DEVELOPMENT AND PERFORMANCE EVALUATION OF A NON-WEIGHING LYSIMETER FOR AFRICAN SPINACH

BY

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CERTIFICATION

This is to certify that this work "**Development and Performance Evaluation of a Non-Weighing Lysimeter for African Spinach**" was carried out by **MICHAEL CHUKWUMAOBI OGBUU, (20074616398)** in partial fulfillment of the requirement for the award of Master of Engineering Degree (M.Eng) in Soil and Water Engineering in the Department of Agricultural Engineering, Federal University of Technology, Owerri.

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DEDICATION

Dedicated to my wife, Mrs. Precious Veronica Chinyere Ogbuu, whose timely encouragement helped to sustain me.

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ABSTRACT

A non-weighing lysimeter was designed, fabricated, tested and installed at Arochukwu, Abia State, Nigeria, where the farmers who engage in dry season vegetable production do so with no knowledge of irrigation water requirements. This method tends to either over-irrigation or under-irrigation below the vegetable water requirements. Too much water can leach costly fertilizers to depths below the root zone, where both the water and fertilizer are permanently lost. Too little water causes the plant to wilt and dry, and sometimes salt accumulation. All these result in decreased yield. In order to provide efficient planning and use of available water, a non-weighing lysimeter was designed to determine the amount of water that could economically be utilized in growing crops. The materials used for the construction of the non-weighing lysimeter of 2.37m x 1.17m surface area with total depth of 0.6m, were locally sourced. Applying the water balance equation, the lysimeter was tested by using it to evaluate the crop evapotranspiration of African Spinach (*Amaranthus Cruenthus*). Irrigation was carried out by sprinkling through pressure generated by differences in head with the aid of a raised water storage tank. The flow rate was 0.38 l/s. The lysimeter was used to monitor irrigation water application, rainfall, drainage etc, and data generated were used to calculate crop evapotranspiration (ETc lysimeter). The climatic data collected during the period was used to evaluate the ETc using Blaney-Morin-Nigeria and Hargreaves-Samani methods. The ETc lysimeter, Etc Blaney-Morin-Nigeria and ETc Hargreaves-Samani were found to be 6.69mm·day, 5.07mm·day and 3.88mm-day respectively. Statistically, the difference between ETc lysimeter value obtained and ETc Blaney-Morin-Nigeria was quite insignificant, while that between ETc lysimeter and ETc Hargreaves-Samani methods were found to be statistically different at $P>0.05$ level of significance. While noticing that Blaney-Morin-Nigeria model is quite reliable in Evapotranspiration studies in Nigeria, the developed non-weighing lysimeter is said to be functional and efficient to use since the obtained ETc lysimeter fell within the acceptable ETc standard for African Spinach.

CHAPTER ONE

1.0 INTRODUCTION

1.1 BACKGROUND

The primary national concern in the agricultural sector is how to rapidly increase the productivity of agricultural enterprises in order to substantially raise the contribution that food and agriculture make to Gross Domestic Product.

A comprehensive research on water requirements of various crops is so important and is a prerequisite for any meaningful integrated research on irrigation concerning accelerated and optimum food production in the rain forest zone and Nigeria at large.

One of the important variables to be considered in the design and establishment of an efficient irrigation system is the consumptive use of crops (CU). Consumptive use of crops, which is considered synonymous with evapotranspiration (ET) is the amount of water taken up by vegetation for transpiration or building of plant tissues plus the unavoidable evaporation of soil moisture, snow and intercepted precipitation associated with vegetable growth. It is the best index of how much water will need to be supplied by irrigation, (Harry et al, 1942) for optimum food production. Therefore knowledge of consumptive use of crop is essential for an efficient irrigation system.

On the basis of the knowledge of available effective rainfall and the estimated consumptive use of crops, the amount of irrigation water requirement (IWR), and other losses can be computed. IWR is the amount of water excluding precipitation that is needed for the

production of crops (Blaney, et al, 1942). It includes transpiration from plant, evaporation, deep percolation, and other economically unavoidable waste.

The tendency for over-irrigation or under irrigation is inevitable without the knowledge of the consumptive use. Every farmer understands that crops need water to grow. Water is life; and they also know that too much or little water can decrease crop yield. Too much water can drown plants or leach costly fertilizers to depths below the root zone where both the root and fertilizer are permanently lost, which result in decreased yield. Too little water also reduces yield due to plant wilting and drying and sometimes salt accumulation. Irrigators need to know when and how much to apply.

Therefore, this research intends to develop a system that will be used to determine the amount of water that is economically utilized in growing crops using a non-weighing lysimeter.

Lysimeter as a term is derived from the Greek words 'lysis' meaning dissolution or movement and 'metro' which stands for measurement (Aboukhaled, et al; 1982). The word lysimeter therefore, stands for the measurement of the movement of water in a soil. A lysimeter is a vessel containing local soil placed with its top flush with the ground surface for the study of several phases of the hydrological cycle, e.g. infiltration, runoff, evapotranspiration, soluble constituents removed in drainage etc (http://www.lysimeter.at/seiten-engl/aboutus/lysimeters.htm). The local soil placed in the vessel is observed and analyzed. The lysimeter facility provides a unique tool for irrigation engineers and helps to provide efficient planning and

use of available water. Lysimeter data are used with environmental and climatic data to calibrate and evaluate proposed vegetative water use models.

Lysimeters are of two main types; these are the weighing lysimeter and the non-weighing lysimeter. The non-weighing lysimeter is also called drainage lysimeter; this is in line with its operational method. From available records and observation, weighing lysimeter has been used extensively for the research of evapotranspiration in the United States and other countries, with varied designs. The design variability is due to area of study, different objectives and refinement on the existing ones (Howell, et al. 1985).

Although, the earth surface abounds with water, about 75%, the movement of water through the hydrologic cycle is erratic, both in time and over area (Linsley, et al, 1982). These however, have made water quite inaccessible both in time and in quantity for meaningful agricultural enterprise, domestic and industrial uses. This condition spells shortage of water, mostly experienced in the developing countries. Some of the most profitable irrigated agriculture are located in areas normally thought to have sufficient rainfall such as Central America, Central Brazil, the West Indies, Western parts of Africa and South Africa. These areas have ample annual rainfall, but during about six months of the year they have virtually no rainfall (Uma, 2004).

The measurement of evapotranspiration has been done by many researchers in the past (King, et al, 1956; Frost, 1962; Pruitt, et al,

1960). The use of lysimeter is a proven method for precise and direct measurement of the amount of water supplied to and lost by the crops (Michael 1985). As the crop water use is known, the irrigation water need is established and this helps to achieve a better irrigation planning scheme for optimum performance thereby providing solutions to water wastage, food shortage and poor crop yields.

Lysimeter is known to be an effective tool for determining and establishing crop water use rate at various stages of crop development. Measurements of crop water use in the field are normally done to take simultaneous account of both plant transpiration and soil evaporation (Klocke, et al, 1985). Transpiration is the process by which water leaves the plant into the atmosphere, and evaporation is the amount of water lost from the soil to the atmosphere. For effective measurement of evapotranspiration and water management research, the lysimeter is a satisfactory device. But due to high cost of construction and installation, only a few are found around the globe (Howell, et al, 1985). Although today we have lysimeters in some of our higher institutions like in Obinna 2014 at Federal University of Technology, Owerri.

This study embarked upon is the design, construction and performance evaluation of a non-weighing lysimeter which will provide a functional means of evaluating crop evapotranspiration of major vegetable crops in Nigeria. The materials are locally sourced, designed, fabricated and installed; then also evaluated.

Amaranthus Cruentus (Africa Spinach) which belongs to the family of *Amaranthaceae* is the vegetable under study. *Amaranthus* is

among the most popular leafy vegetables in Nigeria and beyond. The leaves and succulent stems have high nutritive value and are good sources of Iron (305mg/100g), Calcium (379mg/100g), Vitamin A (8340mg/100g), Vitamin C (99mg/100g). The most valuable property of *Amaranthus* seed and dry leaves is that they contain 16-18% of high quality protein. *Amaranthus* can be grown as a monoculture plant. In *Amaranthus* breeding, the following factors are taken into account; high productivity, seed, colour; stem height, earliness, seed scattering, satisfactory, nutritive and utilization properties (Weber, 1990).

Crop water use data is so important. In irrigation planning there is a great need to determine crop water requirement prior to irrigation project design. According to Nwaukwa (1985), the following importance of crop water use are obtainable:

i) The data are needed to determine the frequency and the amount of irrigation water according to the stages of plant growth and development.
ii) Moreover, crop water use data is needed to quantify project hectarage and to determine diversion requirements from river flows, abstraction from ground-water, aquifers, and to establish reservoirs.
iii) Worthy of mentioning is its usefulness in determining the sizes of pumps, canals, ditches, structures and other parts of irrigation enterprise.
iv) Each phase of irrigation project planning requires a specific type and accuracy of water use data. Accurate crop evapotranspiration (ET) data are required to improve agricultural water resources management.

1.2 STATEMENT OF THE PROBLEM

Crop failure as a result inadequate knowledge of water use rate needs to be addressed. Water use by crop varies significantly, and the knowledge of its variations at the development stages is critical in reducing the risk of crop failure due to over irrigation or under irrigation. The lysimeter is an ideal device for determining and establishing crop water use rate at different stages.

1.3 OBJECTIVES OF THE STUDY

The objectives of this study were:

a. To develop and install a non-weighing lysimeter at Agriculture department cropping land of Arochukwu Local Government Council, Abia State, South East Nigeria.
b. To test and operate the lysimeter and using it to precisely determine the consumptive use of the African Spinach, thus evaluate the performance of the lysimeter by comparing the obtained CU with the standard acceptable value of CU for African Spinach.

1.4 JUSTIFICATION OF THE STUDY

The need to avoid the tendency for over-irrigation or under-irrigation need not be over-emphasized. The evapotranspiration studies using lysimeters is a direct method for estimating crop water use requirement of any crop. The use of local materials for the development of a non-weighing lysimeter is quite feasible. The information (data) will enhance irrigation project planning.

1.5 SCOPE OF STUDY

The scope of this study has to do with the development and installation of a local device (non-weighing Lysimeter) that will be used to estimate the water requirement for the cultivation of *Amaranthus Cruentus*. The study will last throughout the growth duration of the crop under study as this will enable the estimation of water utilization of the crop, thus evaluating the performance of the lysimeter.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 LYSIMETERS

So many projects involving the measurement of water use by crops are effectively being carried out with the use of both disturbed or undisturbed lysimeters. Lysimeters, certainly, have been widely used for the studies of evapotranspiration in various parts of the world. Although it is expensive to construct especially the weighing type which is sophisticated, yet it cost/benefits ratio proves very favourable for it development and use (Nathan et al, 2002). The use of lysimeters is a proven method for measuring movements of water and chemicals through the soil profile. A number of methods for obtaining undisturbed soil monoliths for lysimeters have been used. One method involves excavating around a column of soil and encasing it in a steel or plywood box (Bowman, et, al, 1994). This method works well in heavy soils where a free standing soil column can be maintained but not in coarse – textured soils where an exposed soil column cannot support itself. Similarly other researchers have pressed steel cylinders over an exposed soil column (Brown, et al, 1985; Meshkat, et al 1999). Another method involves using a static load to force steel cylinder or tanks into the soil. (Tackett, et al, 1965; Moyer, et al, 1996; Schneider, et al, 1996). This method requires heavy duty crane equipment and very heavy steel weights or water tanks that could pose safety hazards.

A lysimeter by definition is as measuring device which can be used to measure the amount of actual evapotranspiration which is released by plants usually crops. Generally, it is known to be a tank of different sizes filled up with soil having plant grown on it. In its actual operation, the lysimeter is buried in an excavation such that the top is flush with the excavated soil. The walls of the lysimeters are impervious but the bottom has an opening that allow the passage of water. Water application is done at the surface of the lysimeter to enhance better crop development. The excess water not used by the plants passes through the soil column and is collected in a receiving vessel via a drainage pipe installed at the bottom of the lysimeter. The receiving vessel/measuring gauge is always placed in a pit adjacent to the lysimeter. The calculation of evapotranspiration is done by equating it with the water loss during the growth period of the crop. The water loss is determined always by weighing, moisture sampling, and soil moisture measurement.

The basic definition of the lysimeter is dependent on one's field of research such as economics, hydrology, ecology, agriculture or environment protection. In the field of agriculture by recording the amount of water input, either through precipitation or irrigation that a lysimeter receives and the amount lost through the soil, the amount of water lost through evapotranspiration can be calculated.

2.2 HISTORY OF LYSIMETERS

It is on record that in 1875 Edward Lewis Sturtevant, a botanist from Massachusetts, built the first lysimeter in the United States.

But the first lysimeter ever built for evaporation and evapotranspiration studies showing the difference between water input and output as reported by Hylckama, (1980) was constructed by John Dalton in 1796, while Kohnke, et al, (1940) reported that the first lysimeter study for water use was done by De la Hire of France in the 17th century.

Howell, et, al, (1991) offered a history lysimeter of development and uses. A variety of studies involving lysimeters by various authors can be found in Camp, et, al, (1996). Many other researchers have designed and constructed lysimeters to meet their specific needs and objectives. The proper design can be made by having an accurate knowledge of both the purpose of the experiment, including geology and climate conditions (Kohnke, et, al., 1940). Thornthwaite was presumably the first to apply lysimeter for the measurement of evapotranspiration in the fields conditions (Howell, et al., 1991). Although, initially, the purpose of lysimeter studies was related mainly to hydrology, particularly the quantification of soil water percolation. Later on, other studies were directed at the chemical composition of the percolate as well as the quantity.

Many studies of crop water use have been undertaken for a variety of crops in many different locations and growing environments. Water-use and crop-coefficient curves have been developed from these studies. The results from one environment however, may not be readily transferable to another (Piccini, et, al.,

2002). Installing lysimeters and collecting water use data for local conditions will provide the information needed to develop curves suitable to the local areas. Lysimeters of many different designs, sizes, shapes, and methods of operation have been built.

2.3. TYPES OF LYSIMETERS

Lysimeters of different types have been used to measure and study water use for a variety of crops. From literature 'lysimeter' as a term is used for different objectives such as suction cups, flux meters, etc (Weihermuller, et al, 2007). It is also known that lysimeter types vary according to research interest of the researcher. Meanwhile there are two main types of lysimeter. These are weighing and non weighing lysimeter. These exist in different sizes and shapes. Some are so small and are known as micro lysimeters or mini-lysimeter used to measure evaporation of water (Todd, et al, 2006; Evett, et al, 1995). Lysimeters are designed in various shapes like; square, circular and rectangular.

The non-weighing lysimeter can be non-weighing percolating type or non-weighing constant water table type. The non – weighing does not require a higher technical expertise as in weighing lysimeter which is quite sophisticated in design and operation. Non –weighing lysimeters are set up to enable the operator measure the water balance, water added/applied, water retained by the soil, and water lost through evaporation, transpiration and deep percolation.

Weighing lysimeters can be used to measure by weight, soil plant moisture changes in a variety of environments. It can be

designed with different weighing mechanisms, like floating, hydraulic, mechanical or electronic weighing mechanisms. The key to achieving successful weighing lysimeter is to design a system capable of detecting a change in weight equal to millimeter of water when the lysimeter itself weighs several kilonewtons.

LYSIMETERS TYPES

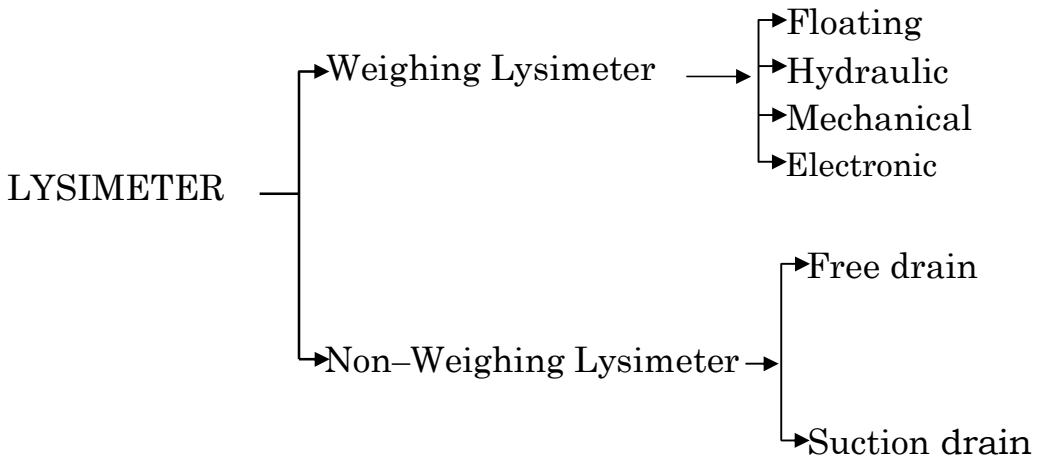

Figure 2.1. Two types of lysimeters

2.4 DIFFERENT USES OF LYSIMETER

The lysimeter facility provides unique tools for research in the field of agriculture, environment protection and ecology; etc. In the field of hydrology, hydrogeology and soil science, lysimeters are used for water budgeting and water balance, soil temperature, water movement, seepage water velocity, infiltration rate etc.

Planted up with an agronomic crop, a weighing lysimeter can be used to measure crop-water use to develop crop coefficient for use with weather based ET – estimate methods, lysimeters being used to

help schedule irrigation of crops. Lysimeters in addition to providing the needed research data serves to demonstrate the best available technology for measuring vegetative water use.

