

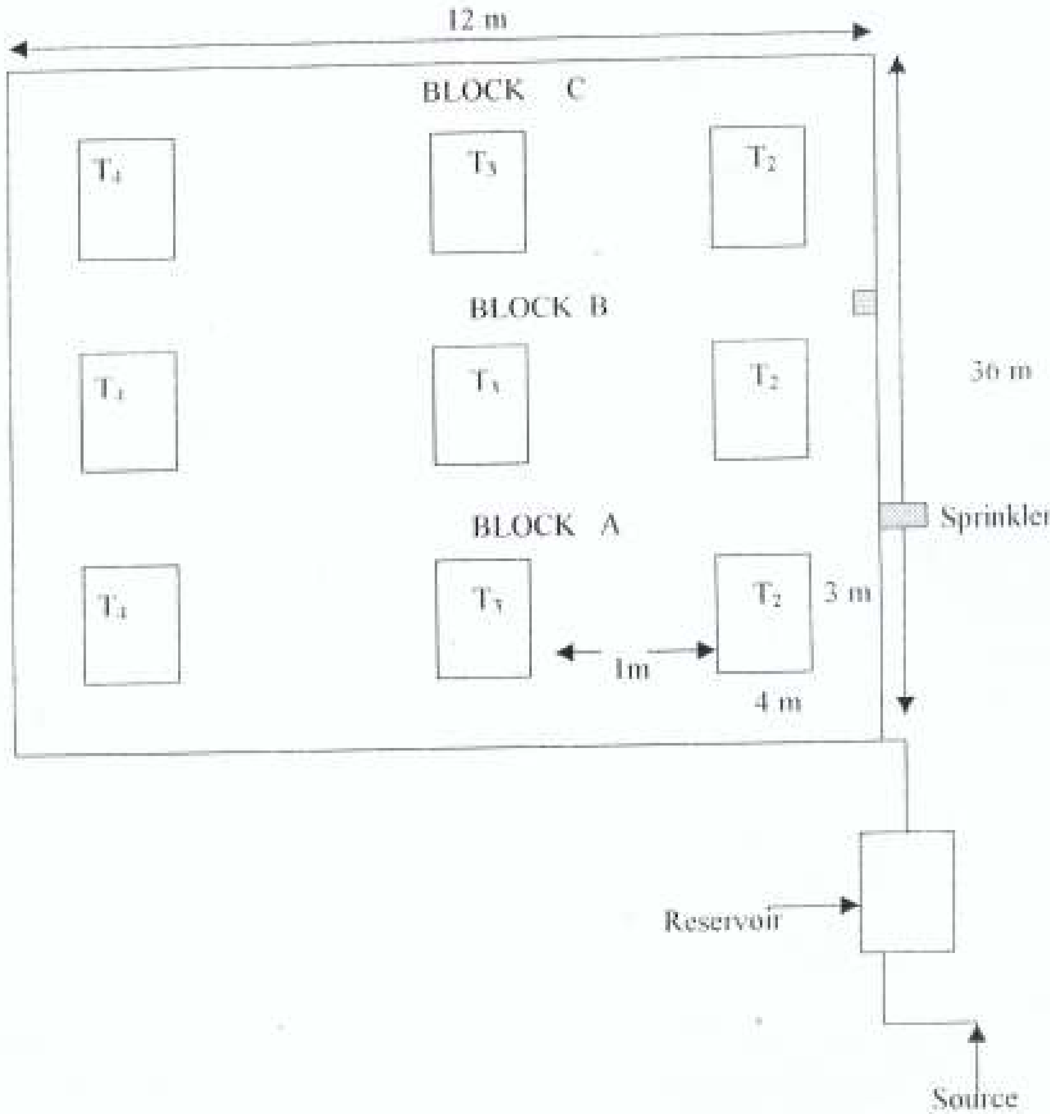


Fig. 1 Layout of Field Plots.

3.3 TREATMENTS AND EXPERIMENTAL DESIGN

There were three irrigation treatments as shown in Table 5

Table 5: Different code for irrigation treatments

Code		Definition
T_4	-	Irrigation at full pan evaporation (Ep)
T_3	-	Irrigation at ¾ pan evaporation (¾ Ep)
T_2	-	Irrigation at ½ pan evaporation (1/2 Ep)

The details of the treatment used in the study is shown below on Table 6:

Table 6: Irrigation Treatments

Treatments		Depth of water for each application (mm)	
Code	Irrigation	March &April (1st Season)2000	Sept. & October (Second Season)2000
T_4	Ep	8.1	12.2
T_3	$^3/_4$Ep	6.1	9.2
T_2	$^1/_2$Ep	4.1	6.1

All irrigation water application was based on pan evaporation (Ep) which are measured at the experimental site. . To estimate quantity of water applied on the crop, the average value of Ep for to the months of March and April for the first season and for months of September and October for second reason were used. The values were 8.1 mm/d and 12.2 mm/d respectively.

The experimental design was Randomized Complete Block (RCB) with three replications. Each plot measuring 3m x 4m containing three rows of amaranths on a sprinkler irrigation of size 12m x 12m on a triangle arrangement was used. Weeds were controlled using manual weeding method starting from two weeks after planting and fourth and sixth weeks after planting i.e. three major weeding were carried out at each of the cropping seasons.

The crop was irrigated uniformly for all the treatments until the plants were fully established, thereafter, variation on the water application to the crop based on the designed treatments was observed throughout the crop growing seasons.

3.4 MEASUREMENT

Measurements taken can be grouped under three sub-titles.

(i) Meteorological variables

(ii) Soil measurements and

(iii) Plant/Agronomic measurements.

3.4.1 Meteorological Variables.

The climatic data collected from a complete weather station installed on the experimental field during the seasons are presented in Table 7.

3.4.2 Soil Measurements

The soil measurements taken include:

(i) Soil Physical Characteristics

Soil Physical Characteristic i.e. Particle size analysis and bulk density were determined. Standard procedures were followed in their determination and the details of calculations and the results are presented in the Appendix A

(ii) Soil Moisture Content

Root zone moisture contents were measured weekly throughout the crop growing season for each treatment by gravimetric method. Soil samples were collected after irrigation when the soil has reached the filed capacity.

On each sampling date, soil samples were collected from three replications of each treatment from a soil profile depth of 0-30 cm at an incremental depth of 10cm. Soil samples were oven dried at a temperature 105^0c for 24hours in the laboratory to determine soil moisture content.

(iii) Evapotranspiration Estimates

Evapotranspiration or Crop water use was determined from the principle of Inflow – Outflow (Water Balance Method) as shown below:

$$ET = P = I - R \pm \Delta S \pm D \text{ ------------------ (2)}$$

Where ET = Evapotranspiration

P = Precipitation

R = Run-off

ΔS = Change in ground water storage

D = Drainage

The precipitation (P) were measured during the period of the experiment by rainfall recording equipment (Raingauage) placed on the site.

The runoff was determined by installation of three $1m^2$ runoff Catchment made of metallic materials, one Catchment on each of the three blocks. Surface outflow from the Catchment were measured immediately from a collection bowl placed adjacent to the runoff Catchment. The runoff values were determined using the relationship:

$$R = \frac{Vw}{Ac} \quad \text{----------------------- (3)}$$

Where R = Run off (mm)

Vw = Volume of Water collected (cm^3)

Ac = Area of Catchment (m^2)

The change in soil water storage (ΔS) was calculated from the difference in water content of the root zone before irrigation and the water content after irrigation. (see appendix B………). The drainage during the period of the experiment was assumed to be negligible.

(iv) Soil Temperature

The soil temperature was determined by using soil thermometer. Soil temperature was determined at 5 cm, 10 cm, 20 cm and 30 cm depth for every week during the first and the second planting seasons.

(v) Water Use Efficiency (WUE)

Water use efficiency was calculated for each treatments using methods similar to those used by Shae et al (1999). A water use efficiency (WUE) or ET ratio (Stanhill, 1986) was defined as:

$$WUE = \frac{Yield}{\Sigma ET} \quad \text{------------------------(5)}$$

WUE = Water Use Efficiency in $Kgha^{-1}mm^{-1}$

YIELD= Sum of fresh weight of leaves, stems and roots in kg.

ΣET = Cumulative water use (mm)

3.4.3 Plant/Agronomic Measurements

The agronomic parameters measured include root depth, plant height, leaf width, leaf length, leaf area, leaf area index and biomass yield.

The measurements were carried out weekly on 9 plants from the crop establishment stage till maturity time.

LEAF AREA

Sampling for leaf area measurement was taken on 3 plants per treatment every week.

The leaf was traced out on graph paper to measure area. From this measurement, leaf surface area (cm^2) and leaf area index were estimated by the formula:

$$\text{Leaf Area Index} = \frac{\text{Total surface area of plant}}{\text{Soil surface area covered by the plant}} \quad \text{------(4)}$$

Total yield per plot was determined by cutting the total plant above the ground and weighed with the result shown in table 29(a) and 30(a)

PLANT HEIGHT

The height of plant was measured from the soil surface to the tip of the plant. Three plants per plot were sampled for height measurement and the average represented the plant height for each plot.

ROOT DEPTH

The method for the estimation of root zone depth was the trench profile method. With the aid of spade and sharp cutlass, trench profiles were dug about 10 mm near the sample plant on each plot. The depth of trench depends on the length of roots.

TOTAL BIOMASS YIELD

A sample plant from each block, after being uprooted was weighed at its fresh state. The weight of the leaves, stems and roots were noted and then the samples were transferred into the oven and dried at 80^0 C for 24 hours. The weight of dry matter was then recorded and the total biomass yield computed as follows:

$$TBY = \frac{F \times Mb}{10^6} \quad (6)$$

Where: TBY = Total biomass yield (ton/ha)

Mb = Sum total of M_L, M_S and M_R

	M_L	=	Weight of leaves (g)
	M_S	=	Weight of stem (g)
	M_R	=	Weight of root (g)
	F	=	L / S (7)
Where:	L	=	1 hectare (10^4 m^2)
	S	=	Spacing between plants (m)
	F	=	The multiply ratio (per ha)

The total biomass yield was taken at the 2nd and 4th weeks after establishment.

3.4.4 Statistical Analysis

Analysis of variance (ANOVA) was performed on soil moisture, soil temperature, root depth, root weight, leaf weight, stem weight, plant height and leaf weights. The ANOVA was performed using Duncan multiple range test for a randomized block design at the $\propto$ = 0.01 and 0.05 level of significance to determine if significant differences existed between treatment means.

CHAPTER FOUR

4.1 RESULTS AND DISCUSSION

Higher rules of relative humidity were recorded during the second (i.e. sent-out) experiment which falls within the second modal period of rainfall. There was no rainfall recorded in the first month of the first season and hence the plant depended on inherent soil water and irrigation water application for its growth. The average air temperature was higher in March and April when compared to the months of September and October.