In a nutshell, in the field of agriculture, lysimeters are used to plan precise irrigation scheduling, monitor the movements of nutrients in the soil, to evaluate the role of rainfall in meeting plant water requirements, determine water demand for agricultural areas, to assess the risk of groundwater contamination from herbicides, to monitor the leaching of agrochemicals. Once operational, lysimeters, in the field of ecology and environment protection are used to determine the effect of precipitation on pollutant leaching losses, to predict sewage water sludge coverings, to study water balance and the performance of surface cover system and drainage compositor.

2.5 SHAPES AND SIZES OF LYSIMETERS

Lysimeters have been designed in different shapes and sizes. Shapes includes square (Marek, et al, 1988; Schneider, et, al, 1998), circular (Pruitt and Angus, 1960; McFarland, et al, 1993; Meshkat, et al, 1999; Seyfried, et al, 2001; Yang, et al, 2003; Young, et, al 1997), and rectangular (Schneider, et al, 1996; Malone, et al, 2000; Klocke, et al, 1955; Marek, et al, 2006). The size of Lysimeters also varies significantly. While the lysimeter designed by Meshkat, et, al, (1999) only had an area of $0.44m^2$, the lysimeter designed by Pruitt and Angus (1960) had an area of $28.27m^2$ (6m in diameter). The size is a

function of the intended purpose and the required or designed resolution.

The resolution of the lysimeter ET measurement is defined as the last significant definable increment of measurement (Howell, et al, 1991). The resolution of a lysimeter system is different from and often smaller than the accuracy. Resolution in mm depth of water can be determined from the resolution of the data logger, i.e., the smallest voltage difference that can be determined by the data logger (analog to digital conversion) multiplied by the lysimeter calibration slope. Researchers also used lysimeter with an area as small as $0.006m^2$, usually known as micro-lysimeters or mini-lysimeters to measure evaporation soil water (Todd, et al, 2006; Evett, et al, 1995).

In design consideration, the dimensions of the lysimeter to a large extent is related to the time frame of the project involving the lysimeter. This should be done in such a way that it will be possible to perform the desired measurement within the time frame of the lysimeter test.

While rectangular shaped tanks are generally more practical for lysimeters, circular cylindrical tanks are normally used for a smaller lysimeter (Cronan, 1978; Mclay, et al, 1992). Rectangular lysimeters are also recommended for studies involving crops at the surface of the lysimeters due to the row crop geometry (Howell, et, al, 1991).

2.6 LYSIMETER DESIGN AND CONSTRUCTION

Design factors involved in lysimeter were reviewed by Harold (1966). Soil profile depth and disturbance, siting, soil thermal modifications, wind, and drainage are important considerations.

Among the important factors affecting the accuracy of a lysimeter is the size (Gangopadhyaya, et al 1996). The lysimeter surface area including its depth should be quite accommodating in order to minimize root restrictions, as noted by Clark and Reddel (1990). Depending on the rooting characteristics of the crop under study the dimension of the lysimeter should be designed accordingly. Small sized lysimeters are not quite reliable due mostly to distortions in thermal properties as reported by Gangopadhyaya, et al, (1996). From their report they came forward with a conclusion that the accuracy of lysimeters increased with an increase in their surface area.

In other to keep rain from entering the lysimeter system, rain shelter has been used all over. The use of rain shelter has generated a debatable concern over the design of the lysimeters. From literature, by keeping unwanted rainfall from the system, rain shelters reduce the uncertainty in ET estimation especially, during the times soon after rainfall when extremely wet soil conditions trigger high ET rate. However, their use in field studies has attracted some criticism. Dugas, et al, (1984) reported that the sides of rain shelter could restrict the wind movement under the shelter causing excessive heat. Furthermore, most authors noted that rain shelters lowered the radiation reaching the plants by 30 - 40 %.

In designing lysimeters, the ease of fabrication, installation, maintenance requirements and cost are other important design considerations. Using readily available materials and components help to keep cost down.

2.7 WEIGHING LYSIMETERS

Weighing lysimeters are known to be the standard method for direct measurement of evapotranspiration (ET). The weighing lysimeter can be used to measure by weight, soil plant moisture changes in a variety of environments. The key parameter in weighing lysimeter is its weighing precision. The higher it is, the better the resolution of weight measurement. A high resolution makes it possible to chart seepage and evapotranspiration over short periods such as hours or less, while a low resolution only allows daily values (Meissner, et al 2010).

The general concept of a weighing lysimeter requires four major elements. These include the container to hold the soil, water and vegetation, a rigid foundation, the force measuring or measuring system, the data acquisition and analysis system. Accessory instrumentation is also required to measure and record climatic data. The key to successful weighing lysimeter is to design a system capable of detecting a change in weight equal to a millimeter of water when the lysimeter itself weighs several kilonewtons. For example, a precipitation event on the surface of a lysimeter equivalent to 1mm of water depth, may weigh approximately 10 Newtons. To detect a change in weight equivalent to 1mm of water, the weighing system would have to be sensitive to approximately the 0.1% level. In actual

practice, the lysimeter weighing system should be sensitive to approximately 0.03%. This can be accomplished by making the top area of the lysimeter large relative to its depth, by maintaining the water table depth precisely and by using modern high technology sensors on the weighing system and a computer controlled data acquisition system.

New lysimeters now exist which are equipped with three shear-stress cells which are placed on top of aluminum pedestals (Xiao, et al, 2009; Meissner, et al, 2010) tested weighing precision of a 2m deep lysimeter with a $1m^2$ cross – sectional area and a total mass of 3500 to 3850kg depending on the soil water content. Weights of 500, 200, 100, 50, 20 and 10g are placed at the center of the lysimeter as well as at 10, 23, 55, 77 and 100cm along two perpendicular lines through the centre of the lysimeter. Mass changes as small as 20g which is equivalent to water gain or loss of 0.02mm can be measured with good accuracy and stability under favourable environmental conditions (low wind speed, relatively constant temperature).

Two different types of weighing lysimeters have been developed. These according to their report involve counterbalancing the dead load (scales approach) of the lysimeter (Black, et al, 1968; Pruitt and Angus, 1960), or using sensitive load measuring devices (Armijor, et al 1972). The later approach is currently more attractive, particularly because of the accuracy, precision and utility of computer controlled data acquisition systems. Often both approaches are combined in weighing lysimeter construction.

A typical weighing lysimeter as illustrated schematically is shown in figure 2.2. It consists of two cylindrical containers, one of which is fitted inside the other. The inner cylinder contains the soil, water and vegetation, and its weight measured using three strain gauge load rings.

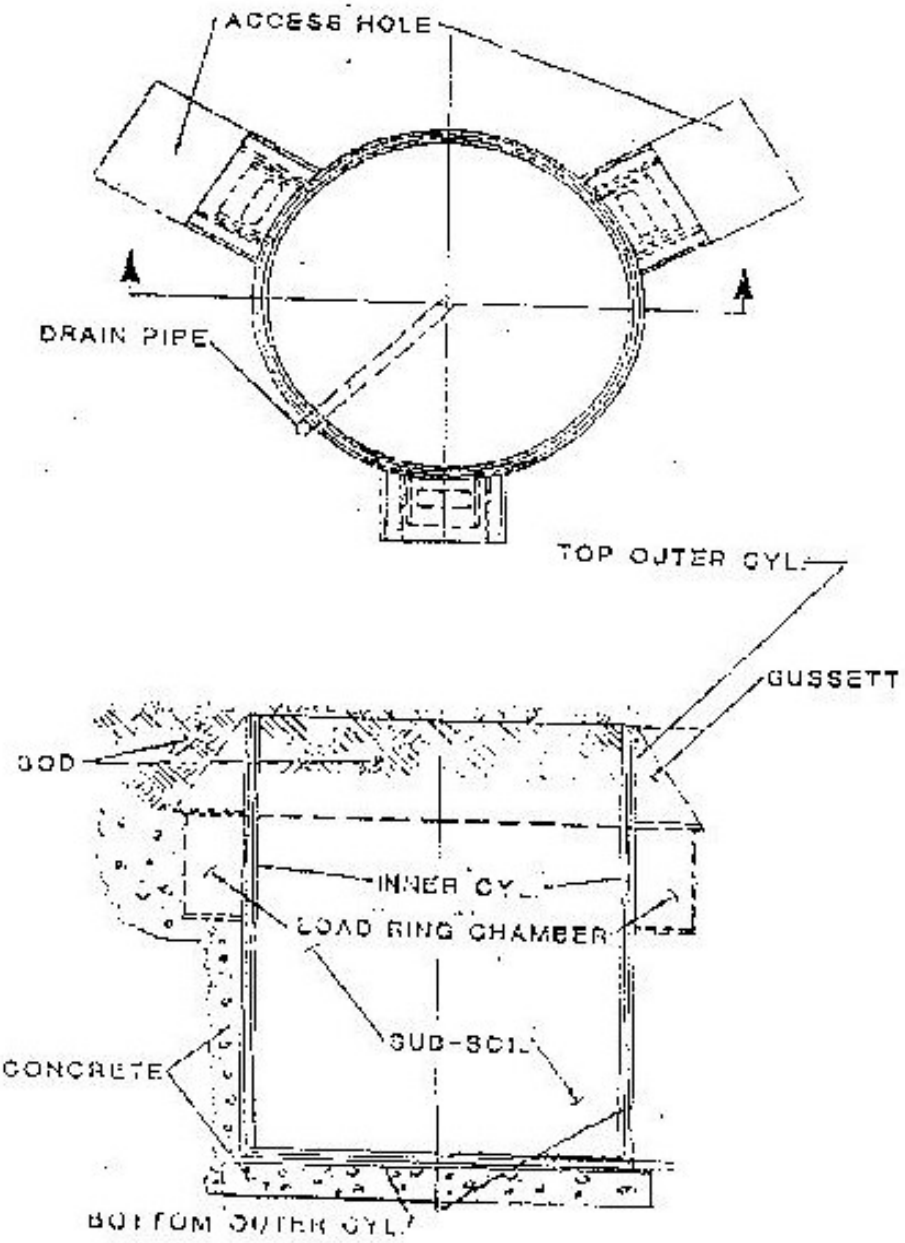

Figure 2.2: Schematic of typical weighing lysimeter

Source: Library.wrds.uwyo.edu/wrp/84-09/84-09.html.

2.8 NON-WEIGHING LYSIMETER

The non weighing lysimeter does not require a higher technical expertise though it gives less accurate results compared to weighing type. The tank which is filled with soil is planted with crop. From the irrigation point of view, the lysimeters are set up to enable the operator measure the water balance, water added/applied, water retained by the soil, and water lost through evaporation, transpiration and deep percolation.

Non-weighing lysimeters are also known as drainage lysimeters, they are normally classified according to their sizes, filling procedure and method of drainage (Bergstrom, 1990). Two types of drainage lysimeter can be distinguished with particular reference to the way water is drained in the system. These are the free drainage system and the suction controlled drainage system. Operationally, in suction controlled lysimeter water does not accumulate in the boundary because it is sucked away through porous ceramic plates, pipes or fiberglass wicks (Boll, et, al, 1992) while in free drainage lysimeter water is allowed to drain freely through the soil under gravity.

Normally lysimeter installation involves excavating soil, placing the tank or lysimeter in the excavation and placing the excavated soil in the lysimeter. The soil profile is disturbed and soil structure is virtually destroyed. Changes in water balance are measured volumetrically daily or once in two days in the non – weighing lysimeter. Initially, water is applied to obtain a favourable moisture

level which is the water holding capacity. Vegetation is seeded or transplanted in the lysimeter. As irrigation water is applied subsequently on the face of the lysimeter, excess water is collected from the bottom through a drainage pipe at intervals.

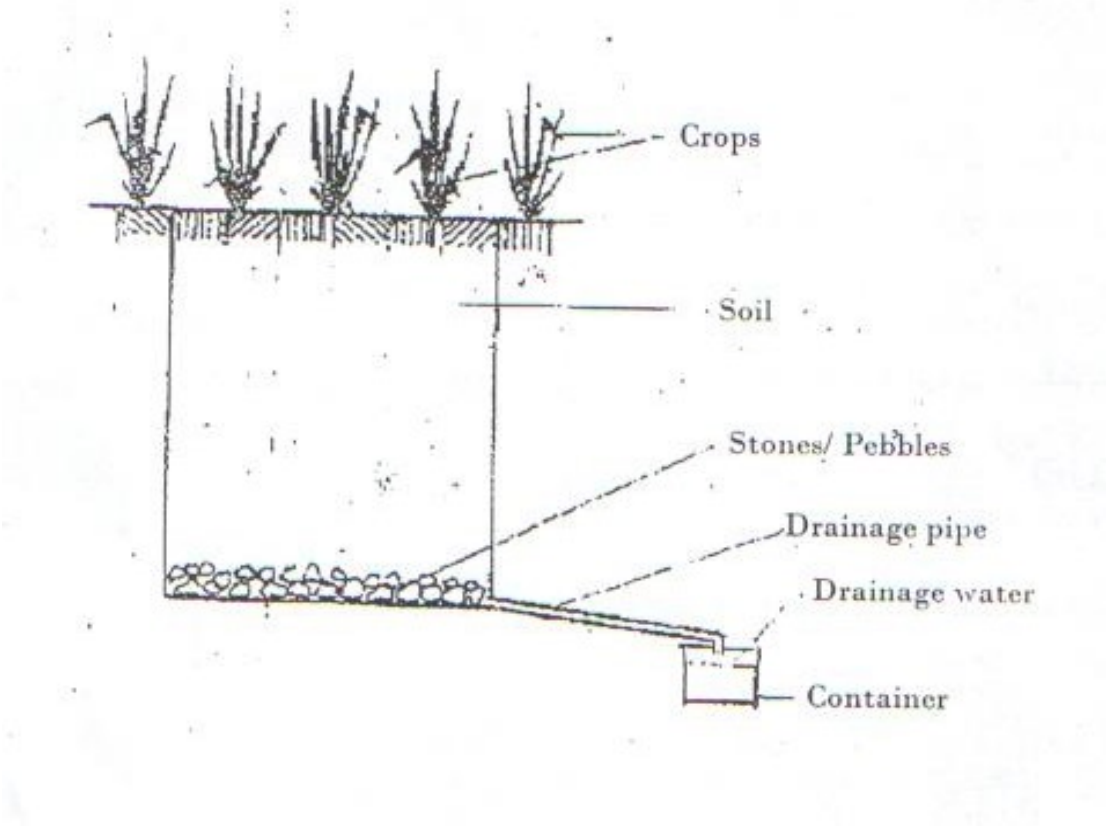

Figure 2.3: A typical drainage lysimeter

2.9 THE MONITORING SYSTEM OF LYSIMETER

So many systems are installed together with the lysimeter that aid data collection for the estimation of evapotranspiration from weighing mechanism or the equation of water balance. Such system includes ceramic cup tension that enables the collection of soil from the vadose zone. Although ceramic suction cups and plates have to a large extent replaced the classical zero-tension drainage lysimeter (Van Der Ploeg and Beese, 1977). Some other systems are soil moisture equipment, rain gauge, evaporation pan etc.

Generally, these monitoring systems are installed to gather soil-water samples at the field sites or variation in the weights of the lysimeter when irrigation, evapotranspiration or drainage takes place.

2.10 SOIL COLLECTION IN THE LYSIMETER

According to how the soil inside the lysimeter is collected, lysimeters can be monolithic, repacked (reconstructed) or a combination of both. In monolithic lysimeter, the soil inside the lysimeter is an intact soil core, (Marek, et al, 1988, 2006; Malone, et al, 2000; Seyfried, et al, 2001). In repacked or reconstructed lysimeters, the soil inside the lysimeter is disturbed and the soil structure virtually destroyed.

Soil samples are often packed simulating the density of the soil under disturbed conditions. This is achieved by carefully pressing the soil into the lysimeter container or by refilling the soil into the

lysimeter using a number of soil horizons of the same thickness and types as found in the natural state of the soil profile. The filled lysimeter may be allowed to stand for a longer period of time exposed to both dry and wet seasons. These efforts aid in maintaining an overall drainage pattern in the lysimeter which is similar to that in the natural field, but do not reduce the problem of changes in micropore size, orientation and changes in bulk density (Grebet and Cuenca, 1991).

Repacked or reconstructed lysimeter have been criticized as compared to undisturbed soil core in the lysimeter column. This is due to the fact that sampling and pretreatment as for homogenization destroys the soil structure and cause potential variations in the soil to disappear (Mclay, et al, 1992). An undisturbed soil monolith is most representative of field conditions, especially because the macro pore system in the soil core is intact. From literature, Mclay, et al (1992) studied the influence of soil structure on Sulphate leaching using undisturbed soil monolith lysimeters and repacked soil columns. From their effort they concluded that there are significant difference between the results of leaching studies conducted using undisturbed soil monolith lysimeters and result obtained from repacked soil column.

2.11 THE HYDROLOGIC CYCLE

Moisture is constantly circulating between the land, the ocean, and the atmosphere. The US National Research Council (1991) defined hydrology as the science that treats the waters of the earth,

their occurrence, circulation and distribution, their chemical and physical properties and their reactions to living things. The hydrologic cycle and its complex series of phase changes and interconnected flow is schematically represented as seen in figure 2.4 overleaf. The circle has neither a beginning nor an end, but the concept of the hydrologic cycle commonly begins with the water of the oceans, since it covers about three fourths of the earth's surface.