Table 7: Prevailing Weather Condition during the experiments

Climatic parameters	March	April	September	October
Av. Air Temperature ^{0}(c)	36.3	36.1	31.1	30.5
Rainfall (mm)	-	71.1	130.8	117.8
Wind Speed (m/s)	0.049	0.056	0.71	0.72
Sunshine hours (hr)	6.5	6.2	6.6	7.4
Relative Humidity(%)	76.4	78.7	87.7	84.5
Solar Radiation(W/m^2)	84.20	82.71	67.86	69.82

TABLE 8: Soil water balance (mm/d) of Amaranthus during year 2000 first planting season.

Calendar Period	Treatment	DAE	P (mm)	I (mm)	$\triangle$ S* (mm)	R (mm)	ET (mm/d)
29TH March – 6th April	T_4	7	22.2	8.1	-2.4	0.9	3.8
	T_3		22.2	6.1	-2.2	0.9	3.5
	T_2		22.2	4.1	-2.3	0.4	3.2
7TH April –14Th April	T_4	14	20.2	8.1	0.8	0.4	4.1
	T_3		20.2	6.1	0.6	0.4	3.7
	T_2		20 .2	4.1	0.8	0.4	3.5
15TH April -21st April	T_4	21	8.3	8.1	-0.0	0.2	2.3
	T_3		8.3	6.1	-	0.2	2.0
	T_2		8.3	4.1	-0.0	0.2	1.7
22nd April -28th April	T_4	28	_	8.1	-0.1	_	11
	T_3		_	6.1	-0.3	_	0.8
	T_2		_	4.1	-0.4	_	0.5

* A negative ΔS indicate a loss while a positive ΔS indicates a gain in the soil water.

TABLE 9: Soil water balance (mm/d) of Amaranthus during 2000 Second planting season.

Calendar Period	Treatment	DAE	P (mm)	I (mm)	△ S* (mm)	R (mm)	ET (mm/d)
15TH Sept. – 21th Sept.	T_4	7	23.4	12.2	-0.6	3.4	4.5
	T_3		23.4	9.2	-0.6	3.4	4.0
	T_2		23.4	6.1	-0.8	3.4	3.6
22TH Sept. –28Th Sept.	T_4	14	57.0	12.2	-0.6	13.1	7.9
	T_3		57.0	9.2	-0.5	13.1	7.5
	T_2		57.0	6.1	-0.5	13.1	7.0
29TH Sept. –5th Oct.	T_4	21	54.0	-	0.9	19.0	5.1
	T_3		54.0	-	0.8	19 .0	5.1
	T_2		54.0	-	0.9	19.0	5.1
6th Oct. 12th Oct.	T_4	28	21.7	12.7	0.8	16.1	2.7
	T_3		21.7	9.2	0.7	16.1	2.2
	T_2		21.7	6.1	0.7	16.1	1.8

TABLE 10: Soil moisture content (% wb) height basis at different treatments during First Season

Treatment	Soil Dept. (cm)	DAE 0	7	14	21	28
T_4	10	9.0	12.9	12.3	12.7	12.7
	20	10.0	13.6	12.9	13.4	13.4
	30	10.9	14.6	13.7	14.3	14.3
T_3	10	8.1	11.7	11.3	11.8	11.8
	20	9.2	13.2	12.1	12.7	12.7
	30	9.8	13.5	13.0	13.7	13.7
T_2	10	7.1	10.8	10.3	10.8	10.8
	20	8.0	11.9	11.0	11.8	11.8
	30	9.4	12.5	11.8	12.9	12.9

TABLE 11: Soil Moisture Content (% wb) at different treatments during Second Season

Treatment	Soil Dept. (cm)	DAE				
		0	7	14	21	28
T_4	10	10.7	11.8	11.1	11.2	11.3
	20	10.9	12.9	12.2	12.8	12.8
	30	11.9	13.4	13.0	13.4	13.4
T_3	10	9.4	10.9	10.3	10.4	10.4
	20	10.2	11.9	11.3	11.4	11.4
	30	11.2	12.9	12.3	12.3	12.4
T_2	10	8.2	10.2	9.7	9.8	9.5
	20	9.2	11.2	10.7	10.8	10.8
	30	10.0	12.2	11.8	11.8	11.8

4.2 SOIL MOISTURE REGIME IN THE TREATMENTS

The soil moisture content on the various treatments from time of planting to 28 DAE are presented in Tables 10 & 11 while Figures 4 & 5 show the soil moisture contents in the different treatments during the growing stages of the crop.

The soil moisture increases during the first week after crop establishment as shown in Fig. 1 & 2 for the two planting seasons.

During the emergencies stage, the plant extracted limited amount of water for its metabolic activities and hence there was an increase in and moisture. However in later stages when the crop needed none water, it extracted more resulting in fall of moisture content

There was negligible increase in the soil moisture again during the last stage of the development, this was as a result of a reduction in the moisture needed during the maturation stage of the crop.

The results obtained for the soil moisture during the period of growth was subjected to statistical analysis and the result is shown in the ANOVA table (12 and 13) below.

TABLE 12(b) ANOVA table for Soil Moisture during first season.

Sources Of Variation	Degree of Freedom	Sum of Square	Mean Square	Observed F	Tabular 5%	F 1%
Week	4	30.34	7.59	948.75	3.84	7.01
Treatment	2	8.09	4.05	506.25	4.46	8.65
Error	8	0.06	0.008	-	-	-
Total	14	38.49	-	-	-	-

TABLE 13 ANOVA table for Soil Moisture during second season).

Sources Of Variation	Degree of Freedom	Sum of Square	Mean Square	Observed F	Tabular 5%	F 1%
Week	4	5.33	1.33	55.42	3.84	7.01
Treatment	2	6.83	3.42	142.50	4.46	8.65
Error	8	0.19	0.024	-	-	-
Total	14	12.35	-	-	-	-

From ANOVA Tables 12 & 13 above, the week and the treatment means is highly significant because the F observed > F tabulated for both planting seasons at 1% level of significant.

4.3 SOIL WATER BALANCE

The water use was estimated based on one-dimensional soil water balance shown in Table 8 & 9 for the two seasons. The detail, of the determination of amount of water stored in the root zone are presented in appendix B.

The ET values differed among the two planting seasons with the highest ET recorded during the calendar period 15th September – 12th October. The increase in the values was due to the increase in the soil moisture as a result of rainfall of high intensity normally recorded in the second modal period of rainfall.

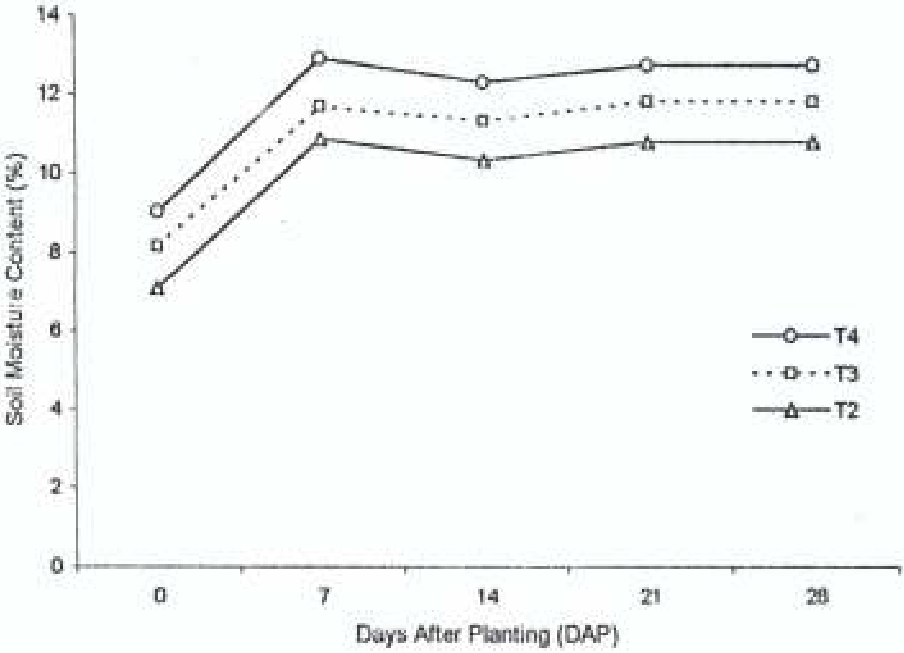


Fig. 1 ; Soil moisture content (%WB) at different treatments during the first season

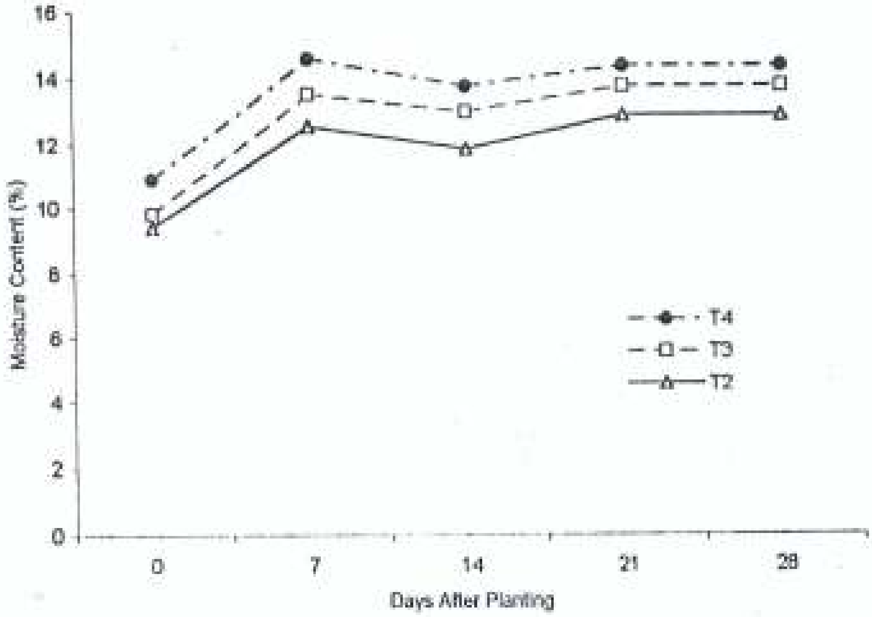


Fig. 2 : Soil Moisture Content (%WB) at different treatments during the second Seasaon

The ET observed during the second week of both planting seasons were the highest as shown in Figure 3 & 4. At this time the plant was at full vegetative stage and hence transpiring water at high rate until sense when the values of ET dropped.

This concurs with observations made by Rowel (1996) for millet crop.

The highest ET recorded in the study was 7.9 mm/day observed in the second planting season, this was due to the present of more moisture in the soil as recorded on T_4 treatment. The highest ET recorded for the first planting season was 4.1 mm/day. Rainfall was of loner magnitude during this season. These results agree with the earlier work reported by Michael and Ogha (1987).