Radiation from the sun evaporates water from the oceans into the atmosphere. The water vapour arises and collects to form clouds. Under certain conditions, the cloud moisture condenses and falls back to the earth as rain, hail, sleet, or snow. Precipitation reaching earth surface may be intercepted by vegetative materials, infiltrate into the ground, flow over the land surface as runoff or evaporated water. Evaporation may be from the surface of the ground, from free water surface or from leaves of plants through transpiration. Some of the precipitation after wetting the foliage and ground surface move over land to streams as runoff while the other part infiltrate the soil. Much of the water that enters the soil is detained in the plant root zone and eventually drawn back to the surface by plant or by soil capillarity. Some of it however, soaks below the plant root zone and under the influences of gravity continues to move downward until it enters the ground water reservoir.

On joining the body of ground water, the percolating water may move through the pores of saturated subsurface materials and may reappear at the surface in areas at lower elevations as subsurface

flow. The streams carrying both surface runoff and subsurface flow eventually flow back to the oceans to restart the cycle.

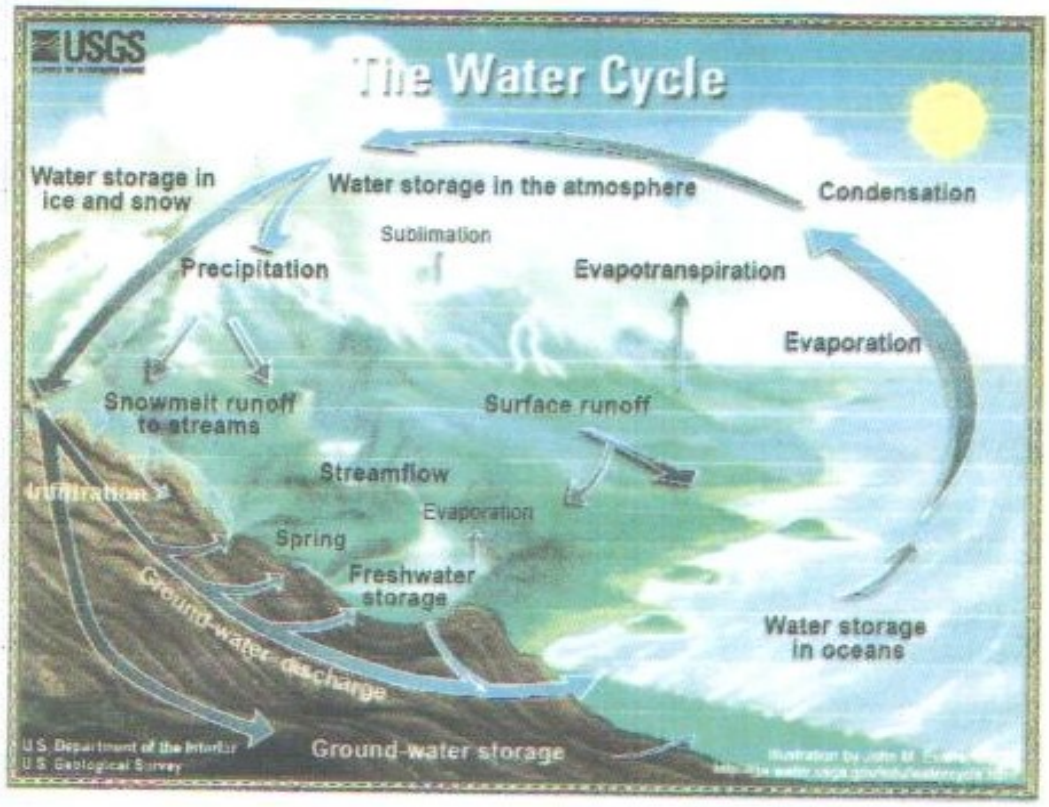

Figure 2.4: The Hydrologic Cycle

2.11.1 Radiation

The solar radiation received at the top of the earth atmosphere on a horizontal surface is known as the Extraterrestrial radiation (Ra). The values of extraterrestrial radiation depend on season change, the position of the sun, and of course the length of the day. It therefore stands that the extraterrestrial radiation is a function of latitude, and the date and time of the day. The solar constant is the radiation striking a surface perpendicular to the sun's ray at the top of the earth's atmosphere and it is some $0.082MJm^{-2}min^{1}$. If the position of the sun is directly overhead, the incidence angle of extraterrestrial radiation is zero. In this case, extraterrestrial radiation is some $0.082MJm^{-2}min^{1}$ (Kosa, 2003).

The amount of radiation penetrating from the atmosphere to a horizontal plane is known as solar or shortwave radiation (Rs). The sun emits energy by electromagnetic waves that include short wavelengths,so solar radiation is referred to as shortwave radiation. In this atmosphere, radiation is absorbed, scattered, or reflected by gases, clouds, and dust. For cloudless day, the solar radiation is about 75% of the extraterrestrial radiation, while it is about 25% of the extraterrestrial radiation on a cloudy day (Kosa, 2003).

The solar radiation which is also known as global radiation is a summation of direct shortwave radiation from the sun and diffuse sky radiation from all upward angles. Relative shortwave radiation (Rs/Rso) is a relationship between shortwave radiation (Rs) and clearly-sky solar radiation (Rso). The shortwave radiation is solar

radiation that actually reaches the earth's surface in a given time, while clearly-sky solar radiation is solar radiation that reaches to the same area with a clearly-sky condition. The relative shortwave radiation is affected by the cloudiness of atmosphere. On a cloudy day, the ratio is smaller than on a cloudy day. The range of this ratio is between 0.33 (cloudy condition) to 1.00 (cloudless condition) (Kosa, 2003).

The cloudiness in the atmosphere is revealed by the relative sunshine duration, (n/N). It is the relationship between the actual duration of sunshine (n) and the maximum possible duration of sunshine, or daylight hours (N). For the cloudless condition, n is equal to N, while n and n/N are nearly zero for the cloudy condition. The maximum possible duration of sunshine, or daylight hours (N), depends on the position of the sun, so it is a function of latitude and date. The daily values of N throughout a year differ with latitude.

The relationship between reflected radiation and total incoming radiation is known as Albedo (α), it varies with both characteristics of the earth's surface and the angle of incidence, or the slope of ground surface. Albedo can be more than 0.95 for freshly fallen snow, and it is smaller than 0.05 for wet bare soil. The range of Albedo for green vegetation is about 0.20-0.25 and Albedo for the green grass reference is 0.23. Net solar radiation (Rns) is the fraction of the solar radiation that is reflected from the ground surface. It can be expressed by the equation below.

$$Rns = (1-\alpha)\, Rs \quad \text{.....21}$$

in which

Rns = net solar radiation

α = Albedo

Rs = solar radiation (short wave radiation)

The difference in value between outgoing and incoming longwave radiation is known as net longwave radiation (RnL). It is solar radiation absorbed by the earth and turned to heat energy. Since the temperature of the earth is less than the sun, so the earth emits longer wavelengths. Terrestrial radiation is referred to as longwave radiation. The emitted longwave radiation (RI, up) is absorbed by the atmosphere or lost into space. The longwave radiation received by the atmosphere (RI down) increases its temperature. Therefore, the earth's surface both emits and receives longwave radiation. The value of outgoing longwave radiation is normally more than the incoming longwave radiation, so the net longwave radiation is used to present the energy loss. Net radiation (Rn) is the difference in value between incoming and outgoing radiation of both short and long wave lengths. It is the balance among energy absorbed, reflected, and emitted by the earth's surface. The net radiation is also the difference in value between the incoming net shortwave (Rns) and the net outgoing longwave (RnI) radiation. It is a positive value during daytime, while it is negative value during nighttime. For the total daily value, it is a positive value except for the condition of high latitude. Soil heat flux (G) is energy that is used

in heating the soil. It is a positive value under the condition of warming soil and negative under cooling soil (Kosa, 2003).

2.11.2 Precipitation

Precipitation is a part of the science of meteorology which has to do with the atmospheric phenomena of heat, moisture and air movement. It may occur in any of a number of forms and may change from one form to another during its descent. The forms of precipitation consisting of fallen water droplets may be classified as drizzle or rain. Drizzle itself consists of quite uniform precipitation with drops less than 0.5mm on diameter, while rain consists generally of larger particles. It is on record also that precipitation may also occur as frozen water particles including snow, sleet, and hail. Characteristically, each of these has its formative procedure; snow is composed of a grouping of small ice crystals known as snowflakes. Sleet forms when raindrops are falling through air having a temperature below freezing. A hail stone is an accumulation of many thin layers of ice over a snow pellet. Moisture is also made available by direct condensation and absorption from the atmosphere as dew (Schwab, et al, 1981).

Condensation is the formation of water droplets in the clouds. Moisture is always present in the atmosphere, even in a cloudless day. For precipitation to occur, some mechanism is required to cool the air sufficiently to bring to or near saturation. The large-scale cooling needed for significant amount of precipitation is achieved by lifting the air. This is accomplished by convective systems resulting

from unequal radiative heating or cooling of the earths' surface and atmosphere or by convergence caused by orographic barriers (Linsley, et al, 1982).

The presence of condensation nuclei is always needed for the formation of raindrops to take place, it is upon this that the droplets crystal form. These nuclei are small particles of various substances, usually ranging in size from about 0.1 to 10μm in diameter. These particles are called aerosols. During the initial occurrence of condensation, the droplets or ice particles are very small and are kept aloft by motion of the air molecules. Once droplets are formed they also act as condensation nuclei. These droplets tend to repel one another, but in the presence of an electric field in the atmosphere they attract one another and are heavy enough to fall through the atmosphere. Some of the droplets evaporate in the atmosphere, some decrease in size by evaporation and some increase in size by impact and aggregation.

A variety of instruments and techniques have been developed for measuring the amount and intensity of precipitation. All forms of precipitation are measured on the basis of the vertical depth of water that would accumulate on a level of surface if the precipitation remained where it fell. In the metric system precipitation is measured in millimeters and tenths (Linsley, et al, 1982). Rainfall/precipitation measurement is very important with regards to the estimation of evapotranspiration.

2.11.3 Infiltration

Infiltration is the process by which water on the soil surface enters the soil. Some precipitation lost due to infiltration may return to streams or interflow and may contribute to runoff. Infiltration is the main source of soil water to sustain the growth of vegetation and deep percolation, recharge of ground water supply of wells, springs and streams. The rate decreases as the soil becomes saturated, and it is affected by soil characteristics including ease of entry, storage capacity, and transmission rate through the soil. The soil texture and structure, and rainfall intensity, all play important role in controlling infiltration rate and capacity. Infiltration rate is a measure of the rate at which the soil is able to absorb rainfall or irrigation water. While infiltration capacity is the maximum rate that water can enter a soil in a given condition. Infiltration is quite important in hydrological studies. It is measured in millimeter per hour.

The infiltration rate is used for the computation of the water loss due to infiltration for the purpose of determining surface runoff. The knowledge of the infiltration character of a soil is basic information required for designing efficient irrigation system.

2.11.4 Transpiration

Transpiration consists of the vaporization of liquid water contained in plant tissues and the vapour removal to the atmosphere. Crops predominantly loose their water through stomata. So transpiration is a process through which water vapour passes into the

atmosphere through the tissue plants or stomata. These are small openings on the plants leaf through which gases and water vapour pass. The water, together with some nutrients, is taken up by the roots and transported through the plants. The vaporization occurs within leaf, namely in the inter cellular spaces, and the vapour exchange with the atmosphere is controlled by the stomatal aperture. Transpiration mainly occurs during daylight hours.

Transpiration, like direct evaporation, depends on the energy supply, vapour pressure gradient and wind. Hence, radiation, air temperature, air humidity, and wind terms should be considered when assessing transpiration. The soil water content and the ability of the soil to conduct water to the roots also determine the transpiration rate, as do water logging and soil water salinity. The transpiration rate is also influenced by crop characteristics, environmental aspects and cultivation practices.

Plant roots can never remove the water completely from the soil. The water contents of the soil when the plant ceases to extract water is called the wilting coefficient. Plants require a large quantity of water for their growth. The rate of transpiration depends upon the growth period of the plant. Transpiration ratio is the ratio of the total weight of water transpired during the entire growth period to the weight of dry matter produced by the plant.

$$\text{Transpiration ratio} = \frac{\text{Weight of water transpired}}{\text{Weight of dry matter produced}} \quad \ldots\ldots\ldots\ldots \quad 2.2$$

For most crops, the transpiration ratio varies from 300 to 800 (Arora, 2002).

2.11.5 Evaporation

Water can exist in the natural environment in three different forms or states – solid (ice), liquid and gas. The process by which water changes from a liquid to a gas is known as evaporation. Above the water surface are the water molecules in the form of water vapour which are always found above liquid water. From time to time one of the water molecules (vapours) on the surface get knocked away or evaporates as they are always found moving around. Evaporation occurs when molecules of water obtain high kinetic energy to eject themselves from the water surface into the atmosphere. The amount of energy used by a unit mass of water from the liquid state to the vapour state at constant temperature is known as the latent heat of evaporation, which is above 585 calories per gram.

The rate of evaporation is influenced by solar radiation, air temperature, vapour pressure, wind, and minimally by atmospheric pressure (Linsley, et al, 1982).

Vapour molecules continuously leave the water during evaporation. The motion of these molecules produces a pressure on the water surface, which is known as vapour pressure. Therefore, vapour pressure is due to vapour molecules present in air. If there is continuous supply of heat energy, more and more molecules accumulate and finally a state is reached when the air above the free surface becomes saturated with vapours and it cannot accommodate more vapours. The partial pressure exerted by the water vapours at

this stage is called the saturation vapour pressure(s). The saturation pressure increases with an increase in temperature if the vapour pressure in the air above the water surface remains less than that of the water surface, evaporation continues. As soon as the vapour pressure reaches the saturation pressure, evaporation stops.

Many evaporation formula for free water surface as based upon Dalton's law. Dalton's law states that rate of evaporation depends on the difference between the saturation vapour pressure and the vapour pressure in the air above. This is given below:

$$E_a = C [e_s - e_a] \quad \text{.....2.3}$$

Where:

e_s = the saturated vapour pressure at the temperature of the water surface in mm of Hg.

e_a = the actual vapour pressure of the air

C = a constant coefficient that depends on Barometric pressure, wind velocity, etc.

E_a = the rate of evaporation [cm/day]

For evaporation to continue, the following three conditions should be satisfied: there should be a constant supply of water, constant supply of heat, and a vapour deficit. Evaporation shall continue till $e_a = e_s$. On the other hand, if e_a is greater than e_s, condensation will take place. In that case, more molecules return to the water surface than those that leave it (Arora, 2002).

Evaporation measurements from free water surface are commonly made using evaporation tanks or pans.

2.12 EVAPOTRANSPIRATION (ET)

By definition ET is the loss of water from a vegetated surface through the combined processes of evaporation and plant transpiration. The term evapotranspiration comes from combing the prefix 'evapo' (for soil evaporation) with the word transpiration. Both soil evaporation and plant transpiration represent evaporative processes. The difference between the two rests in the path by which water moves from the soil to the atmosphere. Water lost by transpiration must enter the plants via the roots, and then pass to the foliage where it is vaporized and lost to the atmosphere through tiny pores in the leaves known as stomata; while water lost through soil evaporation passes directly from the soil to the atmosphere.

Evaporation is governed by the availability of water in the top soil and the fraction of solar radiations reaching soil surface. The amount of solar radiation reaching soil surface varies with the degree of crop shading. While transpiration itself is a function of crop canopy and soil water status. Evaporation has been found to dominate the ET by as much as 100% during early stages of crop growth, while transpiration contributes to nearly 90% of the ET for a fully matured crop (Allen, et al, 1998).

ET can be classified in the following:

i. Reference evapotranspiration, ETo
ii. Crop evapotranspiration ETc

Evapotranspiration (ET) data are usually presented as a depth of water loss over a particular time period in a manner similar to that of precipitation. Common unit for ET are millimeters/day. But in others, the time could be an hour, month, decade or even an entire growing period or year in units of water depth.

2.12.1 Reference Evapotranspiration (ETo)

The evapotranspiration rate from a reference surface, not short of water is called reference crop evapotranspiration and is denoted as ETo. The reference surface is a hypothetical grass reference crop with specific characteristics.

The concept of the reference evapotranspiration was introduced to study the evaporative demand of the atmosphere independently of crop type, crop development and management practices. Relating ET to a specific surface provides a reference to which ET from other surfaces can be related. In other words ETo determines the loss of water from a standardized vegetated surface which helps in fixing the base value of ET specific to that site. The only factors affecting ETo are climatic parameters. Consequently, ETo is a climatic parameter and can be computed from weather data. ETo expresses the evaporating power of the atmosphere at a specific location and time of the year and does not consider the crop characteristics and soil factors.

ETo can be estimated from meteorological data using empirical and semi empirical equations. So many empirical methods have been developed to estimate evapotranspiration from different climatic

variables. Such methods include Blaney -Criddle method and Penman – Montheith method. Certain factors are quite considered in the selection of method. One of the most important factors governing the selection of a method is the data availability. For example, Blaney – Criddle only requires the temperature data while the Penman – Montheith requires additional parameters such as wind, speed, humidity, and solar radiation. In addition, since the Blaney - Criddle method is used to calculate monthly method Kc values (crop coefficient) as compared to daily, less data is needed for this method. Several studies have been conducted over the years to evaluate the accuracy of different ETo estimation methods. Most of these studies have concluded that Penman – Montheith equation in its different forms provides the best ETo estimate under most conditions. Therefore, FAO, the Food and Agricultural Organization recommends FAO - Penman Montheith (FAO-PM) method as the sole standard method for computing ETo (Allen, et al, 1998) Fo-pm provides accurate ETo estimates for weekly or even hourly periods. The FAO-PM is also selected because it closely approximates grass ETo at the location evaluated, is physically based, and explicitly incorporates both physiological and aerodynamic parameters.