The ET value of 5.1 mm/day recorded for T_4, T_3 & T_2 during the calendar period 29th September – 5th October in the second planting season was due to the precipitation of about 54 mm during that period. The heavy rainfall did not necessitate irrigating (Table 9).

The ET value of 3.8 mm/day and 4.5 mm/day were recorded during the initial stage of development for the first and second planting season. The least ET of 0.5mm/day and 1.8mm/day was recorded during the first and the second planting season. At this final stage of maturity of the plant consumptive use rate dropped (Michael, 1978).

4.4 CUMULATIVE WATER USE OF AMARANTHUS

Values of cumulative water use (ET) against weeks after planting

(WAP) are presented in Table ..... The cumulative water use (ET) up to 28 DAP after establishment for irrigation treatments T_4, T_3, and T_2 during the first planting season were 79.1 mm. 70.0 mm and 62.3 mm respectively and the lowest values at the first week after establishment were 26.6 mm, 24.5 mm and 22.4 mm for irrigation treatments T_4, T_3 and T_2 (Table 41)

The values of cumulative water use in the second planting season were observed to be higher than that of the first planting season for the same DAP. The highest values being 141.4 mm; 131.6 mm; and 122.5 mm for T_4, T_3 and T_2 respectively. The least values at first week after establishment for the same treatments were 31.5 mm, 28.0 mm and 25.2 mm. (See Table 42).

There were remarkable difference in the cumulative water use for all the treatments. It was therefore noticed that the cumulative water use depends on the amount of water applied, hence it should be known that amaranths respond very well to water application.

4.5 SOIL TEMPERATURE

The soil temperature at various depths are shown on Tables 14a and 15a and the analysis of variance results are presented in Tables 14b and 15b in order to determine the significant effect on the soil.

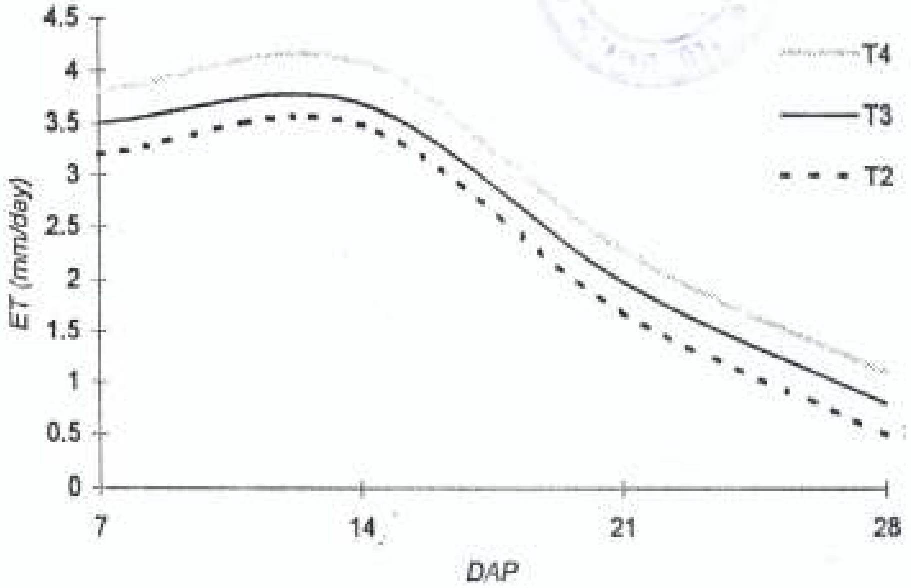


Fig. 3: Evapotranspiration values estimated from water balance equation at various treatments in first season

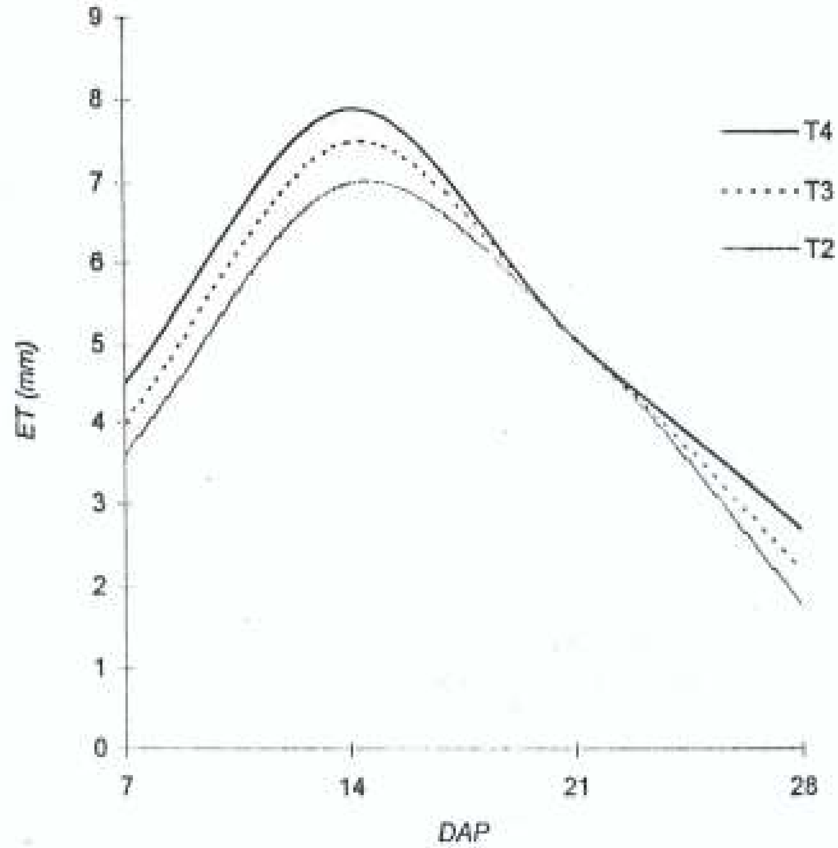


Fig. 4: Evapotranspiration values estimated from water balance equation at various treatments in second season

TABLE 14a: Soil Temperature (^0C) at different depth in the treatments during first season

Treatment	5cm	10cm	15cm	20cm	30cm
T_4	36.9	36.2	35.5	34.7	33.9
T_3	36.8	36.0	35.5	34.9	34.1
T_2	36.9	36.0	35.4	34.8	34.5
Wk. Total	110.6	108.2	106.4	104.4	102.5

TABLE 14b ANOVA table for soil temperature during first season.

Sources Of Variation	Degree of Freedom	Sum of Square	Mean Square	Observed F	Tabular 5%	F 1%
Week	4	13.36	3.34	115.17	3.84	7.01
Treatment	2	0.018	0.009	0.310	4.46	8.65
Error	8	0.232	0.029	-	-	-
Total	14	13.61	-	-	-	-

TABLE 15a: The Soil temperature (^0C) at different depth in the treatment during second season

Treatment	5cm	10cm	15cm	20cm	30cm	Mean
T_4	36.7	36.0	35.5	34.8	33.7	35.34
T_3	36.6	36.0	35.3	34.7	33.7	35.26
T_2	36.7	36.8	35.0	34.5	34.0	35.20
Wk. Total	110.0	107.80	105.80	104.00	101.40	35.27

TABLE 15b ANOVA table for soil temperature during second season.

Sources of Variation	Degree of Freedom	Sum Square	Mean Square	Observed F	Tabular 5%	F 1%
Week	4	14.746	3.687	135.06	3.84	7.01
Treatment	2	0.049	0.025	0.916	4.46	8.65
Error	8	0.218	0.0273			
Total	14	15.013				

From the ANOVA Table 14b & 15b for both first and second planting seasons, the soil depth is highly significant because the F observed for depth > F tabulated at 1% level of significant. Since the F observed for treatment < F tabulated at 1% level of significant, the treatment is not significant.

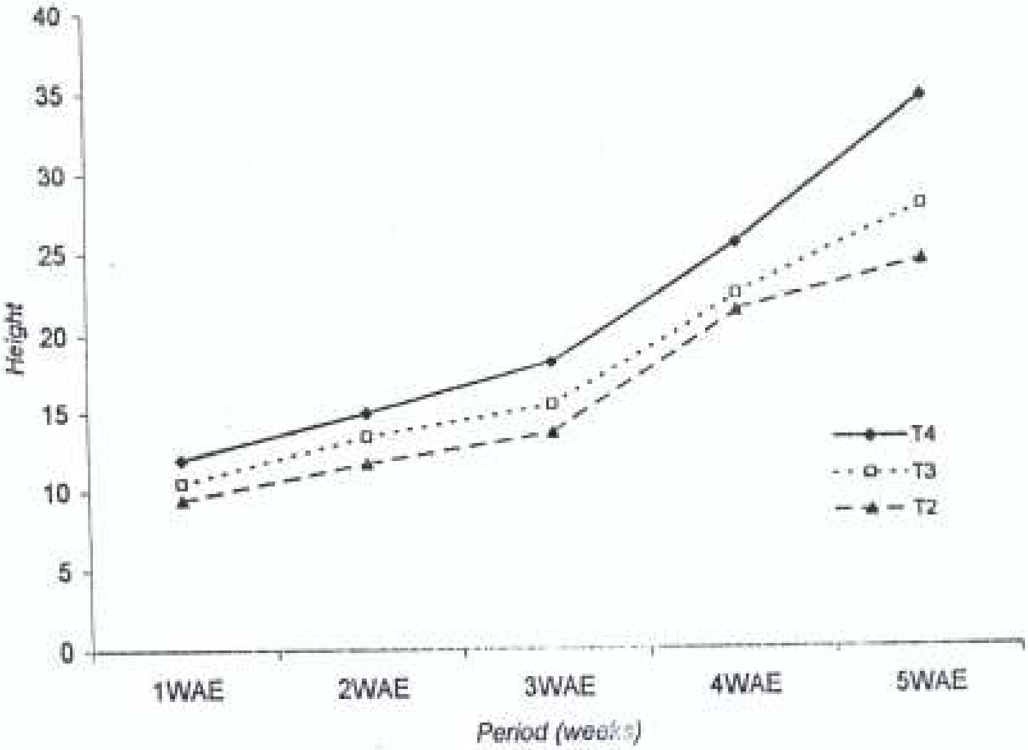
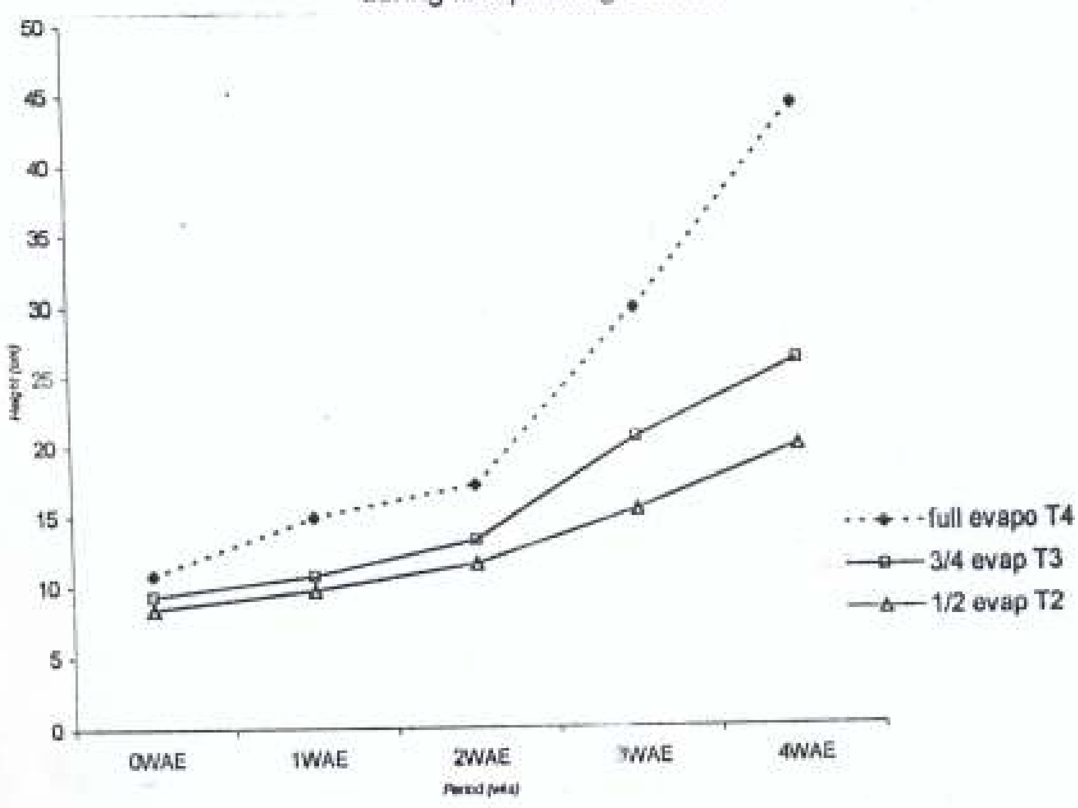


Fig. 5: Plant Height of amaranthus under various treatments during first planting season



4.6 Agronomic Measurement

4.6.1 Plant Height

Figures 5 & 6 show the plant height for every week starting from the establishment date to the period of maturity. It was observed that there was a gradual increase in the plant height based on the type of treatment applied. The T_4 treatment has the highest plant height for both seasons.

After about two weeks, the sudden increase in the height observed was due to the plant reaching the period of maximum vegetative cover.

The result obtained for both planting seasons was subjected to statistical analysis as shown below on Tables 16 & 17.

TABLE 16a: Plant height (cm) grouped by treatment and weeks of growth during season.

Treatment	WK I	WK II	WK III	WK IV	WK V	Total treatment
T_4	10,8	12.8	17.1	29.8	44.1	114.6
T_3	9.3	10.7	13.2	20.5	26.0	79.7
T_2	8.4	9.7	11.5	15.3	19.8	64.7
WK. Total	28.5	33.2	41.8	65.6	98.9	259.0

TABLE 16b: ANOVA table for the plant height during first season.

Sources of Variation	Degree of Freedom	Sum of Square	Mean Square	Observed F	Tabular F 5%	1%
Week	4	876.97	219.24	9.28	3.84	7.01
Treatment	2	262.20	131.10	5.55	4.46	8.65
Error	8	189.01	23.62			
Total	14	1328.18				

TABLE 17a: The plant height (cm) grouped by treatment and weeks of growth during second season.

Treatment	WK I	WK II	WK III	WK IV	WK V	Total treatment
T_4	12.0	14.9	18.2	25.5	34.6	105.20
T_3	10.5	13.3	15.4	22.4	27.8	89.50
T_2	9.4	11.7	13.6	21.4	24.4	80.50
WK. Total	31.90	40.00	47.20	69.30	86.80	275.20

TABLE 17b: ANOVA table for the plant height during second season.

Sources of Variation	Degree of Freedom	Sum of Square	Mean Square	Observed F	Tabular F 5%	1%
Week	4	678.39	169.59	68.30	3.84	7.01
Treatment	2	62.51	31.26	12.59	4.46	8.65
Error	8	19.86	2.483			
Total	14	760.76				

During the first season the F observed> F tabulated (table 15b) for weeks and treatment, hence the week and treatment means are significant at the 5% level of significant. Similarly for the second season (table 17b) the F observed > F tabulated at 1% level of significant for both the weeks and the treatment, hence the week and the treatment means were highly significant.

4.6.2 Leaf Area Index

The LAI values are presented in Tables 18a & 18b for both planting seasons. Fig 7 and 8 show the LAI in the different treatments taken at the 2nd and 5th weeks during the first and second planting season. The irrigation at full Ep (T_4) have the greater vegetative growth than the other treatments.

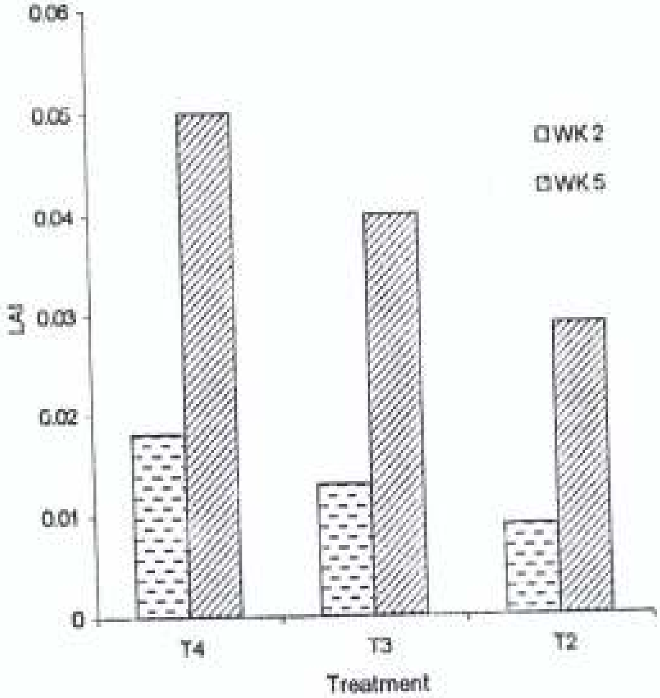


Fig. 7 : Leave Area Index (LAI) under various treatments during first Season

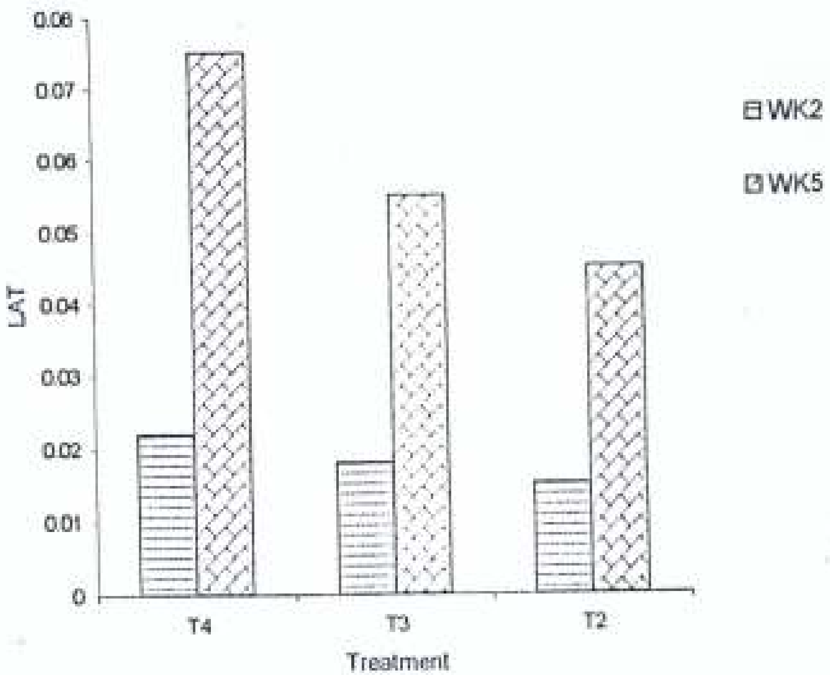


Fig. 8 : Leave Area Index (LAT) under variuos treatments during 2nd Season

TABLE 18a Leaf area index during first season.

Treatment	WK. I	WK II	WK III	WK IV	WK V
	LAI	LAI	LAI	LAI	LAI
T_4	0.003	0.018	0.037	0.044	0.050
T_3	0.001	0.013	0.023	0.038	0.040
T_2	0.001	0.009	0.023	0.030	0.029

TABLE 18b Leaf area index during second season.

Treatment	WK. I	WK. II	WK.III	WK.IV	WK.V
	LAI	LAI	LAI	LAI	LAI
T_4	0.005	0.022	0.049	0.065	0.075
T_3	0.004	0.018	0.045	0.051	0.055
T_2	0.002	0.015	0.038	0.044	0.045

Note: LAI = Leaf Area index.

4.6.3 BIOMASS YIELDS

Table 19 – 30 show the result of biomass yield in all the treatment taken during the period for both planting seasons. The treatment T_4 gave the best result in terms of biomass yield followed by treatment T_3. The plant must have benefited from accumulated water in the root zone. Results obtained in the second planting season planting season for all treatments show higher biomass yield than that observed in the first planting season.

Biostatical analysis of biomass yield at @ = 0.01 and 0.05 level of significance showed there were significant different in the biomass yield for the varying treatment in first and season planting seasons (Table 33 – 38).

The highest value of biomass yield (fresh) at 2 WAE in first season was 0.38 ton / ha in treatment T_4 while lowest value 0.03 ton / ha was observed in treatment T_2.

WAE during first planting season, the highest biomass yield 1.24 ton/ha was observed in treatment T_4 and the lowest value was 0.08 ton / ha in treatment T_2.