2.12.2 Crop Evapotranspiration (ETc)

The crops evapotranspiration (ETc) under standard condition is the evapotranspiration from disease-free, well fertilized crops, grown in large fields, under optimum soil water conditions, and achieving full production under the given climatic conditions. That means that actual crop water use depends on climatic factors, crop type, crop

growth/development and crop management practices. While ETo provides the climatic influence on crop water use, the effect of crop type and management is addressed by ETc. Factors affecting ETc such as ground cover, canopy properties and aerodynamic resistance for a crop are different from the factors affecting reference crop; therefore ETc differs from ETo. The characteristics that distinguish field crops from the reference crop are integrated into a crop factor or crop coefficient (Kc) (Allen et al., 1998).

Crop evapotranspiration can be calculated from climatic data and by integrating directly the crop resistance, albedo and air resistance factor in the Penman – Montheith approach. The Penman – Montheith method is used for the estimation of the standard reference crop to determine its evapotranspiration rate, ETo. Experimentally determined ratio of ETc/ETo, is the crop coefficient (Kc) and it is used to relate ETc to ETo.

$$ETc = Kc\ ETo \quad \ldots\ldots 2.4$$

Due to variation in the crop characteristics throughout its growing season Kc for a given crop changes from sowing till harvest.

2.13 FACTORS AFFECTING EVAPOTRANSPIRATION

The rate of ET for a given environment (vegetation) is a function of certain critical factors. Weather parameters, crops characteristics, management and environmental aspects are factors affecting evaporation and transpiration.

2.13.1 Weather Parameters

The principal weather parameters affecting evapotranspiration are radiation, air temperature, humidity and wind speed. Several procedures have been developed to assess the evaporation rate from these parameters. The evaporation power of the atmosphere is expressed by the reference crop evapotranspiration (ETo). The reference crop evapotranspiration represents the evapotranspiration from a standardized vegetated surface.

2.13.2 Crop Factors

The crop type, variety and development should be considered when assessing the evapotranspiration from crops grown in large, well – managed fields. Differences in resistance to transpiration, crop height, crop roughness, reflection, ground cover and crop rooting characteristics result in different ET levels in different types of crops under identical environmental conditions. Crop evapotranspiration standard conditions (ETc) refers to the evaporating demand from crops that are grown in large fields under optimum soil water, excellent management and environmental conditions, and achieve full productions under the given climatic conditions.

2.13.3 Management and Environmental Conditions

Factors such as soil salinity, poor land fertility, limited application of fertilizers, the presence of hard or impenetrable soil horizons, the absence of control of diseases and pests and poor soil management may limit the crop development and reduce the evapotranspiration. Other factor to be considered when assessing ET are ground cover, plant density and the soil water content. The effect

of soil water content on ET is conditioned primarily by the magnitude of the water deficit and the type of soil. On the other hand, too much water will result in water logging which might damage the root and limit root water uptake by inhibiting respiration.

When assessing the ET rate, additional consideration should be given to the range of management practices that act on the climatic and crop factors affecting the ET process. Cultivation practices and the type of irrigation method can alter the micro climate, affect the crop characteristics or affect the wetting of the soil and crop surface. A wind breaker reduces wind velocities and decreases the ET rate of the field directly beyond the barrier. The effect can be significant specially in windy, warm and dry conditions, although evapotranspiration from the tree themselves may affect any reduction in the field. Soil evaporation in a young orchard, where trees are widely spaced, can be reduced by using a well – designed drip or trickle irrigation system. The drippers apply water directly to the soil near trees, thereby leaving the major part of the soil surface dry, and limiting the evaporation losses. The use of mulches, especially when the crop is small, is another way of substantially reducing soil evaporation. Anti-transpirants, such as stomata – closing, filming-forming and reflecting materials, reduce the water losses from the crop and hence the transpiration rate (Shirish, 1996).

2.14 CROP COEFFICIENT (Kc)

The values of crop - coefficient (Kc), increase as a crop grows, reaches a plateau as crop growth peaks, and decreases as the crop.

Therefore, crop coefficients are dependent mostly on crop type and stage of growth and not on climate conditions. The idea is that crop coefficient remains essentially the same for the same crop, location and climate, notwithstanding, so once the Kc values for a given crop and variety are determined, they can be applied almost anywhere. If this transferability were not valid it would not make much sense to determine ETc through such a product of terms instead, it would be necessary to calibrate ET equations for each site and each crop type individually. So, with crop coefficients it is only necessary to estimate ETo at a given site, then multiply by the appropriate value of the Kc to arrive at the estimated evapotranspiration rate of the crop. The crop evapotranspiration differs distinctly from the reference evapotranspiration (ETo) as the ground cover, canopy properties and aerodynamic resistance of the crop are different from grass. The effects of characteristics that distinguish field crops from grass are integrated into the crop coefficient (Kc). In the crop coefficient approach, crop evapotranspiration is calculated by multiplying ETo by Kc. Therefore, the crop coefficient (Kc) is computed as the ratio of reference and crop ET as given in the equation below:

$$Kc = ETo/Etc \quad \ldots\ldots 2.5$$

Where;

Kc = Crop Coefficient (Dimensionless)

ETc = Crop evapotranspiration mm/day

ETo = Reference evapotranspiration mm/day

ETc is the crop water use and is always estimated as,

$$ETc = Kc \times ETo \quad \text{.....2.6}$$

The factors affecting Kc are crop type, crop growth stage, climate, soil moisture. Kc is always expressed as a function of time, though as a function of time it does not take into account environmental and management that influence the rate of canopy development (Grattan, et al, 1998). This therefore has made most researchers report Kc as a function of days after transplanting (DAT) which helps to reference Kc on crop development stage (Allen et al, 1998; Tyagi, et al, 2000; Kaspyap and Panda, 2001).

Numerous studies have been carried out over the years to develop the Kc for different agricultural crops. Since most of the studies have been specific to one or two crops, Dorrenbus and Pruitt (1977) prepared a comprehensive list of Kc for various crops under different climatic conditions by compiling results from different studies. Similar list of Kc was also given by Allen, et al, (1998) and Doorenbus and Kassam (1979). However, Kc for a crop may vary from one place to another depending on factors such as climate, soil, crop type, crop variety, irrigation methods (Kang, et al, 2003). Thus, for accurate estimation of the crop water use, it is important to use Kc from the same region. Researchers have emphasized the need for regional calibration of Kc under climatic conditions (Dorrenbus and Pruitt, 1977; and Kang, et al, 2003). It therefore stands that the reported values of Kc should be used only in situations when regional data are not available. For example, the South West Florida region that has unique conditions compared to other regions of the world.

Development of regional Kc for crops should be carried out for better estimate of crop water use in order to achieve an efficient and profitable irrigation planning.

2.14.1 Single Crop Coefficient (Kc)

ETc is determined by the crop coefficient approach whereby the effect of the various weather conditions are incorporated into ETo and the crop characteristics into the kc coefficient. In order words, in the single crop coefficient approach, the effect of crop transpiration and soil evaporation are combined into a single Kc coefficient. The coefficient integrates differences in the soil evaporation and crop transpiration rate between the crop and the grass reference surface. As soil evaporation may fluctuate daily as a result of rainfall or irrigation, the single crop coefficient expresses only the time–averages (multi-day) effect of crop evapotranspiration. As the single Kc coefficient averages soil evaporation and transpiration, the approach is used to compute ETc for weekly or longer time periods, although calculations may proceed on a daily time step. The time averages single Kc is used for planning studies and irrigation system design where the averages effect of soil wetting are acceptable and relevant. This is the case for surface irrigation and set sprinkler irrigation systems where the time interval between successive irrigation is of several days, often ten days or more. For typical irrigation management, the time – averaged single Kc is valid.

2.14.2 Dual Crop Coefficient (Kc = Kcb + Ke)

Dual crop coefficient presents the procedure for predicting the effects of specific wetting events on the value for the crop coefficient Kc. The solution consists of splitting Kc into two separate coefficients, one for crop transpiration, i.e. the basal crop coefficient Kcb, and one for soil evaporation (Ke). In other words the effects of crop transpiration and soil evaporation are determined separately.

$$Kc = Kcb + Ke \quad \text{.....2.7}$$

The dual crop coefficient approach is more complicated, and more computationally intensive than the single crop coefficient approach (Kc). The procedure is conducted on a daily basis and is intended for application using computers. It is recommended that the approach be followed when improved estimates for Kc are needed; for example to schedule irrigations for individual fields on a daily basis.

The calculation procedure for crop evapotranspiration, ETc using dual crop coefficient approach consists of:

i. Identifying the length of crop growth stages, and selecting the correspondent Kcb coefficients
ii. Adjusting the selected Kcb coefficients for climate conditions during the stage.
iii. Constructing the basal crop coefficient curve
iv. Determining daily Ke values for surface evaporation
v. Calculating ETc as the product of ETo and (Kcb + Ke) i.e.

$$ETc = (Kcb + Ke) \times ETo \quad \text{.....2.8}$$

2.14.3 Crop Coefficient Curve

When the selection of the calculation approach is fully done, the determination of the lengths for the crop growth stages and corresponding crop coefficients, a crop coefficient curve can be constructed. The changes in the crop coefficient over the length of the growing season is fully shown in figure 2.5. The shape of the curve represents the changes in the vegetation and ground cover during plant development and maturation that affect the ratio of ETc to ET. From the curve, the Kc factor and hence ETc can be derived for any period within the growing season.

As the crop develops, the ground cover, crop height and the leaf area change. Due to differences in evapotranspiration during the various growth stages, the Kc for a given crop will vary over the growing period. As shown in the figure 2.5, the growing period is divided into four distinct growth stages, namely: initial, crop, development, mid season and the late season. The initial period turns from planting date to approximately 10% ground cover. The length of the initial stage is highly dependent on the crop, the crop variety, the planting date and climate. The end of the initial period is determined as the time when approximately 10% of the ground surface is covered by green vegetation.

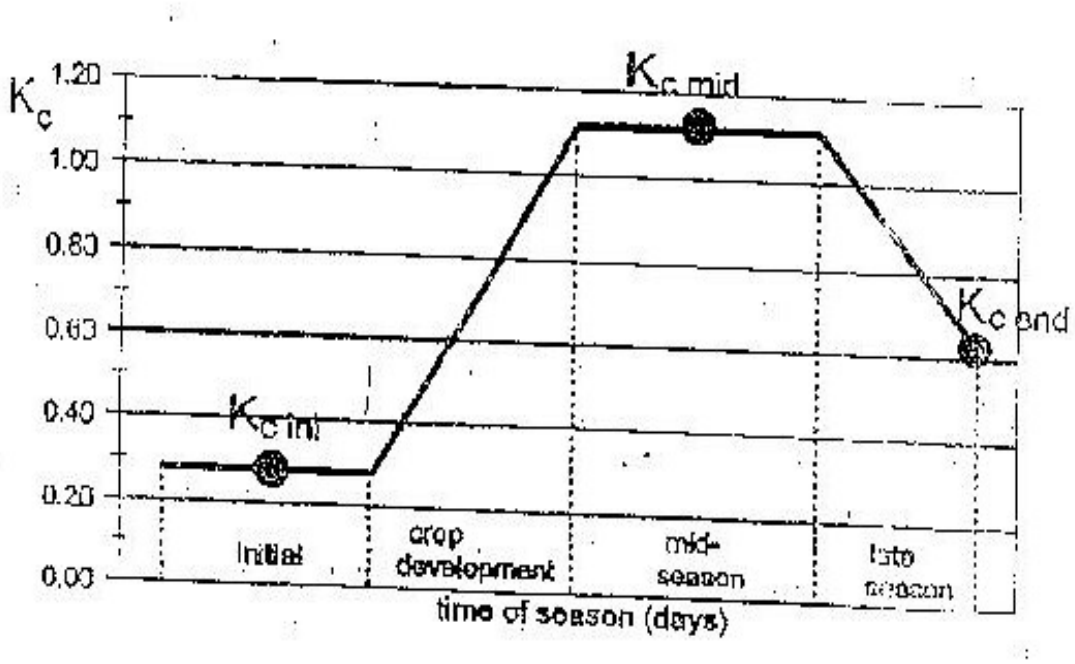

Figure 2.5: Crop coefficient curve

Source: www.fao.org/docrep/x490e/x0490e ob.html.

For perennial crops, the planting data is replaced by the 'green up' data, i.e. the time when the initiation of the new leaves occurs.

The crop development stage runs from 10% ground cover to effective full cover. Effective full cover for many crops occurs at the initiation of flowering. For row crops where rows commonly interlock leaves such as beans, sugar beets, potatoes and corn. The mid season stage runs from effective full cover to the start of maturity. The start of maturity is often indicated by the beginning of the ageing, yellowing leaf drop, or the browning of fruit to the degree that the crop evapotranspiration is reduced to the reference ETo. The mid-season stage is the longest stage for perennials and for many annuals, but it may be relatively short for vegetable crops that are harvested fresh for their green vegetation. The late season stage runs from the start of maturity to harvest or full senescence. The calculation for Kc and ETc is presumed to end when the crop is harvested, dries out naturally, reaches full senescence or experiences leaf drop.

2.15 EVAPOTRANSPIRATION DETERMINATION

Evapotranspiration is not easy to measure. Specific devices and accurate measurement of various physical parameters or the soil water balance in lysimeters are required to determine evapotranspiration. The methods are often expensive, demanding, in terms of accuracy of measurement and can only be fully exploited by well trained research personnel. Although the methods are

inappropriate for routine measurements, they remain important for evaluation of ET estimates obtained by indirect methods.

The evapotranspiration rate from a cropped surface can be directly measured by the mass transfer or the energy balance method. It can also be derived from studies of the soil water balance determined from cropped fields or from lysimeters. Crop evapotranspiration can be derived from meteorological and crop data by the means of Penman – Montheith equation. By adjusting the albedo and canopy surface resistances to the growing characteristics of the specific crop, the evapotranspiration rate can be directly estimated. The albedo and resistances are, however, difficult to estimate accurately as they may vary continually during the growing season as climatic conditions change, or as the crop develops, and with wetness of the soil surface. The canopy resistance will further be influenced by soil water availability, and it increases strongly if the crop is subjected to water stress. Crop evapotranspiration can also be derived from meteorological and crop data by means of FAO Penman – Montheith equation as in the equation below:

$$ETo = \frac{0.408\Delta\,(Rn - G) + \dfrac{Y\ 900\ \mu 2}{(T + 273)}(e_s - e_a)}{\Delta + Y\,(1 + 0.34\ \mu 2)} \quad \ldots\ldots\ldots\ldots\ldots\ldots 2.9$$

Where

ETo = reference evapotranspiration [mm day^{-1}]

Rn = net radiation at the crop surface [MJm^{-2} day^{-1}]

G = soil heat flux density [MJm^{-2} day^{-1}]

T = mean daily air temperature at 2m height [^{o}C]

$\mu 2$ = wind speed at 2m height [ms^{-1}]

e_s = saturation vapour pressure [Kpa]

e_a = actual vapour pressure [Kpa]

$e_s - e_a$ = saturation vapour pressure deficit [Kpa]

Δ = slope vapour pressure curve [Kpa $^{o}C^{-1}$]

Y = psychrometric constant [Kpa $^{o}C^{-1}$]

2.15.1 Energy Balance Method

Evaporation of water requires relatively large amount of energy, either in the form of sensible heat or radiant energy. Therefore the evapotranspiration process is governed by energy exchange at the vegetation surface and is limited by the amount of energy available. Because of this limitation, it is possible to predict the evapotranspiration rate by applying the principle of energy conservation. In which case, the energy arriving at the surface must equal the energy leaving the surface for the same time period.

This energy balance equation can be used for hourly or shorter values especially during daylight hours. The Bowen ratio approach is the most commonly used method. It is the ratio of energy flux from one medium to another by sensible and latent heating respectively. The instrumentation requirements and technical procedures involved generally limit the energy balance method to research studies over relatively short periods of time, but the result can be very reliable if the measurements are accurate because they are obtained under natural environmental conditions.

The energy balance is as given below;

$$Rn - G - \lambda ET - H = O \quad \text{.....2.10}$$

Where

Rn = Net radiation

G = Soil heat flux

H = Sensible heat

λET = Latent heat flux

2.15.2 Soil Water Balance Method

Also, Evapotranspiration can be determined by measuring the various components of the soil water balance as given in equation 2.11. The method consists of assessing the incoming and outgoing water flux in the crop root zone over some time period. Irrigation [I] and rainfall [P] add water to the root zone. Part of I and P might be lost by surface runoff [RO] and by deep percolation [DP] that will eventually recharge the water table. Water might also be transported upward by capillary rise (CR) from a shallow water table towards the root zone or even transferred horizontally by subsurface flow in (SFin) or out of (SFout) the root zone. In many situations, however, except under conditions with large slopes, SFin and SFout are minor and can be ignored.

$$ET = 1 + P - RO - DP + CR \pm \Delta SF \pm \Delta SW \quad \text{.....2.11}$$

Soil evaporation and crop transpiration deplete water from the root zone. If all fluxes other than evapotranspiration [ET] can be assessed, the transpiration can be deduced from the change in soil water content (ΔSW) over the period.

2.15.3 Lysimeter Method

By isolating the crop root zone from its environment and controlling the processes that are difficult to measure, the different terms in the soil water balance equation can be determined with greater accuracy. This is done in lysimeters where the crop grows in isolated tanks filled with either disturbed or undisturbed soil.