At 4 WAE the highest biomass yield was 1.95 ton / ha in treatment T_4 and lowest biomass at 4 WAEW was 0.20 ton/ ha in treatment T_4 and lowest biomaa at 4WAEW was 0.20 ton/ ha in treatment T_2 during second planting season. The yield obtained varied onn function of amount of water applied. Yield was highest when crops were at full evaporation (T_4) and lowest at

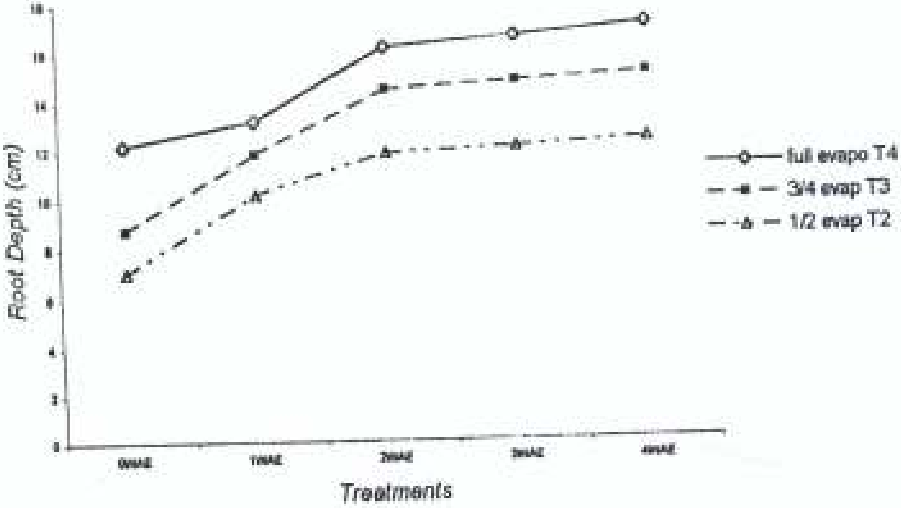


Fig. 9: Root Depth of amaranthus under various treatments during first planting season

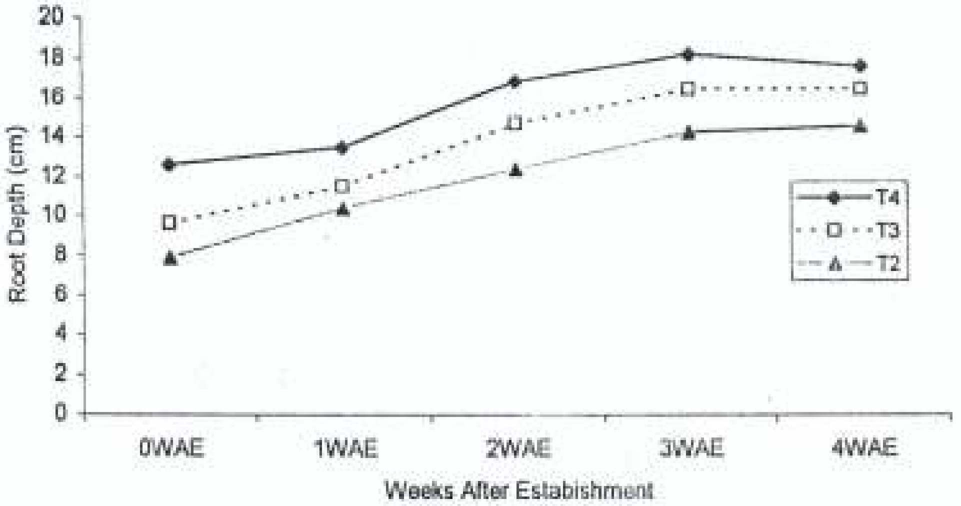


Fig. 10: Root depth of amaranthus under various treatments during 2nd planting season

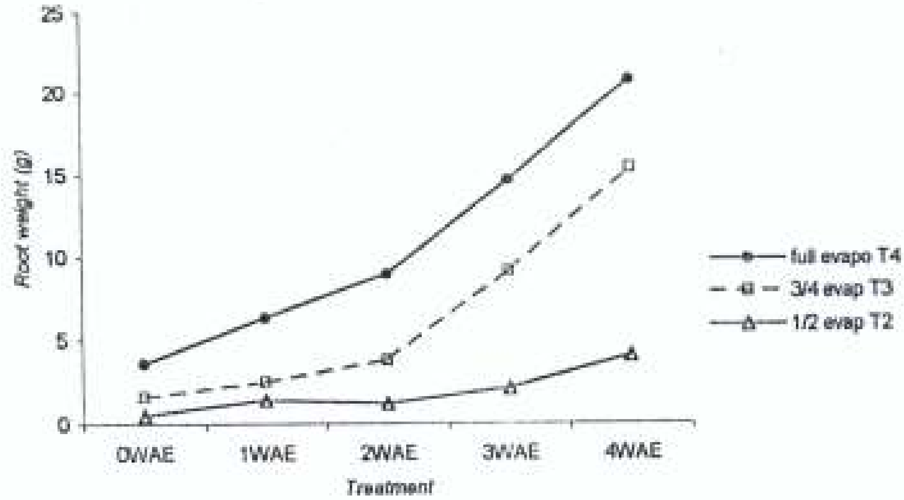


Fig. 11: Root Weight of amaranthus under varioustreatments during first planting season

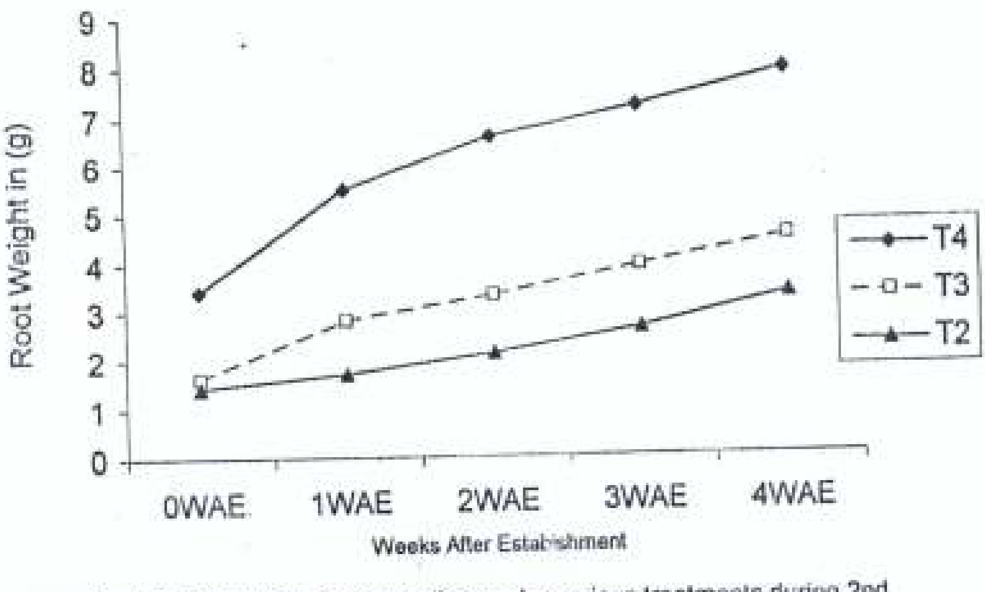


Fig. 12: Root weight of amaranthus under various treatments during 2nd planting season

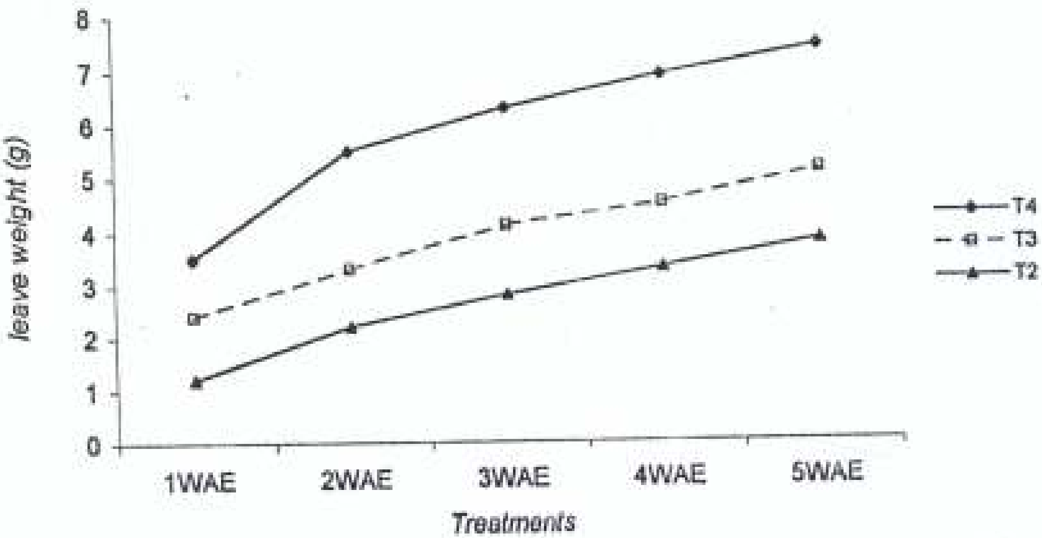


Fig. 13: Leave Weight of amaranthus under various treatments during first planting season

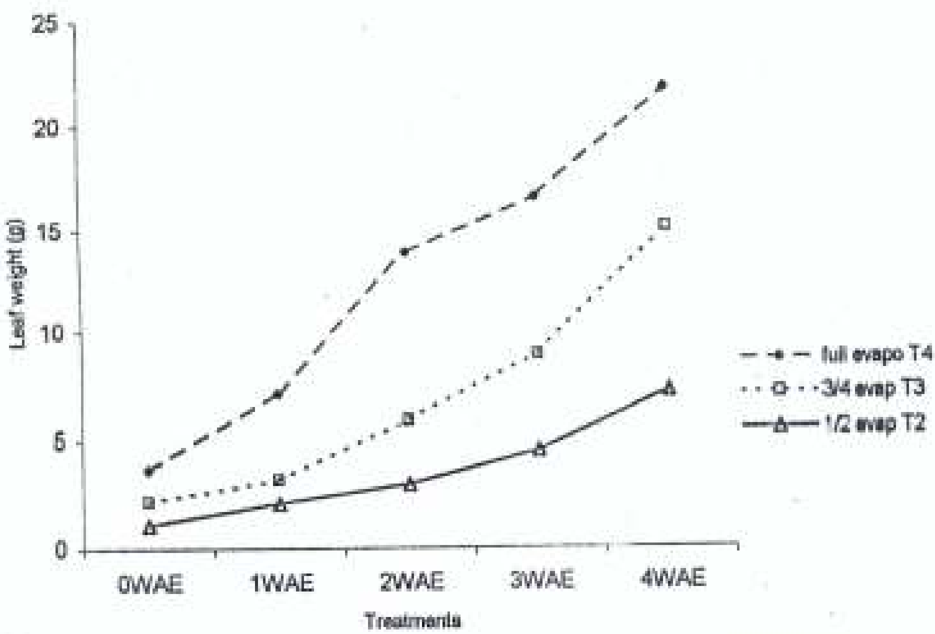


Fig. 14: Leaf Weight of amaranthus under various treatments during first planting season

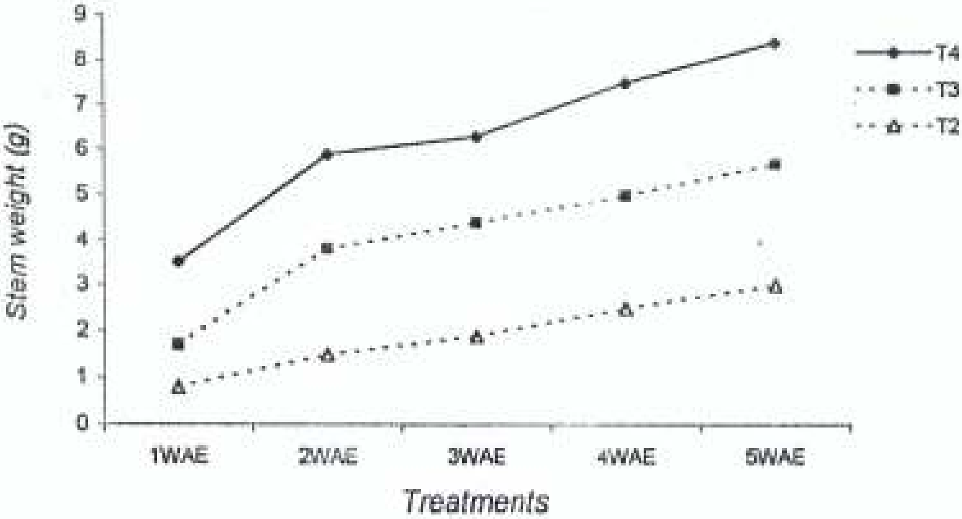


Fig. 15: Stem Weight ofmaranthusunder various treatments during first planting season

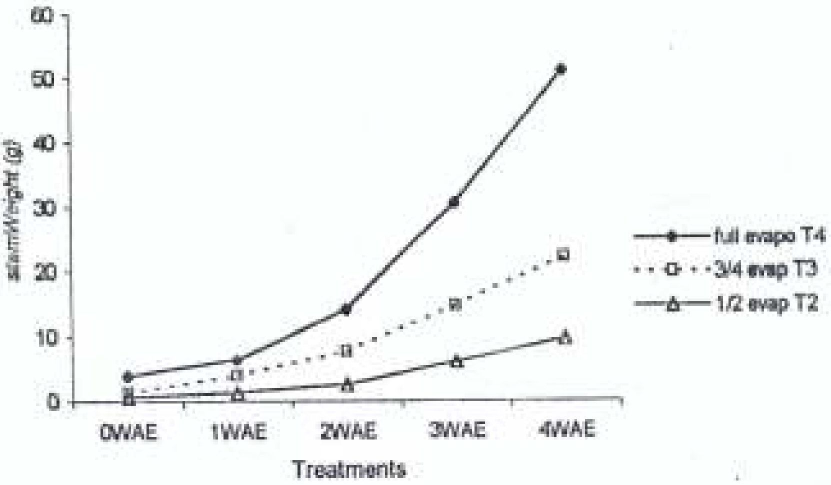


Fig. 16: Stem weightof amaranthus under various treatments during the second planting season

½ pan evaporation (T_2).

Figure 9 & 10, 11 & 12, 13 & 14, 15 & 16 show the /root dept, root weight leaf and stem weight within the period of growth. In all the parameters, the treatment, T_4 have the highest value for both seasons. This was due to availability of moisture needed for the normal growth. It was observed that the root develops with the period of growth until about two weeks when the plant have reached the maturation stage. The development of the root then remained almost constant. clean (figure 9 & 10). The root weight increase gradually from the first week until the second week when there was to get to the full vegetative period (FIG. 11 & 12).

The leaf and stem weight also increased with the weeks after planting clean. The treatment T_4 had the highest value for both planting seasons as shown in the figure.

Table 19: Total biomass (ton /ha) in block A at 2 WAE during first planting season.

	Stem wt.		Root wt.		Leaf wt.		Tt Biomass yield	
Treatment	Fresh	Dry	Fresh	Dry	Fresh	Dry	Fresh	Dry
T_4	0.13	0.02	0.12	0.02	0.13	0.02	0.34	0.08
T_3	0.04	0.01	0.04	0.01	0.05	0.02	0.14	0.04
T_2	0.02	0.003	0.02	0.004	0.03	0.005	0.07	0.01

Table 20: Total biomass (ton /ha) in block B at 2 WAE during first planting season.

	Stem wt.		Root wt.		Leaf wt.		Tt Biomass yield	
Treatment	Fresh	Dry	Fresh	Dry	Fresh	Dry	Fresh	Dry
T_4	0.09	0.01	0.08	0.01	0.10	0.02	0.28	0.04
T_3	0.08	0.02	0.04	0.008	0.05	0.01	0.17	0.04
T_2	0.02	0.003	0.03	0.006	0.04	0.01	0.09	0.02

Table 21: Total biomass (ton /ha) in block C at 2 WAE during first planting season.

	Stem wt.		Root wt.		Leaf wt.		Tt Biomass yield	
Treatment	Fresh	Dry	Fresh	Dry	Fresh	Dry	Fresh	Dry
T_4	0.02	0.004	0.03	0.005	0.03	0.006	0.08	0.02
T_3	0.02	0.003	0.01	0.001	0.02	0.001	0.05	0.001
T_2	0.01	0.001	0.006	0.001	0.01	0.001	0.03	0.003

Table 22: Total biomass (ton /ha) in block A at 4 WAE during first planting season.

	Stem wt.		Root wt.		Leaf wt.		Tt Biomass yield	
Treatment	Fresh	Dry	Fresh	Dry	Fresh	Dry	Fresh	Dry
T_4	0.57	0.08	0.38	0.06	0.29	0.04	1.24	0.18
T_3	0.23	0.04	0.22	0.04	0.13	0.02	0.58	0.10
T_2	0.08	0.04	0.03	0.01	0.05	0.01	0.16	0.04

Table 23: Total biomass (ton /ha) in block A at 4 WAE during first planting season.

	Stem wt.		Root wt.		Leaf wt.		Tt Biomass yield	
Treatment	Fresh	Dry	Fresh	Dry	Fresh	Dry	Fresh	Dry
T_4	0.45	0.05	0.10	0.02	0.25	0.04	0.80	0.11
T_3	0.25	0.04	0.09	0.01	0.15	0.02	0.49	0.07
T_2	0.12	0.02	0.04	0.01	0.09	0.02	0.25	0.05

Table 24: Total biomass (ton /ha) in block C at 4 WAE during first planting season.

	Stem wt.		Root wt.		Leaf wt.		Tt Biomass yield	
Treatment	Fresh	Dry	Fresh	Dry	Fresh	Dry	Fresh	Dry
T_4	0.14	0.02	0.07	0.01	0.08	0.01	0.29	0.04
T_3	0.08	0.01	0.03	0.01	0.06	0.01	0.17	0.03
T_2	0.03	0.01	0.02	0.003	0.03	0.009	0.08	0.02

Table 25: Total biomass (ton /ha) in block A at 2 WAE during first planting season.

	Stem wt.		Root wt.		Leaf wt.		Tt Biomass yield	
Treatment	Fresh	Dry	Fresh	Dry	Fresh	Dry	Fresh	Dry
T_4	0.15	0.03	0.14	0.03	0.15	0.03	0.44	0.09
T_3	0.05	0.009	0.04	0.01	0.05	0.02	0.14	0.04
T_2	0.02	0.005	0.04	0.009	0.03	0.004	0.09	0.02

Table 26: Total biomass (ton /ha) in block B at 2 WAE during first planting season.

	Stem wt.		Root wt.		Leaf wt.		Tt Biomass yield	
Treatment	Fresh	Dry	Fresh	Dry	Fresh	Dry	Fresh	Dry
T_4	0.09	0.009	0.10	0.01	0.11	0.02	0.30	0.04
T_3	0.08	0.02	0.03	0.009	0.05	0.01	0.16	0.04
T_2	0.02	0.004	0.04	0.006	0.04	0.01	0.10	0.02

Table 27: Total biomass (ton /ha) in block C at 2 WAE during first planting season.

	Stem wt.		Root wt.		Leaf wt.		Tt Biomass yield	
Treatment	Fresh	Dry	Fresh	Dry	Fresh	Dry	Fresh	Dry
T_4	0.02	0.006	0.03	0.008	0.03	0.009	0.08	0.02
T_3	0.01	0.01	0.03	0.009	0.02	0.01	0.06	0.02
T_2	0.01	0.004	0.01	0.003	0.02	0.01	0.04	0.02

Table 28: Total biomass (ton /ha) in block A at 4 WAE during first planting season.

	Stem wt.		Root wt.		Leaf wt.		Tt Biomass yield	
Treatment	Fresh	Dry	Fresh	Dry	Fresh	Dry	Fresh	Dry
T_4	1.02	0.13	0.55	0.09	0.38	0.05	1.95	0.27
T_3	0.76	0.11	0.63	0.05	0.20	0.03	1.59	0.19
T_2	0.14	0.03	0.26	0.04	0.09	0.02	0.49	0.09

Table 29: Total biomass (ton /ha) in block B at 4 WAE during first planting season.

	Stem wt.		Root wt.		Leaf wt.		Tt Biomass yield	
Treatment	Fresh	Dry	Fresh	Dry	Fresh	Dry	Fresh	Dry
T_4	0.73	0.12	0.20	0.03	0.35	0.04	1.28	0.19
T_3	0.44	0.05	0.14	0.03	0.17	0.04	1.75	0.12
T_2	0.23	0.03	0.08	0.03	0.16	0.04	0.47	0.10

Table 30: Total biomass (ton /ha) in block C at 4 WAE during first planting season.

	Stem wt.		Root wt.		Leaf wt.		Tt Biomass yield	
Treatment	Fresh	Dry	Fresh	Dry	Fresh	Dry	Fresh	Dry
T_4	0.23	0.04	0.10	0.03	0.13	0.03	0.46	0.08
T_3	0.14	0.03	0.05	0.02	0.07	0.03	0.26	0.04
T_2	0.11	0.03	0.04	0.02	0.05	0.02	0.20	0.07

The results obtained for the biomass yield were subjected to statistical analysis and the results are shown below

TABLE 31a The root depth (cm) grouped by treatment and week during first season.

Treatment	WK. I	WK. II	WK.III	WK.IV	WK.V
T_4	12.1	13.1	16.1	16.5	17.0
T_3	8.7	11.8	14.1	14.6	15.0
T_2	7.0	10.1	11.8	12.0	12.3
WK Total	27.8	35.1	42.3	43.2	44.3

TABLE 31b ANOVA table for root depth during first season.

Sources of Variation	Degree of Freedom	Sum of Square	Mean Square	Observed F	Tabular F 5%	1%
Week	4	678.39	169.59	68.30	3.84	7.01
Treatment	2	62.51	31.26	12.59	4.46	8.65
Error	8	19.86	2.483			
Total	14	760.76				

TABLE 32a The root depth (cm) grouped by treatment and weeks during second season.

Treatment	WK. I	WK. II	WK.III	WK.IV	WK.V
T_4	12.6	13.5	16.9	18.3	17.7
T_3	9.6	11.5	14.7	16.5	16.5
T_2	7.9	10.4	12.4	14.3	14.6
WK Total	30.10	35.40	44.00	49.10	48.80

TABLE 32b ANOVA table for root depth during second season.