In precision weighing lysimeters where the water loss is directly measured by the change of mass, evapotranspiration can be obtained with a few hundredths of a millimeter; and small time periods such as hour can be considered. In non-weighing lysimeters the evapotranspiration for a given time period is determined by deducting the drainage water, collected at the bottom of the lysimeters, from the total input. Thus in using lysimeters, such occurrences like deep percolation and upward capillary rise from shallow water table are eliminated since the lysimeter is a barrier to these problems. Therefore, equation 2.11 can be reduced as given in equation 2.12.
(input – output = change in storage (ΔS). For quantification of evapotranspiration, the equation is written as;

$$ETc = P + 1 - D - R - \Delta S \quad \text{.....2.12}$$

Where

ETc = Crop evapotranspiration (mm-d)

P = Rainfall (mm)

D = Drainage (mm)

I = Irrigation (mm)

Δ = Water drained (mm)

ΔS = Change in the soil water

2.16 SOIL MOISTURE

Among the components of hydrological circle, soil moisture is so important, both on a small agricultural scale and in large scale modeling of land/atmosphere interaction. Vegetation and crops always depend more on the moisture available at root level than on precipitation occurrence. Water budgeting for irrigation planning, as well as the actual scheduling of irrigation action, requires local soil moisture information. Knowledge of the degree of soil wetness helps to forecast the risk of flash floods, or the occurrence of fog.

However, the soil moisture has been seldom observed routinely in meteorological stations. Documentation of soil wetness was usually to the description of the state of the ground by means of WMO code table 0901 and 0975, and its measurement was left to hydrologist, agriculturalist and other actively interested parties. Around 1990 the interest of meteorologists in soil moisture measurement increased. This was partly because after pioneering work by Deardoff (1978), numerical atmosphere models at various scales became more adept at handling fluxes of sensible and latent heat in soil surface layers. Moreover, newly developed soil moisture measurement techniques are more feasible for meteorological stations than most of the classic methods.

2.17 MEASUREMENT OF SOIL MOISTURE

Soil moisture measurements are important in the suitable scheduling of irrigation and estimating the amount of water to apply in each irrigation. Measurement of changes in soil moisture storage

with time is important in estimating evapotranspiration (Michael, 1985).

Soil moisture determinations measure either the soil water content or the soil water potential. Soil water content is an expression of the mass or volume of water in the soil, while the soil water potential is an expression of the soil water energy status. The relation between content and potential is not universal and depends on the characteristics of the local soil, such as soil density and soil texture. Soil water content on the basis of mass is expressed in the gravimetric soil moisture content. θg, as given in equation 2:13.

$$\theta g = \frac{Mwater}{Msoil} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.13$$

Where θg = Gravimetric soil moisture content

Mwater = Mass of the water in the soil sample

Msoil = Mass of dry soil that is contained in the sample

Values of θg in meteorology are usually expressed in percent. Because precipitation, evapotranspiration and solute transport variables are commonly expressed in terms of flux volumetric expressions for water content are often more useful. The volumetric soil moisture content of a soil sample, θv, is as given in the equation below.

$$\theta v = \frac{Vwater}{Vsample} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.14$$

Where:

Vwater = The volume of water in the soil sample

Vsample = The total volume of dry soil + air + water in the sample. The ratio is usually expressed in per cent. The relationship between gravimetric and volumetric moisture contents is shown in the equation below.

$$\theta v = \theta g\ (\ell b/\ell w) \quad \text{.....2.15}$$

Where

ℓb = dry soil bulk density

ℓw =the soil water density

2.17.1 Gravimetric Method for Soil Moisture Measurement

The basic measurements of soil moisture are made on soil samples of known weight or volume, using gravimetric method. Soil samples of about 50g are removed from the field with the best available tools, e.g. augers, etc, disturbing the sample soil structure as little as possible (Dirksen, 1999). The soil sample should be placed immediately in a leak – proof, seamless, pre-weighed and identified container. As the sample will be placed in oven, the container should be able to withstand high temperature without melting or losing significant mass. The most common soil containers are aluminum cans, but non – metallic containers should be used if the samples are to be dried on microwave ovens in the laboratory. If soil samples are to be transported for a considerable distance, tape should be used to seal the container to avoid moisture loss by evaporation.

In carrying out the measurement exercise, the sample and container are weighed in the laboratory both before and after drying, the difference being the mass of water originally in the sample. The

drying procedure consists of placing the open container in an electrically heated oven at 105^0C until the mass stabilizes at a constant value. The drying times required usually vary between 16 and 24 hours. Note that drying at 105 ± 50^oC is part of the usually accepted definition of 'soil water content' originating from the aim to measure only the content of 'free' water which is not bound to the soil matrix. If the soil sample contains considerable amount of organic matter excessive oxidation may occurs at 105^0c and some organic matter will be lost from the sample. Although the specific temperature at which excessive oxidation occurs is difficult to specify, lowering the oven temperature from 105^oC to 75^oC seems to be sufficient to avoid significant loss of organic matter, but this can lead to water content values that are too low. Oven temperatures and drying times should be checked and reported.

2.17.2 Tensiometers

Tensiometers are simple instruments, usually consisting of a porous ceramic cup and a sealed plastic cylindrical tube connecting the porous cup to some pressure – recording device at the top of the cylinder. They are the most widely used least expensive water potential measuring device. They measure the matrix potential, because solute can move freely through the porous cup. The tensiometer establishes a quasi-equilibrium condition with the soil water system. The porous ceramic cup acts as a membrane through which water flows, and therefore must remain saturated if it is to function properly. Consequently, all the pores in the ceramic cup and

the cylindrical tube are initially filled with de-aerated water. Once in place, the tensiometer will be subject to negative soil water potential, causing water to move from the tensiometer into the surrounding soil matrix. The water movement from the tensiometer will create a negative potential or suction in the tensiometer cylinder which will register on the recording device.

In recording, a simple u–tube filled with water and/or mercury, a Bourdon – type vacuum gauge or a pressure transducer (Marthaler, et al, 1983) is suitable. If the soil water potential increases, water moves from the soil back into the tensiometer, resulting in a less negative water potential reading. This exchange of water between the soil and the tensiometer, as well as the tensiometers exposure to negative potentials will cause dissolved gases to be released by the solution, forming into bubbles. The formation of air bubbles will alter the pressure readings in the tensiometer cylinder and will result in faulty readings. Another limitation is that the tensiometer has a practical working limit of Ψ = - 85kpa. Beyond – 100kpa (≈atm), water will boil at ambient temperature, forming water vapour bubbles which destroy the vacuum inside the tensiometer cylinder.

Consequently, the cylinder occasionally needs to be de-aired with hand – held vacuum pump and then refilled. Under drought conditions, appreciable amounts of water can move from the tensiometer to the soil. Thus, tensiometer can alter the very condition they were designed to measure. Additional proof of this process is that excavated tensiometers often have accumulated large numbers of roots in the proximity of the ceramics cups. Typically, when the

tensiometer acts as an 'irrigator' so much water is lost through the ceramic cups that a vacuum in the cylinder cannot be maintained, and the tensiometer gauge will be inoperative.

Before installation, but after the tensiometer has been filled with water and degassed, the ceramic cup must remain wet. Wrapping the ceramic cup in wet rags or inserting into a container of water will keep the cup wet during transport from the laboratory to the field. In the field a hole of the appropriate size and depth is prepared. This hole should be large enough to create a snug fit on all sides, and long enough so that the tensiometer extends sufficiently above the soil surface for refilling access. Since the ceramic cup must remain in contact with the soil, it may be beneficial in stony soil to prepare thin slury of mud from the excavated site and to pour it into the hole before inserting the tensiometer. Care should be taken also to ensure that the hole is back-filled properly, thus eliminating any depressions that may lead to ponded conditions adjacent to the tensiometer. The latter precaution will minimize any water movement down the cylinder walls, which would produce unrepresented soil water conditions. Only a small portion of the tensiometer is exposed to ambient conditions, but its interception of solar radiation may induce thermal expansion of the upper tensiometer cylinder. Similarly, temperature gradients from the soil surface to the ceramic cup may result in thermal expansion or contraction of the lower cylinder. To minimize the risk of temperature induced false water potential readings, the tensiometer cylinder should be shaded and constructed of non-conducting materials, and

readings should be taken at the same time every day, preferably in the early morning. A new development is the Osmotic tensiometer, where the tube of the meter is filled with a polymer solution in order to function better in dry soil.

2.17.3 Electrical Resistance Block

The dependence of electrical conductivity of a porous solid on the amount of water forms the basis of the method. Electrical resistance blocks, although insensitive to water potentials in the wet range, are excellent companions to the tensiometer. They consist of electrodes encased in some type of porous material that within about two days will reach a quasi – equilibrium state with the soil. The most common block materials are nylon fabric, fiberglass and gypsum, with a working range of about– 50kpa (for nylon) or - 100kpa (for gypsum) up to - 1500kpa. Typical block sizes are 4cm x 4cm x 1cm. Gypsum blocks last a few years, but less in very wet or saline soil.

Electrical resistance block method determines water potential as a function of electrical resistance measured with an alternative current bridge (usually ≈1000Hz) because direct current gives polarization effects. However, resistance decreases if soil is saline, falsely indicating a wetter soil. Gypsum blocks are less sensitive to soil saltiness effects because the electrodes are consistently exposed to a saturated solution of Calcium Sulphate. The output of gypsum blocks must be corrected for temperature. Because resistance blocks do not protrude above the ground, they are excellent for semi –

permanent agricultural network of water potential profiles, if installation is careful and systematic (WMO, 2001).

When installing the resistance blocks it is best to dig a small trench for the lead wires before preparing the hole for the blocks in order to minimize water movement along the wires to the blocks. A possible field problem is that shrinking and swelling soil may break contact with the blocks. On the other hand, resistance blocks do not affect the distribution of plant roots. Resistance blocks are relatively inexpensive. However, they need to be calibrated individually. This is generally accomplished by saturating the blocks in distilled water and then subjecting them to a predetermined pressure in a pressure – plate apparatus (Wellings, et al, 1985) at least at five different pressures before field installation. Unfortunately, the resistance is less on a drying curve than on a wetting curve, thus generating hysteresis errors in the field because resistance blocks are slow to equilibrate with varying soil wetness. As resistance block calibration curves change with time, they need to be calibrated before installation and to be checked regularly afterwards, either in the laboratory or in the field.

2.17.4 Psychrometers

Another method used in soil moisture measurement is the Psychrometer, Psychrometers are used in the laboratory research on soil samples as a standard for other techniques (Mullins, 2001), but a field version is also available called the spanner Psychrometers. This consists of a miniature thermocouple placed within a small chamber with a porous wall. The thermocouple is cooled by the peltier effect,

condensing water on a wire junction. As water evaporates from the junction, its temperature decreases and a current is produced which is measured by a meter. Such measurements are quick to respond to changes in soil water potential, but are very sensitive to temperature and salinity. It is known that the lowest water potential typically associated with active plant water uptake corresponds to a relative humidity of between 98 and 100 percent. This implies that, if the water potential in the soil to be measured accurately to within 10kpa, the temperature would have to be controlled to better than 0.001k. This means that the use of field psychrometers is most appropriate for low matrix potentials of less than – 300kpa. In addition, the instrument components differ in heat capacities, so diurnal soil temperature fluctuations can induce temperature gradients in the psychrometer (Brunini and Thurtell, 1982). Therefore, Spanner psychrometers should not be used at depths of less than 0.3m, and reading should be taken at the same time each day, preferably in the early morning. Summarizing, soil psychrometer is a difficult and demanding method, even for specialists.

2.17.5 Radiological Method

Radiological method is among the methods used in measuring soil water content, and two different radiological methods are available. One is the widely used neutron scatter method, which is based on the interaction of high energy (fast) neutrons and the nuclei

of hydrogen atoms in the soil. The other method measures the attenuation of gamma rays as they pass through soil. Both methods used portable equipment for multiple measurements of permanent observation sites and require careful calibration, preferably with the soil in which the equipment is to be used. When using any radiation emitting device, some precautions are necessary. The manufacturer will provide a shield that must be used at all times. The only time the probe leaves the shield is when it is lowered into the soil access tube.

2.18 DESCRIPTION OF *AMARANTHUS*

Amaranthus Cruenthus (African Spinach) which belongs to the family of *Amaranthaceous* is the vegetable understudy. It is among the most popular leafy vegetables in Nigerian and beyond. The leaves and succulent stems have high nutritive value and are good source of Iron (303mg/100g), Calcium (397mg/100g), Vitamin A (8340 microgram/100g) and vitamin C (99mg/100g). *Amaranthus* is spread in all continents and is characterized by good adaptability. The most popular quality of *Amaranthus* seeds and leaves is that they contain 16-18% of high protein. The content of lysine, the chief amino acid in *Amaranthus* is 3 – 3.5 times higher than in maize, 2 – 2.5 times higher than in wheat.

Some are weedy and others cultivated. Four groups of *Amaranthus* are currently being bred. Lettuce (leaf), grain, garden and ornamental (Kauffman and Weber, 1990). In Amaranth breeding the following factors are taken into account: seed colour, high

productivity, stem height earliness, seed shattering, satisfactory nutritive and utilization.

Amaranthus consists of above 60 species of plant, most of which are wild (Stallknecht, et al, 1993). A dubius, A tristis, A tricolour, A cruentus are among the common leafy vegetables, whereas hypochoridriacus is a grain type. In leafy *Amaranthus* the seed is scandal yellow. The grain *Amaranthus* is rich sources of protein and essential amino acids, lysine, Leusaine etc.

When planted, the seed germinates as it comes at the soil surface or the upper layer less than 3cm depth. The common practice in Uganda and in Western Kenya is to sow directly, broadcast or in rows, 15-20cm only with a seed rate 2.5g/m^2. Another cultivation method is sowing in a 3-10g/m^2 and transplanted 2-3 weeks after. *Amaranthus* can be sole planted, intercropped or mixed cropped with other vegetables. Emergence of the seedling takes place 3-5 days after sowing and vegetative development is fast. Like wheat and sugarcane, *amaranthus* is characterized by the C4 – cycle photosynthesis pathway, which means high rate of photosynthesis at high temperature and radiation. In other words, *amaranthus* is attributed to the plants with C4 types CO_2 fixation. Plants of the C4 types are characterized by a more effective photosynthesis, more intensive nitrogen metabolism, as well as physiological and biological peculiarities of metabolic processes (Breus, 1997).

The depth of rooting increases during the vegetative and flowering periods. The hotter the climate or the longer the growing period, the deeper the root will penetrate. Crops requiring only 2

months to mature generally do not penetrate more than 30 to 60cm. Generally, amaranth is a shallow rooted crop.

With regard to the yield potential of *amaranthus,* varieties do affect the yield of the crop. Good growers normally harvest 2.0 - 2.5kg/m^2 (maximum 3.0kg/m^2) of an uprooted crop. The first cutting of a ratooned crop yield 1.0 – 1.5kg/m^2 (edible portion, 70-80%) the following cuttings range between 0.5 and 1.0kg/m^2. On the average a total green yield 10 – 15 tons can be harvested from one hectare in 4 – 6 cuttings, being the yield of pure leave of excellent quality. The seed yield of vegetable *amaranthus* is up to 2t/ha, while the seed yield of grain type is up to 5t/ha.

2.18.1 Soil and Climate Requirement

The crop is adapted to a wide range of soil conditions. Sandy soil with slight acidity is best suited. A medium heavy drained soil with about 1.7 – 3.3% humus, having a pH value of 6.7 – 7.5 is optimum for amaranth. Most *amaranth*us varieties like fertile, well drained soil with a loose structure, and their mineral uptake is very high.

As for daylight and temperature, a temperature range of 20 – 30^0C is required for better vegetative growth. It is known from literature, that vegetable *amaranthus* grow well at day temperature above 25^0C and night temperature not lower than 15^0C. Shade is disadvantageous except in case of drought stress. *Amaranthus* is a quantitative short day plant, which is advantageous in the subtropics where the generative stage is retarded during summer. Humidity has to be very low as this may help to control disease.

2.18.2 Nutritive Value

The leaves and succulent stems of *amaranthus* crops are good sources of Iron, Protein, Calcium, Vitamins, Carotene, Phosphorus and other valuable substances. The leaves of young *amaranthus* plants are used as lettuce in many regions. Of all green vegetables, they contain the highest content of Calcium, Phosphorus and Iron. The seed is a rich source of protein and essential amino acids like lysine, isoleucine etc. Hereunder, is the nutritional data of *amaranthus*.

Table 2.1: Nutritional data of *amaranthus* (Amount in 100grams of edible protein).

NUTRIENTS	**UNITS**	***AMARANTHUS* CROP**
1	2	3
Water	9	9.84
Energy	Kcal	374
Energy	Kj	1,565
Protein	g	14,45
Total lipid (fat)	g	6.51
Ash	g	3.04
Carbohydrate	g	66.17
Fiber, total dietary	g	15.2
Minerals		
Calcium	mg	153
Iron	mg	7.59

Magnesium	mg	266
Phosphorus	mg	455
Potassium	mg	366
Sodium	mg	21
Zinc	mg	3.18
Copper	mg	0.777
Manganese	mg	2.260
Vitamins		
Ascorbic acid	mg	4.2
Thiamin	mg	0.080
Riboflavin	mg	0.208
Niacin	mg	1.286
Panthothenic	mg	1.047
Vitamin B-6	mg	0.223
Folate	mg	49
Vitamin E	mg	1.030
Lipids		
Saturated total	g	1.662
Monounsaturated total	g	1.433
Polysaturated total	g	2.891
Amino acids	g	
Tryptophan	g	0.181
Threonine	g	0.558
Isoleucine	g	0.582

Leucine	g	0.879
Lysine	g	0.747
Methionine	g	0.226
Cystine	g	0.191
Phenylalanine	g	0542
Tryosine	g	0329
Valine	g	0.679
Arginine	g	1.660
Histidine	g	0.389
Alanine	g	0.799
Aspartic acid	g	1.261
Glutanic acid	g	2.259
Glycine	g	1.636
Proline	g	0.698
Serine	g	1.148

Source: USDA nutrient database for standard reference, release 13 (1999).