Sources of Variation	Degree of Freedom	Sum of Square	Mean Square	Observed F	Tabular F 5%	1%
Week	4	94.82	23.705	115.63	3.84	7.01
Treatment	2	37.67	18.835	91.88	4.46	8.65
Error	8	1.64	0.205			
Total	14	134.13				

Since the F observed > F tabulated at 1% level of significant for both planting seasons. The treatment and week means is highly significant.

TABLE 33a The Root weight (g) grouped by treatments and weeks during first season.

Treatment	WK. I	WK. II	WK.III	WK.IV	WK.V
T_4	3.6	6.3	8.9	14.6	20.7
T_3	1.6	2.5	3.8	9.1	15.3
T_2	0.5	1.4	1.2	2.1	4.0
WK Total	5.7	10.2	13.9	25.8	40.0

TABLE 33b ANOVA table for root weight during first season.

Sources of Variation	Degree of Freedom	Sum of Square	Mean Square	Observed F	Tabular F 5%	1%
Week	4	255.83	63.95	7.21	3.84	7.01
Treatment	2	201.65	100.82	91.88	11.37	8.65
Error	8	70.95	8.86			
Total	14	528.43				

TABLE 34a The root weight (g) grouped by treatments and weeks during second season.

Treatment	WK. I	WK. II	WK.III	WK.IV	WK.V
T_4	3.4	5.5	6.6	7.2	7.9
T_3	1.6	2.8	3.3	3.9	4.5
T_2	1.4	1.7	2.1	2.6	3.3
WK Total	6.40	10.00	12.00	13.70	15.70

TABLE 34b ANOVA table for root weight during second season.

Sources of Variation	Degree of Freedom	Sum of Square	Mean Square	Observed F	Tabular F 5%	1%
Week	4	16.99	4.248	13.40	3.84	7.01
Treatment	2	41.036	20.52	64.73	4.46	8.65
Error	8	2.534	0.317			
Total	14	60.56				

From the AVOVA Tables above for first and second planting season, the week and the Treatment means were highly significant because the F observe > F tabulated at 1% level of significant.

TABLE 35a The leaf weight (g) grouped by treatments and weeks during first season.

Treatment	WK. I	WK. II	WK.III	WK.IV	WK.V
T_4	3.7	7.1	13.9	16.6	21.8
T_3	2.2	3.2	5.9	8.9	15.1
T_2	1.1	2.1	3.0	4.5	7.2
WK Total	7.0	12.4	22.8	30.0	44.1

TABLE 35b ANOVA table for leaf weight during first season.

Sources of Variation	Degree of Freedom	Sum of Square	Mean Square	Observed F	Tabular 5%	F 1%
Week	4	287.42	71.85	10.47	3.84	7.01
Treatment	2	207.91	103.95	15.15	4.46	8.65
Error	8	54.89	6.86			
Total	14	550.22				

TABLE 36a The leaf weight (g) grouped by treatments and weeks during second season.

Treatment	WK. I	WK. II	WK.III	WK.IV	WK.V
T_4	3.5	5.5	6.3	6.9	7.4
T_3	2.4	3.3	4.1	4.5	5.1
T_2	1.2	2.2	2.8	3.3	3.8
WK Total	7.10	11.00	13.20	14.70	16.30

TABLE 36b ANOVA table for leaf weight during second season.

Sources of Variation	Degree of Freedom	Sum of Square	Mean Square	Observed F	Tabular 5%	F 1%
Week	4	17.06	4.265	43.17	3.84	7.01
Treatment	2	27.13	13.57	137.35	4.46	8.65
Error	8	0.79	0.099			
Total	14					

From the AVOVA Tables above for first and second planting season, the week and the Treatment means were highly significant because the F observe > F tabulated at 1% level of significant.

TABLE 37a The stem weight (g) grouped by treatments and weeks during first season.

Treatment	WK. I	WK. II	WK.III	WK.IV	WK.V	Total Treatment	Treatment mean
T_4	3.8	6.3	14.2	30.6	51.1	106.0	21.20
T_3	1.3	3.9	7.7	14.8	22.1	49.8	9.96
T_2	0.6	1.3	2.5	5.9	9.6	19.9	3.98
WK Total	5.7	11.5	24.4	51.3	82.8	175.7	11.71

TABLE 37b ANOVA table for stem weight during first season.

Sources of Variation	Degree of Freedom	Sum of Square	Mean Square	Observed F	Tabular F 5%	1%
Week	4	1357.34	339.46	5.01	3.84	7.01
Treatment	2	764.38	382.19	5.64	4.46	8.65
Error	8	542.00	67.75			
Total	14	2664.22				

TABLE 38a The stem weight (g) grouped by treatments and weeks during second season.

Treatment	WK. I	WK. II	WK.III	WK.IV	WK.V	Total Treatment	Treatment mean
T_4	3.5	5.9	6.3	7.5	8.4	31.60	6.32
T_3	1.7	3.8	4.4	5.0	5.7	20.60	4.12
T_2	0.8	1.5	1.9	2.5	3.0	9.70	1.94
WK Total	6.00	11.20	12.60	15.00	17.10	61.90	4.13

TABLE 38b ANOVA table for stem weight during second season.

Sources of Variation	Degree of Freedom	Sum of Square	Mean Square	Observed F	Tabular F 5%	1%
Week	4	22.63	5.658	13.07	3.84	7.01
Treatment	2	47.96	23.98	55.38	4.46	8.65
Error	8	3.46	0.433			
Total	14	74.05				

From the ANOVA Table 37b for the first season, the week and the treatment means is significant because the F observed > F tabulated at 5% level of significant. But in case of the ANOVA Table (38b) for the second season, the week and the treatment means are highly significant because the F observed > F tabulated at 1% level of significant.

The variation in the level of significant for both season might due to high moisture experienced during the second planting season that made the treatment and the weeks of growth have tremendous effect on the stem weight.

Table 39: Cumulative water use (mm) of Amaranths for the different treatments during first planting season.

		Treatments		
Calendar Period	WAE	T_4	T_3	T_2
29th March – 6th April	1	26.6	26.6	22.4
7th April – 14th April	2	55.3	50.3	57.6
15TH April -21st April	3	71.4	64.4	103.1
22nd April -28th April	4	97.1	70.0	158.9

Table 42: Cumulative water use (mm) of amaranths for the different treatments during second planting season.

		Treatments		
Calendar Period	WAE	T_4	T_3	T_2
15th Sept. –21st Sept.	1	31.5	28.0	25.2
22nd Sept. – 28th Sept.	2	86.8	80.5	74.2
29th Sept.-5th Oct.	3	122.5	116.2	109.9
6th Oct. -12th Oct.	4	141.4	131.6	122.5

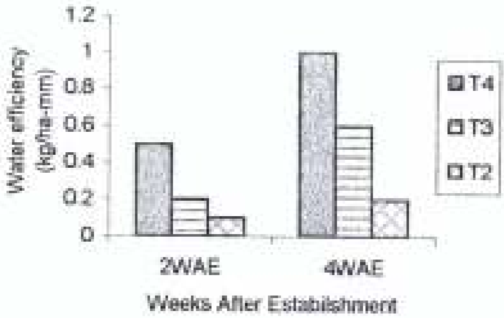


Fig. 17: Water use efficiency at the 2nd and 4th WAE for the various treatments in block A in 1st season

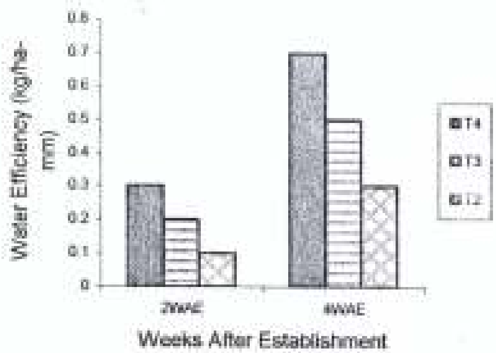


Fig. 18: Water use efficiency at the 2nd and 4th WAE for the various treatments in block B during 1st season

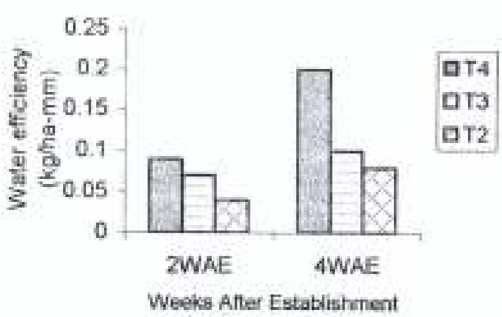


Fig. 19: Water use efficiency at the 2nd and 4th WAE for the various treatments in block C during 1st season

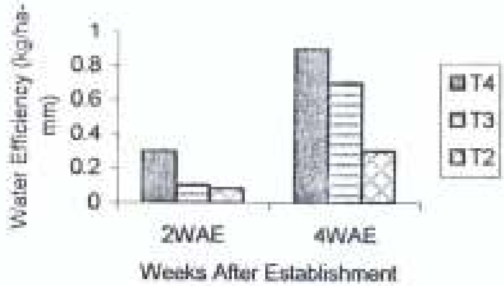


Fig. 20: Water use efficiency at the 2nd and 4th WAE for the various treatments in block A during 2nd season

Fig. 21: Water use efficiency at the 2nd and 4th WAE for teh various treatments in block B during the 2nd season

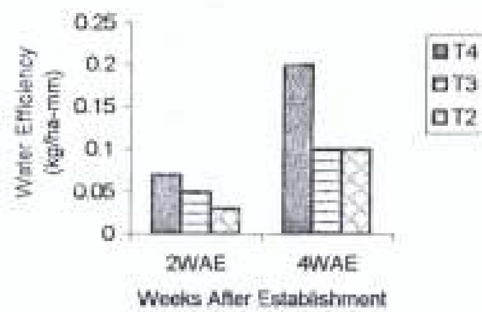


Fig. 22: Water use efficiency at the 2nd and 4th WAE for the various treatments in block C during the 2nd season

4.7 WATER USE EFFICIENCY

Water use efficiency against week after establishment is shown in figures (17-22). The water use efficiency was determined at 2nd and 4th WAE (on fresh weight basis) for all treatment during both planting seasons.

The highest and the lowest values of water use efficiency (WUE) at 2nd WAE during the first planting season were 0.34 kg/ha-mm and 0.2 kg/ha-mm of water in treatments T_4 and T_2 respectively. Also at 4th WAE the highest and lowest values of water use efficiency were 0.9 kg/ha-mm and 0.3 kg/ha-mm of water in treatment T_4 and T_2. It was observed that the water use efficiency increased at 4th WAE in treatment T_4 but decreased in treatment T_2. This may be due to decrease in consumptive use of crop during maturity.