2.18.3 Agronomic Practices

Agronomics practices well carried out are essentially beneficial for optimum agricultural production. Nursery enables the young seedling to develop under a favourable condition. The soil used for filling the nursery boxes is normally a mixture of top soil and

vegetable compost and often sterilized. It is often an advantage to establish nursery boxes because they are relatively easy to water.

Successive crops of amaranth should not be grown on the same land, but should be rotated with other crops preferably not of the same family. If the same crop is planted on the same plot of land year after year, the crop yields will decrease. This is partly due to increase in the soil insect, fungi, virus, bacteria, and nematodes (Epenhuijsen, 1974).

Land preparation is carried out by ploughing or digging followed by leveling. Then shallow trenches of width 30 – 35cm are made 30cm apart. Well rotten farm yard manure (FYM) is mixed with soil in the trenches. But generally *amaranthus* vegetable can be planted on raised, flat or sunken seedbed depending on the existing environmental conditions such as climate, soil type and depth of water table. On transplanting, 20-30days old seedlings are transplanted from the nursery to the shallow trenches (sunken bed) at a distance of 20cm in two rows. During rainy season planting should be done on raised beds. Crop spacing depends on the season of the year. In dry season, *amaranthus* vegetable should be spaced 20cm apart in rows.

As for nutrient management, 50 tonnes of FYM per ha is applied as basal dose before planting. After preparing trenches, NPK fertilizer at 50:50:50kg/ha is applied. Another 50kg of N can be applied at regular intervals as topdressing. Spraying 1% Urea immediately after each harvest will increase the yield. In management; during early stages; complete control of weeds could be

obtained by raising cowpea in the interspaces. In garden where this is not possible, pre-emergence application of diferon 1.5kg/ha or oxylfourfen 0.2kg/ha is effective. Weeds emerging later could be controlled by the application of paraquet 0.4kg/ha or glyphosate 0.4kg/ha. Hand weeding can also be resorted to. Generally, herbicide application on amaranth crops is not advisable. It is recommended to sow *amaranthus* with wide row spacing, which facilitates mechanical weed control. It is essential to control weeds by pre-sowing soil tillage (StallKnecht, et al, 1993).

Disease and pest control management are part of effective agronomic practices in cultivating *amaranthus*. Stemrot caused by the fungus choanephora cucurbitarium is the main diseases. It is favoured by wet conditions, poor soil fertility and high nitrogen doses. Chemical control by repeated spraying with fungicides such as meneb or carbatene reduces the losses, but is seldom applied. While rust incidence can also occur, in this case you spray indofil-m45 at 2kg/L of water. As far as possible, avoid use of insecticides or fungicides. In severe case of leaf Webber attack, spray Malathion 0.1% or dust Malathion 10% DP. Insects are serious problem for *amaranthus* growers. Caterpillars and sometimes grasshoppers are the most harmful. Commercial growers spray insecticides to dispel insects instead of the traditional control method of spreading wood ash. *Amaranthus* is not very susceptible to nematode damage.

As regards *amaranthus* water use, if rainfall is not sufficient, irrigation by sprinkling should be done before the plants reach their

wilting point. Watering everyday with 8mm (8liters/m^2) is generally sufficient. On the other hand, water shortage causes early flowering.

In crop harvesting commercial growers harvest *amaranthus* by uprooting or by cutting. If the crop was sown directly, the once over harvest by uprooting or by cutting at ground level may be done 3-4 weeks after sowing. Second harvest can also be made 3 weeks later from the re-growth of the smaller plants. When harvest is done repeating, the first cutting takes place about 3 weeks after transplanting and then every 2-3 weeks for a period of one or two months. Therefore 4-6 cutting are possible. Cutting should be done at a height that leaves at least 2 leaves and buds for re-growth. The height of the cutting is normally 10-15cm.

CHAPTER THREE
MATERIALS AND METHODS

3.1 THEORETICAL DESIGN CONSIDERATION

Certain important parameters that were considered in the design and use of the non- weighing lysimeter include the following: tank size, durability of the materials, soil type, bulk density of soil in the experimental plot and root depth. In designing the lysimeter, ease of fabrication, simple installation, low maintenance requirement, and low cost were also important considerations. Materials were selected based on availability, quantity and cost-benefit ratio. Using readily available materials and components helped keep cost down, and a simple design allowed fabrication using common tools.

The non-weighing lysimeter consists of the following components: tank (planted up with vegetable), filter, drainage pipe, and a receiving vessel. These components were installed in the field.

3.2 DESIGN METHODOLOGY

3.2.1 Soil Tank

The lysimeter was made from readily available materials. The tank which is the soil collector was fabricated using steel plate of 2mm thickness and shaped as a rectangular box (Marek, et al, 2006). The 2mm thickness is very strong yet enhances ease of fabrication. After construction, all the joints were welded efficiently using electric welding to make sure there was no leakage. Before installation, the lysimeter was tested for leakage and thereafter painted with oil paint. The leakage was tested by filling the tank with water and

leaving it for three days. In the design it was necessary that root development was not inhibited by limited dimensions of the lysimeter. It was designed to have enough depth to accommodate the rooting depth (30cm) of most vegetable crops and the surface to contain a good number of crops (Shukla, et al, 2007).

The upper part of the lysimeter has the shape of a rectangle with a surface area of 2.77m^2, and a total depth of 0.6m. The bottom section of the lysimeter is trapezoidal in shape having an opening at the center for drainage. Upon the circular opening was a filter formed, and this filter was made of steel wire-wrapped screen. The installation of the filter was necessary to prevent transport of material from the soil into the drain pipe. For drainage collection at the bottom, a galvanizing pipe of diameter 6.6cm and 1.65m long was connected.

3.2.2 Lysimeter Drain

The drain pipe of galvanized steel was welded to the bottom of the tank with the aid of an elbow joint. This pipe was installed beneath the filter to collect the water percolated from the soil in the tank. This pipe served as a conveyance structure for the percolated water into the receiving vessel. The pipe, being a gravity drain system, has a slight fall between the tank and the receiving vessel.

3.2.3 Receiving Vessel

The drainage pipe was connected to a 20 litre drainage collection unit called the receiving vessel. The receiving vessel, though not calibrated, is a discarded 20-litre plastic emulsion paint container.

From the receiver the amount of water percolated each event was measured and recorded. The amount of water sprinkled was such that there was percolation each day, although the amount always varied according to the time of the year and weather conditions. Percolated water was recycled to minimized loss of nutrient.

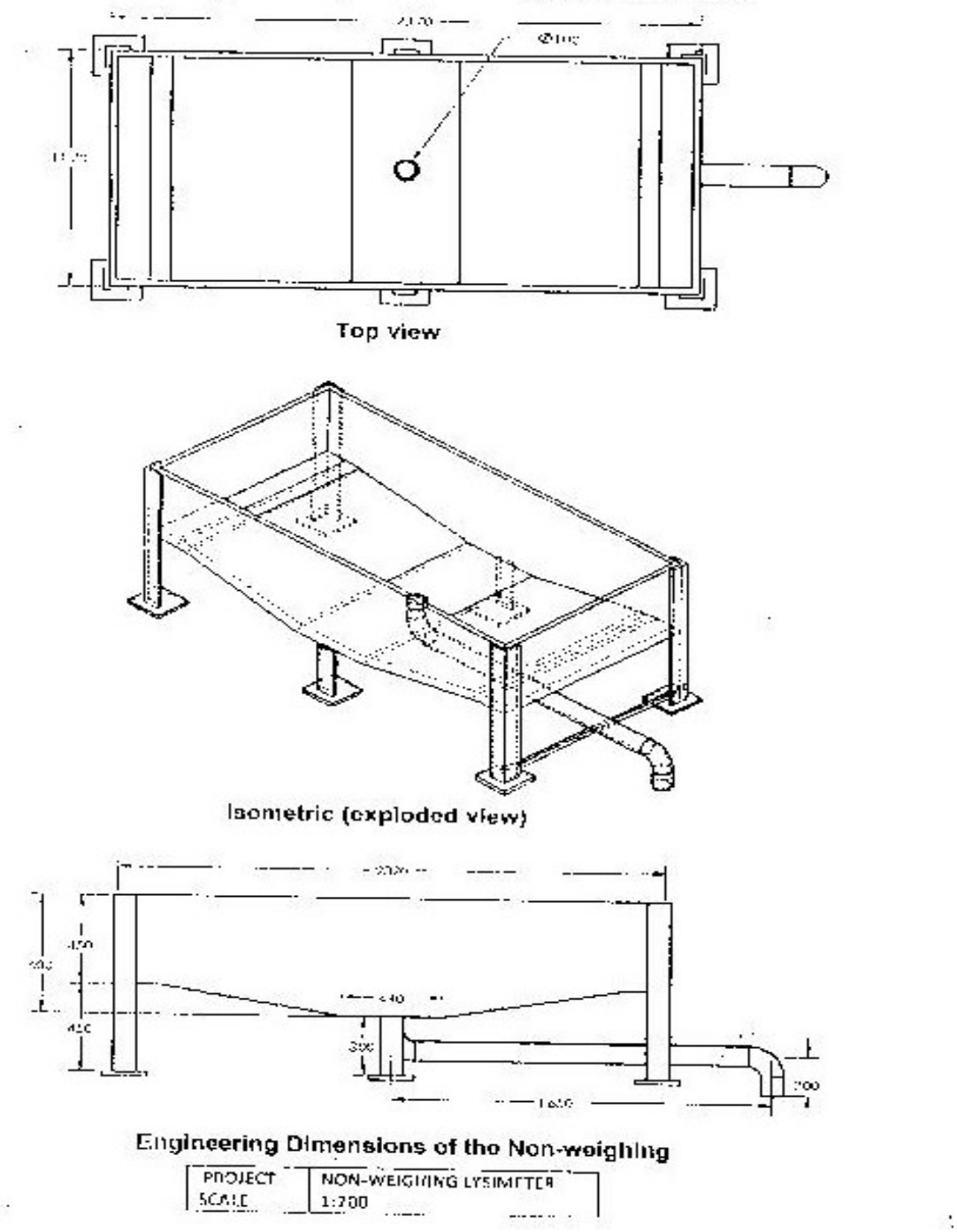

Figure 3.1: Engineering Drawing of the Non-weighing Lysimeter

Figure 3.2: The Lysimeter after construction

3.3 THE STUDY AREA

The lysimeter is located in the cultivable land of Arochukwu Local Government Council in Arochukwu, Abia State, Nigeria. The area is quite close to the Abia State College of Education Technical, Arochukwu. The non-weighing lysimeter covers 2.77m^2 of land. Arochukwu local government is located on latitude $5^0$22'E and longitude $7^0$50'N. The people of the area are predominantly farmers having been blessed with rich farm land for massive cultivation of stable food crops. Food crops like yam, cassava, vegetables, rice and maize are produced in commercial quantities. The area has two distinct weather conditions dry season (including harmattan) and wet season. It is in the humid tropical climate region characterized by the stated seasons. The dry season lasts from November to March, while the wet season spans between April and October. The soil type of the study area is found to be sandy loam, using USDA. The high humidity of the area together with its abundant rainfall favours the growth of tropical crops, while some farmers engage in dry season vegetable farming with irrigation application produce and supply succulent young stems and leaves for money making.

3.3.1 Site Preparation and Field Layout

The location for excavation was marked after clearing the site from its previous vegetation in preparation for installation of the non-weighing lysimter. To effect installation, the soil was excavated in layers, with soil from each layer placed in a separate pile. When the

proper depth was reached; the bottom of the hole was leveled. The surface area of the excavation – 3.58m^2 by 1.6m deep was done manually by hired labourers. This was done to provide some space to allow for the installation of the lysimeter manually.

The field layout for the experiment consists of the developed lysimeter planted up with *amaranthus* stands transplanted from the nursery. The vegetable under study was transplanted on a spacing of 20cm by 15cm. An overhead carrying a 300-litre capacity tank was constructed to help store irrigation water.

3.4 INSTALLATION

The lysimeter installation was accomplished by six people with the use of shovels, and a few hand tools. The tank was lowered into and centered in the hole upon a stable concrete foundation. The tank was checked to ensure that it sat level on the bottom of the hole. Soil was backfilled around the outer tank to stabilize the tank as can be seen in figure 3.3. In other words, the outside lysimeter was first filled with soil to provide a firm support to the lysimeter. In other to prevent transport of materials from the soil into the drain pipe, a wire mesh of about 0.20mm was placed at the bottom of the lysimeter, upon the hole drilled, to act as a filtering mechanism. The formation of the filter was achieved first by placing a screen over the hole, then gravel and finally sand. Then the inner tank was backfilled with soil, restoring the soil to the depth from which it was excavated. The soil was packed periodically in an attempt to return it to its original bulk density. In the installation, a freeboard of about 10cm from the

ground surface was allowed and the process of irrigation was carried out with its attendant drainage. But before the transplanting, the lysimeter has stopped draining from the drainage pipe after saturation and the initial soil moisture data taken. The receiving vessel being a discarded plastic 20-litre emulsion paint container was placed in an adjacent pit for the collection of the percolated water.

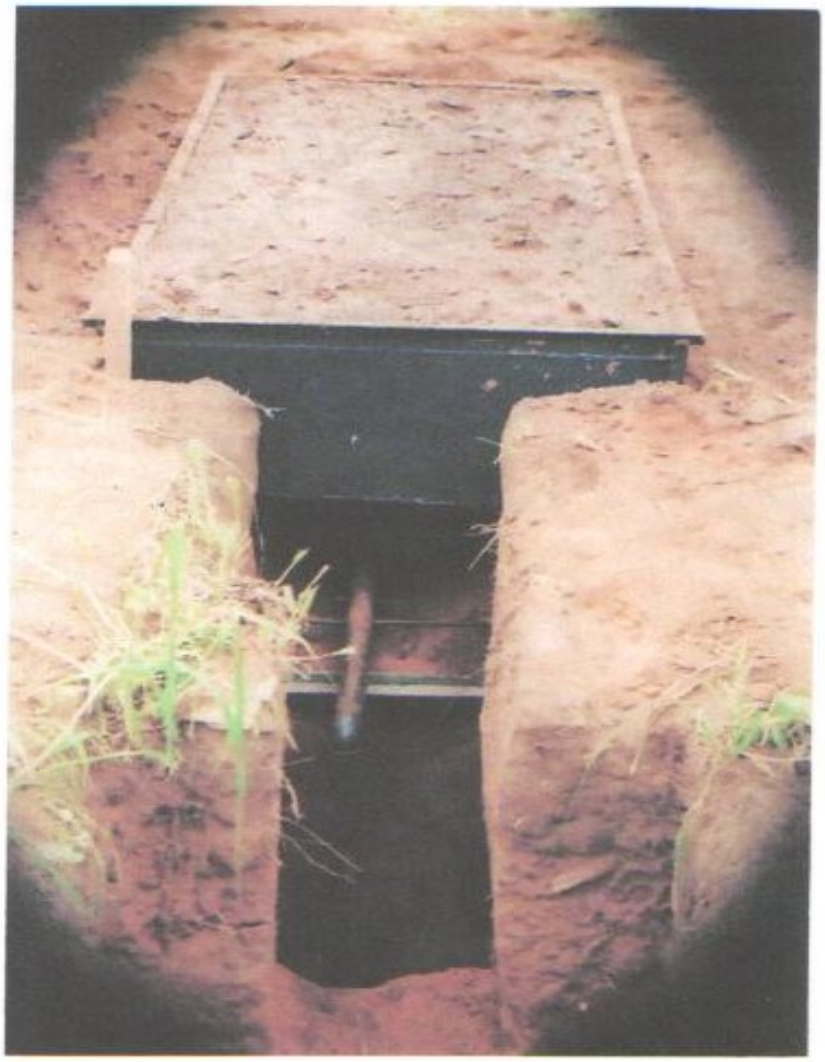

Figure 3.3: Installation of the Lysimeter

3.5 DESCRIPTION OF THE IRRIGATION METHOD USED

The irrigation method used in applying water to the crop was the sprinkler method, in which water was made available to the crop simulating rainfall. This was achieved by the spray of water through a locally fabricated rose containing 30 orifices of about 2mm in diameter on the average, attached to the end of a 2cm diameter hose. In this case irrigation water was directly sprinkled on the crop within the surface area of the lysimeter.

A structure (tank stand) fig. 3.4 of 1.8m high was constructed to carry the 300-litre capacity tank in which the irrigation water was stored. The spray was achieved by the flow of water under pressure through the small orifices, while the pressure was developed due to the differences in head (head difference). Observations from several trials, showed that the flow rate was 0.38 l/s per second. In order to obtain the quantity of water applied in each irrigation application, the time spent during that irrigation was multiplied by the flow rate.

The analysis and design of the framework to support the weight due to the 300 litres of water plus the self weight of the frame material and tank was achieved with the engineering considerations as expressed below:

Soil: The water tank stand was constructed on a firm, non-shrinkable subsoil of safe bearing capacity of 400 KN/m^2.