The water use efficiency (WUE) at 2nd and 4th WAE during the second planting season was the highest in treatment T_4 and lowest in treatment T_2 with values 0.2 kg/ha-mm and 0.07 kg/ha-mm of water respectively. The highest WUE was obtained in the 4th WAE and the value is 0.5 kg/ha-mm in treatment T_4. The highest value observed in treatment T_4 may be due to the accumulated moisture in the soil from rainfalls obtained in the second planting season.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

This study evaluated the performance of Amaranthus under three different methods of water application – full evaporation (T_4), ¾ evaporation (T_3) and ½ evaporation (T_2).

Soil water content was monitored on each treatment. Results shows that plant height, leaf area and total biomass yield are indicative of the amount of water available in soil for plant growth.

Biomass yield was greatest under irrigation at full evaporation (1.24 ton/ha for the first planting season and 1.95 ton/ha for the second season). This was followed by irrigation at ¾ evaporation (0.58 ton/ha for the first season and 1.59 ton/ha for the second season). The least yield was recorded from irrigation at ½ evaporation
(0.08 ton/ha during the first season and the 0.20 ton/ha in the second season).

Amaranthus appear to be very sensitive to soil water status, because the greater the soil water content during the crop cycles, the greater the biomass yield observed. Other agronomic measurements such as plant height, root depth, leaf area indices were highest in treatment T_4. The consumptive use of *quinoa* decreased in the order $T_4 > T_3 > T_2$ among treatments. It was observed that soil water balance properly reflected soil water regime in the treatment and the biomass yield of the crop. The notable difference in the performance of the crop among treatments further proves the necessity of water in plant growth and yield.

The overall results shows that *quinoa* can be best grown when irrigation water is applied at ¾ evaporation during the emergence, at full evaporation during the period of maximum vegetative cover which is three weeks after planting, and at ½ evaporation during the crop maturation stage when the crop water needs is minimal.

It is recommended that modern field equipment should be made available on the farm site to ease the problem of data collection. Also a weather station should be positioned very close to the field for easy collection of climatological data. A better result will be obtained if facilities like weighing machine, computer etc. to process the data collected from the field are located very close to the farm site.

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APPENDIX A

Particle Size analysis

The soil particle size analysis was determined by the hydrometer method using sodium hexamphosphate (Calgon) as dispersing agent.

Table A-1: Results of initial soil mechanical analysis during first season.

BLOCK	% Sand	% Silt	% Clay	%Organic matter
A	72	11	17	2.16
B	73	10	17	1.97
C	73	10	17	1.97
Total	218	31	51	6.1
Mean	72.67	10.33	17	2.03

Table A-2: Results of initial soil mechanical analysis during second season.

BLOCK	% Sand	% Silt	% Clay	%Organic matter
A	74	12	14	2.25
B	73	11	16	2.20
C	73	13	14	2.16
Total	220	36	44	6.61
Mean	73.33	12.00	14.67	2.20

Soil bulk density

Soil samples were taken from block A, B and C for the determination of bulk densities. The bulk density was calculated using the formula below:

$$\text{Bulk Density} = \frac{\text{Mass of oven dried soil}}{\text{Volume of soil}}$$

$$\text{Dry Density} = \frac{\text{Bulk density}}{1 + \text{Moisture Content (\%)}}$$

APPENDIX B.

Table B-1: Results of Soil moisture content and depth of water stored during first season (March & April)

For plot T_4

$$Ds = \frac{Db}{1 + Mc}$$

DAE	Db	Mc (%)	Ds	Mc (Vol. basis) Ds x Mc	Dept of Soil (cm)	Dept. of water stored (cm)
0	1.65	9.03	1.52	0.137	10	1.37
		10.07	1.50	0.150	20	1.50
		10.93	1.49	0.162	30	1.62
						4.49
7	1.65	14.40	1.51	2.17	10	2.17
		15.30	1.50	0.229	20	2.29
		16.30	1.49	0.243	30	2.43
						6.89
14	1.73	12.50	1.54	0.193	10	1.93
		12.20	1.53	0.202	20	2.02
		14.10	1.52	0.214	30	2.14
						6.09
21	1.73	12.30	1.54	0.189	10	1.89
		13.80	1.52	0.209	20	2.09
		14.60	1.51	0.220	30	2.20
						6.18
28	1.73	12.60	1.52	0.207	10	2.07
		13.90	1.51	0.209	20	2.09
		14.70	1.50	0.221	30	2.21
						6.37

Table B-2: Results of Soil moisture content and depth of water stored during first season (March & April)

For plot T_3

$$Ds = \frac{Db}{1 + Mc}$$

DAE	Db	Mc (%)	Ds	Mc (Vol. basis) Ds x Mc	Dept of Soil (cm)	Dept. of water stored (cm)
0	1.60	7.60	1.49	0.113	10	1.13
		8.80	1.47	0.129	20	1.29
		9.50	1.46	0.139	30	1.39
						4.49
7	1.60	13.50	1.41	0.190	10	1.90
		14.60	1.40	0.204	20	2.04
		14.80	1.39	0.206	30	2.06
						6.00
14	1.60	11.90	1.43	0.170	10	1.63
		12.20	1.42	0.173	20	1.79
		13.30	1.41	0.188	30	1.89
						6.09
21	1.60	11.30	1.44	0.163	10	1.63
		12.60	1.42	0.179	20	1.79
		13.40	1.41	0.189	30	1.89
						5.31
28	1.60	12.60	1.42	0.179	10	1.79
		13.10	1.41	0.185	20	1.85
		14.30	1.39	0.199	30	1.99
						5.63

Table B-3: Results of Soil moisture content and depth of water stored during first season (March & April)

For plot T_2

$$Ds = \frac{Db}{1 + Mc}$$

DAE	Db	Mc (%)	Ds	Mc (Vol. basis) Ds x Mc	Dept of Soil (cm)	Dept. of water stored (cm)
0	1.63	6.20	1.53	0.095	10	0.95
		7.30	1.52	0.111	20	1.11
		8.80	1.50	0.132	30	1.32
						3.38
7	1.63	12.50	1.45	0.181	10	1.81
		13.40	1.44	0.193	20	2.93
		14.20	1.43	0.203	30	2.02
						5.77
14	1.63	10.70	1.47	0.159	10	1.57
		11.30	1.46	0.165	20	1.65
		12.00	1.45	0.174	30	1.74
						4.96
21	1.63	10.50	1.48	0.155	10	1.55
		11.20	1.47	0.165	20	1.65
		12.60	1.45	0.183	30	1.83
						5.03
28	1.63	11.60	1.46	0.169	10	1.69
		12.50	1.45	0.181	20	1.81
		13.40	1.44	0.193	30	1.93
						5.43

Table B-4 Results of Soil moisture content and depth of water stored during second season (Sept. – Oct.)

For plot T_4

$$Ds = \frac{Db}{1 + Mc}$$

DAE	Db	Mc (%)	Ds	Mc (Vol. basis) Ds x Mc	Dept of Soil (cm)	Dept. of water stored (cm)
0	1.80	10.70	1.63	0.174	10	1.74
		10.90	1.62	0.177	20	1.77
		11.90	1.61	0.192	30	1.92
						5.43
7	1.80	11.80	1.61	0.189	10	1.89
		12.90	1.59	0.205	20	2.05
		13.40	1.58	0.212	30	2.12
						6.06
14	1.80	13.50	1.59	0.215	10	2.15
		14.30	1.57	0.225	20	2.25
		14.90	1.56	0.232	30	2.32
						6.72
21	1.80	11.20	1.62	0.181	10	1.81
		11.90	1.61	0.192	20	1.92
		12.90	1.59	0.205	30	2.05
						5.78
28	1.80	9.30	1.65	0.153	10	1.53
		10.20	1.63	0.166	20	1.66
		11.00	1.62	0.178	30	1.78
						4.97

e B-5 Results of Soil moisture content and depth of water stored during second season (Sept. – Oct.)

For plot T_3

$$Ds = \frac{Db}{1 + Mc}$$

Db	Mc (%)	Ds	Mc (Vol. basis) Ds x Mc	Dept of Soil (cm)	Dept. of water stored (cm)
1.71	9.50	1.56	0.148	10	1.47
	10.20	1.55	0.158	20	1.58
	11.20	1.54	0.172	30	1.72
					4.78
1.71	10.90	1.54	0.168	10	1.68
	11.90	1.53	0.182	20	1.82
	12.90	1.51	0.195	30	1.95
					5.45
1.71	12.40	1.52	0.188	10	1.88
	13.20	1.51	0.199	20	199
	14.20	1.49	0.212	30	2.12
					517
1.71	10.40	1.55	0.161	10	1.61
	11.00	1.54	0.169	20	1.69
	12.30	1.52	0.187	30	1.87
					5.17
1.71	8.60	1.57	0.135	10	1.35
	9.40	1.56	0.147	20	1.47
	11.30	1.55	0.159	30	1.59
					4.09

Table B-6: Results of Soil moisture content and depth of water stored during second season (Sept. – Oct.)

For plot T_2

$$Ds = \frac{Db}{1 + Mc}$$

DAE	Db	Mc (%)	Ds	Mc (Vol. basis) Ds x Mc	Dept of Soil (cm)	Dept. of water stored (cm)
0	1.75	8.20	1.62	0.133	10	1.33
		9.20	1.60	0.147	20	1.47
		10.00	1.59	0.159	30	1.59
						4.39
7	1.75	10.20	1.59	0.162	10	1.62
		11.20	1.57	0.176	20	1.76
		12.20	1.56	0.190	30	1.90
						5.28
14	1.75	12.40	1.52	0.188	10	1.88
		13.20	1.51	0.199	20	199
		14.20	1.49	0.212	30	2.12
						517
21	1.75	9.40	1.59	0.149	10	1.49
		10.50	1.58	0.166	20	1.66
		11.00	1.57	0.173	30	1.73
						4.88
28	1.75	7.40	1.63	0.121	10	1.21
		8.50	1.61	0.137	20	1.37
		9.50	1.59	0.151	30	1.51
						4.09

APPENDIX C.

Rainfall Runoff Parameters.

Table C-1: Rainfall and Runoff Data during first planting season (March – April)

Date	Rainfall	Runoff
6/4/2000	22.2	0.95
9/4/2000	15.2	2.45
12/4/2000	5.0	—
16/4/2000	8.3	0.28

Table C-2: Rainfall and Runoff Data during second planting season (September - October)

Date	Rainfall	Runoff
12/9/2000	2.60	0.15
15/9/2000	17.00	2.92
21/9/2000	6.40	0.48
24/9/2000	27.00	2.03
26/9/2000	30.00	11.10
30/9/2000	23.00	9.47
1/10/2000	15.00	5.92
2/10/2000	6.00	1.85
3/10/2000	10.00	1.78
8/10/2000	13.00	10.70
9/10/2000	2.70	212
10/10/2000	1.00	—
11/10/2000	5.00	3.28