Dimension: The stand was made of three walls each of height 1.8m above ground level. Length 0.9m and width 0.15m with a space of 0.22m among them.

Materials: The materials used for the construction of the stand included cement, sand, gravel, water and dense blocks.

Foundation: The three walls were established on a single excavated portion of 1.2 x 1.2m, having a reliable depth of 0.2m. The foundation was cast with well – proportioned concrete (1:3:6 - cement, sand, gravel) to depth of 0.15m, providing a solid base (G. Nash, 1980).

Load: The blocks being solid ones with about 10KN/mm^2 resistance to crushing from vertical load imposed upon them can safely transmit a weight of 1,500kg. The weight of water, the tank and the frame being 300kg, 15kg and 25kg respectively is safely transmitted.

Figure 3.4: Full view of the system with the overhead storage tank to enable the spray of water through pressure generated by head difference

3.6 EXPERIMENTAL PROCEDURE

The tests were conducted between 15th march, 2012 and 1st May 2012. The various tests helped in determining the performance of the lysimeter. First a preliminary test was conducted for 3 days to evaluate the ability of the lysimeter to hold water without leakage. This was done by filling the tank with water and observing it for some hours.

Meanwhile, the nursery box of 60×45×12cm was prepared on 25th February 2012 with a mixture of soil treated with poultry droppings. The seeds were sown by broadcasting, and the nursery was frequently watered. Germination occurred on 29th February 2012. The lysimeter was installed on 16th March, 2012, (fig 3.3). The installation was achieved by placing the lysimeter in the excavation made and filling up the lysimeter with the excavated soil. The soil therefore, is repacked or reconstructed. Certain tests like mechanical analysis, soil texture determination and gravimetric moisture content were conducted to determine the apparent specific gravity and moisture content of the soil in the experimental plot. The soil in the lysimeter was brought to field capacity having been irrigated thoroughly and the subsequent percolated water recorded. After preparing the soil in the lysimeter with poultry dropping incorporated, transplanting was done on the 21st March, 2012. Some agronomic practices like spraying against infestation of pest, fertilizer application and weeding were carried out. The pesticide used was Multhrin 10EC applied at the rate of 1ml per 1L of water.

The process of irrigation water application started immediately after transplanting. As the process continued a record of artificial water application, drainage, and rainfall was kept.

3.7 MONITORING SYSTEM

The artificial water application was monitored by noting the time spent on each irrigation and multiplying same by the flow rate of the system – 0.38 l/s. By this, the quantity of water applied was determined. Drainage water or percolated water was captured in the receiving vessel placed at the adjacent pit through the drainage pipe. The quantity of water collected was always measured and recorded. After recording, the percolated water was recycled to minimize loss of nutrients. The changes in the soil moisture were determined by gravimetric method in the soil laboratory at the National Root Crop Research Institute, Umuahia. Rain gauge was installed at the site to catch daily rainfall readings in the case of rainfall since a little part of the study period entered into the rainy season. The drainage was monitored two times daily to be sure it does not overflow the receiving vessel.

Meteorological data were collected from a nearby weather station included the following: temperature, relative humidity, sunshine hours, rainfall, radiation, these data being computed on average daily values were used in analyzing the study with the empirical formulae of Blaney-Morin-Nigeria and Hargreaves-Samani.

3.8 DATA ACQUISITION AND RECORDING

Various data were collected from the non-weighing lysimeter. The amount of rainfall and irrigation water falling on the lysimeter were recorded, percolated water was also recorded. These were used for the computation of evapotranspiration using the water balance equation.

3.9 MATURITY

*Amaranthus S*PP is a fast maturing crop. It matures when it starts flowering. But lack of adequate water supply causes premature flowering of the crop. Since much interest is on the leaves, the crop should be harvested before flowering in order to obtain the greenish colour and the fresh succulent stems. The succulent shoot is due for harvest within three to six weeks of sowing depending on the variety and environmental conditions (Uguru, 1996).

Figure 3.5: Nursery stage of the crop under study

Figure 3.6: Crop responding to irrigation and other agronomic practices

Figure 3.7: The process of reading and recording the quantity of water applied and the quantity discharged

Figure 3.8: Irrigation water application in session

Figure 3.9: The final demonstration of the irrigation water application

3.10 DETERMINATION OF ETc USING WATER BALANCE EQUATION

The experiment was designed using the water balance method (equation) which is also known as inflow – outflow method. This is represented by the following hydrologic equation.

$$ETc = 1 + P - D - \Delta S \quad \text{.....3.1}$$

Where

ETc = Crop evapotranspiration (mm/day)

D = Drainage (mm)

ΔS = Change in soil water storage

I = Irrigation water (mm)

P = Precipitation (mm)

The values of irrigation, rainfall, and drainage were collected from the lysimeter, and these values were converted to millimeter. The conversion was effected first by converting litres to millimeters then dividing by the surface area of the lysimeter. In determining the soil moisture content, the gravimetric method was employed and values were gotten in percentage. The runoff in and out of the lysimeter was nil since the design and installation of the lysimeter was to avoid runoff going into or out of the lysimeter by the freeboard of 10cm above the ground surface and the brick work placed at the upper part as can be seen in figure 3.4. From the non-weighing lysimeter, the crop evapotranspiration was determined by the water balance equation as given in equation 3.1.

3.11 ESTIMATION OF CROP EVAPOTRANSPIRATION USING CLIMATIC DATA

The models employed here are Blaney-Morin-Nigeria and Hargreaves – Samani.

The Blaney-Morin-Nigeria models is of the forms (Duru J. O. 1984).

$ET = rf\,(0.45Ta - 8)(H - R^m)$……3.2

Where

ET = Evapotranspiration (mm/day)

rf = Ratio of monthly radiation to annual radiation

Ta = Mean monthly temperature (^{0}C)

R = Mean monthly relative humidity (%)

H and m are model constants of 520 and 1.31 respectively.

The values of rf are gotten from the tables prepared by Cocheme and Franquin (1967).

The estimation of ET with Hargreaves-Samani is calculated by the equation (Hargreaves – Samani, 1985).

$ETo = C\,(Timed - 17.78)(Tmaxi - Tmin)^{0.5}\,Ra$……3.3

Where,

ETo = The potential evapotranspiration (mm/day)

Tmax = Daily maximum temperature (^{0}C)

Tmin = Daily minimum temperature (^{0}C)

Tmed = Daily mean temperature (^{0}C)

C = 0.0023

Ra = Water equivalent of the extraterrestrial radiation mm-d

3.12 DATA ANALYSIS

The data was analysed using Analysis of Variance (ANOVA) and Correlation. Ducan's Least Significant Difference (LSD) was used to determine significant differences among the means.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 RESULTS

The crop evapotranspiration (ETc) for African Spinach were estimated using three different methods. The methods included lysimeter method, Blaney-Morin-Nigeria and Hargreaves-Samani methods. The results of these estimates are presented in Appendix I.

A record of observation of weather variables was kept on daily basis. These are temperature, radiation, sunshine hours, relative humidity and rainfall (as shown in Appendix II). Crop performance parameters were also measured and recorded, i.e. increase in crop height and girth enlargement as shown in Tables 4.1 and 4.2 respectively.

Table 4.1 Crop development – height parameters

Readings (5days)	Height (cm)
1st reading	16.30
2nd	20.05
3rd	24.84
4th	29.93
5th	45.15
6th	60.31
7th	70.34
8th	82.81
9th	100.73

Table 4.2: Crop development – girth enlargement

Readings (5 days interval)	Girth
1st Reading	1.47
2nd "	1.77
3rd "	2.88
4th "	2.96
5th "	3.37
6th "	3.95
7th "	4.42
8th "	5.02
9th "	5.50

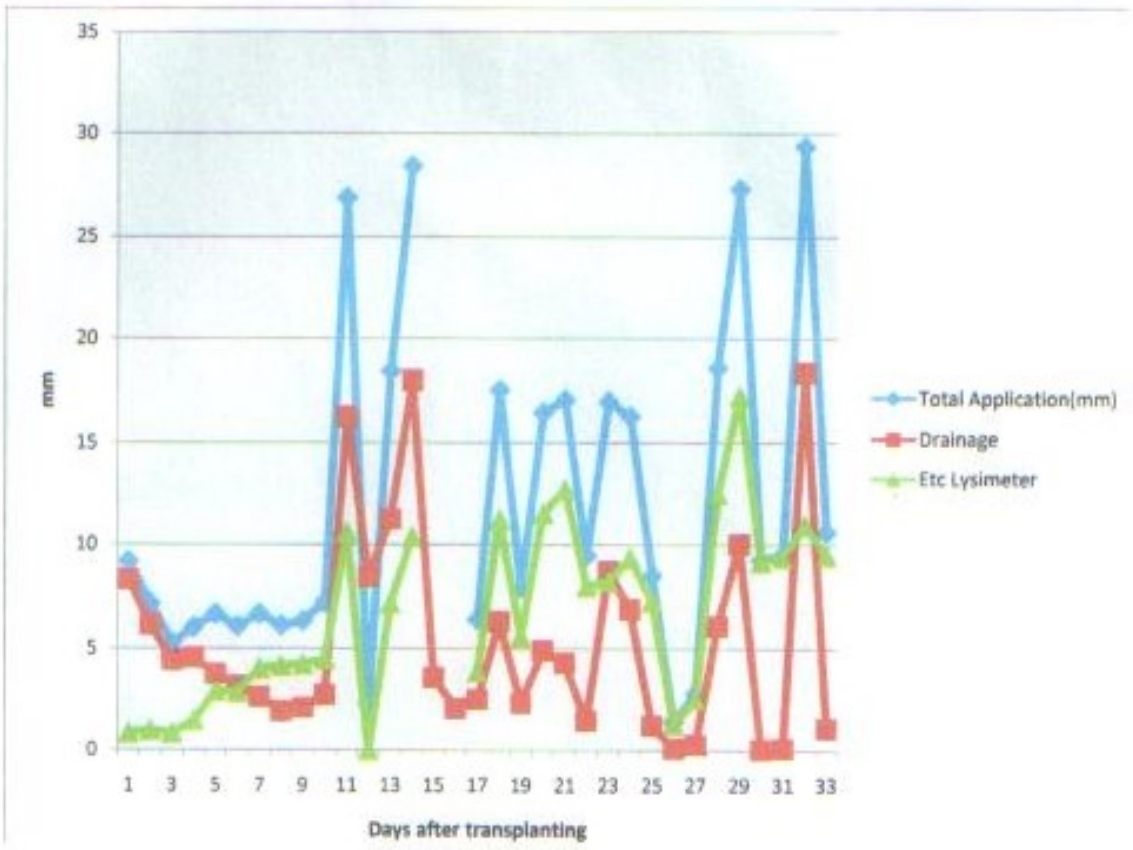

Figure 4.1: Graph showing Irrigation/Rainfall, Drainage and Crop Evapotranspiration

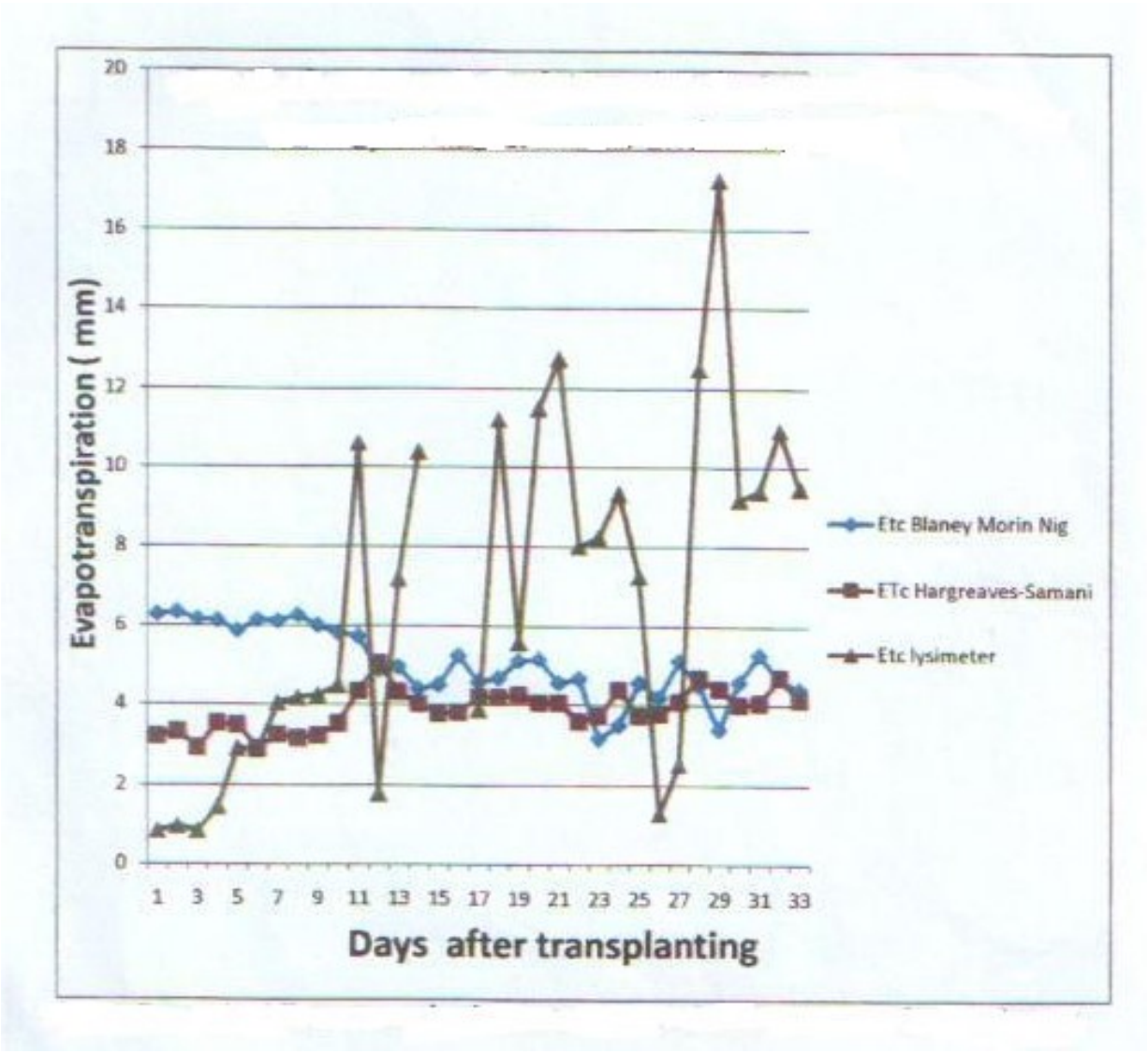

Figure 4.2: Determined Evapotranspiration from the three different methods for the planting period

4.1.1 STATISTICAL ANALYSIS

In the statistical analysis, a statistical package (Gen Stat) with one-way ANOVA without blocking was used to test the level of significance (Gen Stat, 2007). Here the days of planting were taken as the replications while ETc lysimeter, ETc Blaney-Morin-Nigeria and ETc Hargreaves-Samani were the treatments. Table 4.3 below shows the summary of the result with the analysis of variance (ANOVA).

Table 4.3: Summary of the ANOVA

Source of Variance	df	s.s	ms	P-value	F-statistics	F crit
Total	96	727.17	7.57	0.05	13.16	3.15
Treatment	2	158.93	79.47			
Residual	94	568.24	6.05			

From the result/summary fstat>fcript. This shows there is a significant difference among the treatments at P>0.05.

Table 4.4: LSD (Least Significant Difference)

Properties	Mean	Standard Deviation
ETc Lysimeter	6.688a	4.350
ETc Blaney – Morin- Nigeria	5.081a	0.893
ETc Hargreaves – Samani	3.889b	0.540
F – Statistics	11.300***	

Note: Means with different superscripts are significantly different at P>.0.05 level.

***means that the result is significant at P>0.05 level.

The result of the correlation analysis using Pearson Product Moment in determining the relationship between ETc Lysimeter, ETc Blaney-Morin-Nigeria and ETc Hargreaves-Samani is presented in Table 4.5.

Table 4.5: Correlation Analysis of the Relationship between ETc Lysimeter, ETc Blaney-Morin-Nigeria and ETc Hargraves-Samani

	ETc Blaney-Morin-Nigeria	ETc Hargreaves-Samani	ETc Lysimeter
ETc Blaney – Morin- Nigeria	1	-0.630***	0.631**
ETc Hargreaves – Samani		1	0.5721**
ETc Lysimeter			1

** - means that the result is significant at P>0.05 level.

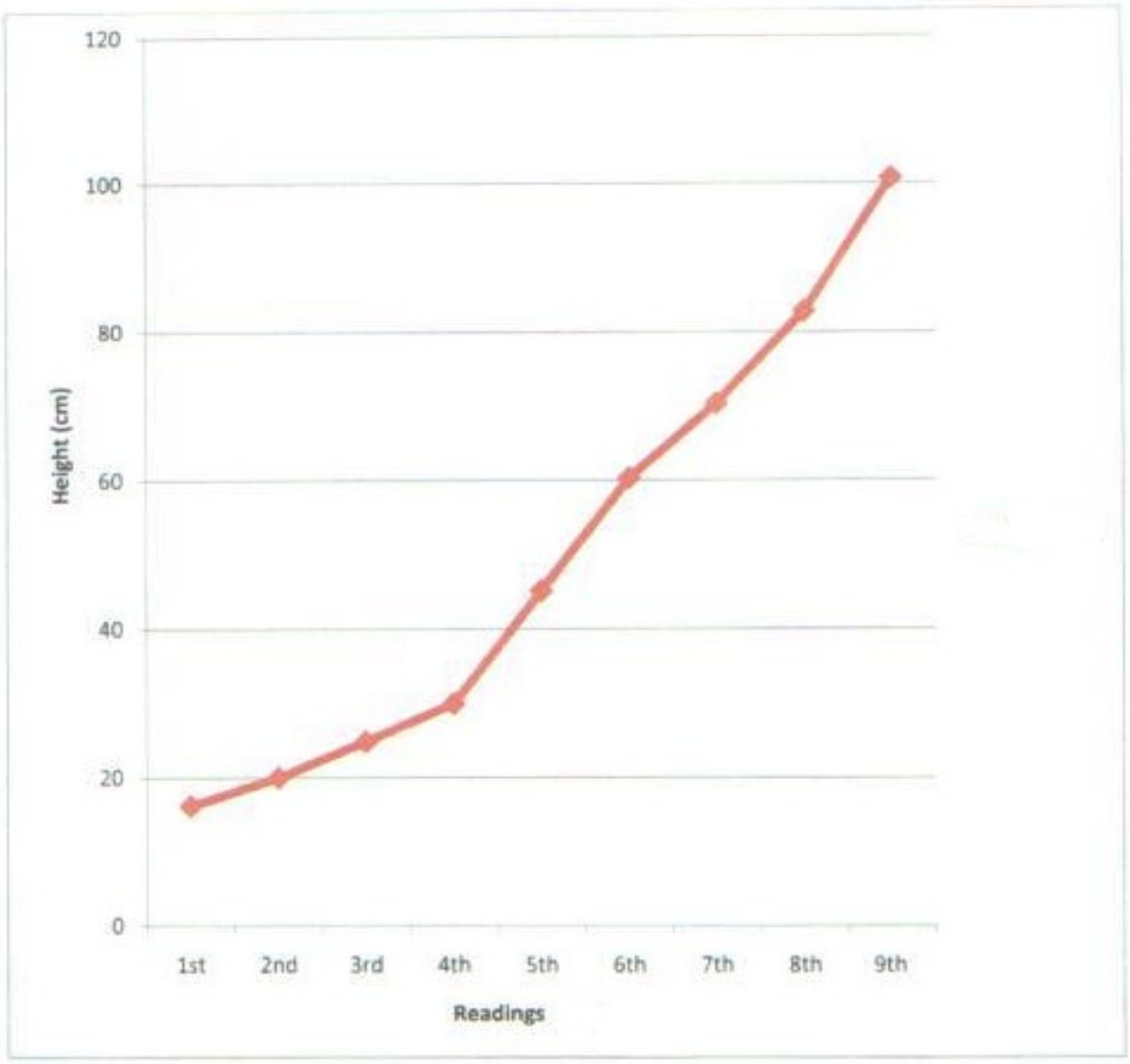

Figure 4.3: Graph showing height of Crop in response to water

Application

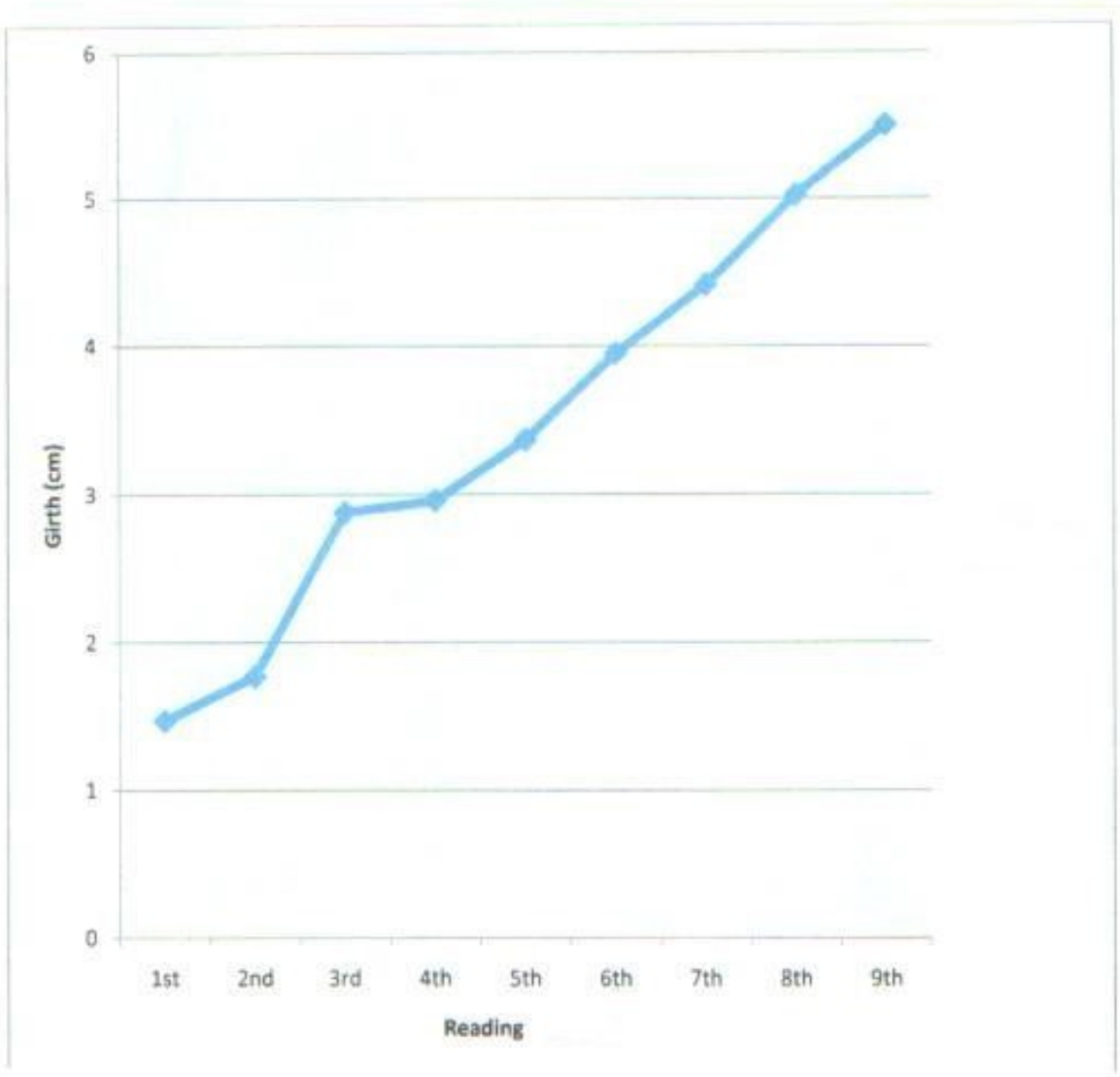

Figure 4.4: Graph showing Girth of Crop in response to water application

4.2 DISCUSSIONS

From Figure 4.1, water application and drainage pattern almost followed the same trend. From the result as can be seen in the graph, it is obvious that drainage increased as irrigation water application increased.

Appendix i recorded the values of ETc lysimeter, ETc Blaney-Morin-Nigeria and ETc Hargreaves-Samani, the total values being 207.33mm, 167.26mm and 128.15mm respectively.

Table 4.3 is the summary of the result with the Analysis of Variance (ANOVA). It shows that there is a significant difference among the treatments – ETc Lysimeter, ETc Blaney-Morin-Nigeria and ETc Hargreaves-Samani at $P>0.05$.

But the Least Significant Difference as seen in Table 4.4 shows that there is a significant difference between the mean values of ETc lysimeter 6.688^{a} and ETc Hargraves 3.889^{b}. While the mean values of ETc lysimeter 6.688^{a} and ETc Blaney-Morin-Nigeria 5.081^{a} are statistically similar. As seen in the table, the means with different superscripts are significantly different, and the means with the same superscript are statistically similar.

The correlation result in Table 4.5 showed a correlation coefficient (R) of -0.630 between ETc Blaney-Morin-Nigeria and ETc Hargreaves-Samani. This indicated a weak negative relationship between ETc Blaney-Morin-Nigeria and ETc Hargreaves-Samani.

The table also showed a correlation coefficient R of o.631 between ETc Lysimeter and ETc Blaney-Morin-Nigeria. This indicated a positive relationship between the values obtained from the experiment for ETc lysimeter and the values obtained using the already established empirical method of ETc Blaney-Morin-Nigeria.

The study, therefore showed that the Blaney-Morin-Nigeria approach works well with the Nigeria climate and should be adopted for studies of evapotranspiration in Nigeria as it showed no difference result with the ETc lysimeter values obtained practically.

Considering figure 4.4 in which the height of crop (average) was plotted against time, it was observed that growth increased with time as irrigation application went on. The rate of crop increase became prominent between the 3rd and 6th reading after transplanting. From observation, it is believed that this period was the period of maximum vegetation of the crop. Likewise in Figure 4.5, the relationship between the crop girth and time is a positive relationship between the values.

The developed non-weighing lysimeter is said to be functional, as the ETc lysimeter 6.67mm/d practically obtained falls within the acceptable values of CU for African Spinach (*Amaranthus*) (6-8mm/day) (G. J. H. Grubben et al, 2004).

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The prime aim of irrigation practice is that of improving agricultural production in terms of quantity, quality and timeliness of operation. It is a justifiable measure for accelerated food production (vegetables, root crops etc) in Nigeria and the world at large. Estimation of crop water need is profitable in establishing irrigation water requirement of optimum crop production. The developed non – weighing lysimeter (drainage lysimeter) can be said to be functional, useful and efficient to use. From the study, it is revealed that the crop water use or evapotranspiration of African Spinach (*Amaranthus Cruentus*) in Arochukwu, Southeast zone of Nigeria between 21st March and 1st May 2012 is 207.33mm.

The total production cost of the lysimeter is one hundred and thirty eight thousand hundred and fifty five naira as at February 2012 which is quiet inexpensive compared to (Daniel 2004) which stood at $1700.

5.2 RECOMMENDATIONS

The following recommendations are made in the light of the study.

i. Further researches can be carried out in a season devoid of rainfall interference.

ii. Other researches can also be carried out for one year to extend the findings of work in order to establish a picture of the annual evapotranspiration value.
iii. Since the lysimeter is utility equipment, it can be used for other related researches.

REFERENCES

Aboukhaled, A.; Alfaro, A; and Smith, M (1982). Lysimeters FAO Irrigation and Drainage Paper No. 39 Rome P. 68.

Allen, R. G.; Fisher D. K. (1990). Lower cost electronic weighing lysimeters. Trans ASAE 33. 1823–1833.

Allen R.G.; Pereira, L. S.; Raes, D,; Smith, M. (1998). Crop evapotranspiration Guidelines for computing crop water requirements, FAO Irrigation and Drainage paper 56, Food and Agriculture organization of United Nations, Rome Italy.

Armijo I. D.; Twitchell, G. A; Burman, R. D; and Nunn, J. R. (1972). A large, undisturbed, weighing lysimeter for grassland studies. TRANSACTIONS of the ASAE 15 (5); 827-830.

Arora, K. R. (2002). Irrigation water power and water resources engineering, Standard Publishers Distributors, New Delhi. 4th edition, Reprinted in 2009.

Bergstrom, L. F. (1990). Use of lysimeter to estimate leaching of pesticides in agricultural soils, Environmental pollution 67, pp 325 – 347.

Black, T. A.; Thurtell, G. W; and Tanner, C. B. (1968). Hydraulic load–cell lysimeter, construction, calibration, and tests. Soil Sci. Soc. Am. Proc. 32:623-629.

Blaney, H. F,; Ewing, P. A.; Morin, K. V,; and Criddle, W. D.; (1942). Consumptive water use and requirement. Report of the participating agencies. Pecos River joint investigation. National resources planning.

Boast, C. W. and Robertson, T. M. (1982). A micro–Lysimeter method for determining evapotranspiration from bare soil: description and laboratory evaluation. Soil science society of America Journal 46:689-696.

Boll, J,; Steenhuis, T. S,; and Selker, J. S. (1992). Fiberglass wicks for sampling of water and solute in the Vadose zone. Soil Science Society of American Journal 56. pp 701 – 707.

Bowman, B. T.; Brunke, R. R.; Reynolds, W. D.; and Wall, G. J. (1994). Rainfall simulator – grid lysimeter system for solute transport studies using large intact soil blocks. J. Environ. Qual. 23:815–822.

Brenner, D. M.; Baltenspenger, D. D.; Kulakow, P. A.; Lehnman, J. W.; Myers, R. L.; Slabert, M. M.; Sleugh, B. B. (2000). Genetic resources and breeding of Amaranthus. Plant Breed Rev., 19:227–285.

Breus, I. M. (1997). Productivity, Chemical composition and fertilizing of Amaranth growing for green matter yield. Agricultural chemistry 10:52–74 (Russian).

Brown, K. W.; Thomas, J. C.; and Aurelius M. W. (1985). Collecting and testing barrel sized undisturbed soil monoliths. Soil Sci. Soc. Am. J. 49:1067-1069.

Brunini, O. and Thurtell, G. W. (1982). An improved thermocouple hygrometer for in situ measurement of soil water potential. Soil Science Society of American Journal. 46. pp 900–904.

Burman, R. D.; Nixon, P. R.; Wright J. L; and Pruitt, W. O. (1980). Water requirements in Design and Operation systems. Ed. M. E. Jensen. St. Joseph Michigan: ASAE.

Camp, C. R.; Sadler, E. J.; and Yoder, R. E.; (1996). Evapotraspiration and irrigation scheduling, proceedings of the international conference. San Antonio, Texas USA.

Chernov, I. A.; (1992). Amaranth-physiological-biochemical background for introduction. Kazanji. KTU, 87P (Russian).

Clark, G. A.; and Reddell, D. L.; (1990). Construction details and microclimate modifications of a permanent rain sheltered lysimeter system. Transactions of ASAE 33 (6): 1813–1822.

Corwin, D. L. and LemMrt R. D. (1994). Construction and evaluation of an inexpensive weighing lysimeter for studying contaminant transport. J. Contam. Hydrol. 15:107 – 123

Cronan, C. S. (1978). A soil column tension lysimeter that minimizes experimental edges effects. Soil Sci. 125, PP. 306–309.

Daniel, K. Fisher (2004). Simple and Inexpensive Lysimeter for Monitoring Reference – and Crop – ET, ASDA Agricultural Science. Application and Production Technology Research Unit. 141 Experiment Station Road Stoneville, Mississippi 38776 USA.

Deardoff, J. W. (1978). Efficient prediction of ground surface temperature and moisture with inclusion of a layer of

vegetation. Journal of Geophysical Research. 83 pp 1889–1904.

Dirksen. C. (1999). Soil physics measurements. Catena Verlag. Reiskirchem. Germany 154 pp.

Doorrenbos, J.; Kassam, A. H. (1979). Yield response to water: FAO Irrigation and Drainage paper 33. Food and Agriculture Organization of United Nations. Rome, Italy.

Doorenbos, J.; and Prutt, W. O. (1977). Crop water requirement. Irrigation and Drainage Paper 24. Food and Agricultural Organization of United Nations, Rome Italy.

Dugas. W. A. and Upchurch, D. R. (1984). Microclimate of a rainfall shelter. Agronomy Journal, 76(6): 867 – 871.

Epenhuijsen, C.N.V. (1974). Growing vegetable in Nigeria. FAO Rome, Italy.

Evett, S. R.; Warrick, A. W.; Mathias, A. D (1995). Wall materials and capping effects on micro–lysimeters temperature and evapotranspiration. Soil Sci. Soc. Am. J 59:329–336.

Francaviglia, R.; Capri E,; and Trevisan, M.; (2000). Experimental guidelines for lysimeters studies in the Mediterranean area.

Frost, K. R. (1962). A weighing evatranspirometer, Agr. Eng., 43, 160 – 162.

Gangopadhyaya, M.; Harbeck, G. E.; Nodenson, T. J,; Omar M. H.; and Uryvae (1996). Measurement and estimation of evaporation and evapotranspiration. World

Meteorological Organization Tech. Note No 83. WMO No 20 ITP. 105, World Meteorological organization.

Garcia, M; Raes D.; Allen, R. G;. and Herbus, C;. (2004). Dynamics of reference evapotranspiration in the Bolivian high lands (Altiplano). Agric. For Meteorol 125: 67–82.

Gazula, A.; Simonne, E.; Duke, D.; Hockmuth, J.; Hockmuth R.; and Studstill, W.; (2006). Optimization of Drainage Lysimeter design for field determination of nutrients loads Proc. Flo. State Hort. Soc. 1919:231–233.

G. J. H. Grubben; and O. A. Denton (2004). Plant Resources of Tropical Africa 2 Vegetables. PROTA Foundation/Blackhuys. Publishers/CTA Wagneingen, Netherland.

Grattan, S. R;. Bowers, W.; Drong, A.; Snyder, R. L.; Carol, J. J.; and George, W. (1998) Crop Coefficient. The key to improving crop yield. Irrigation Journal, July/ august, (1998).

Grebet, R. and Cuenca, R. H (1991). History of Lysimeter design and effects of environmental disturbances pp 10-18 in lysimeters for evapotranspiration and environmental measurements,Proceedings of International symposium on lysimetry. July, 23-25 1991, Honolulu Hawaii.

Hanry, F. B; Paul, A. E; Karl, V. M; and Wayne, D. C. (1942). Consumptive Water Use and Requirements; Report of the Participating Agencies. Pecos, River Joint Investigation, National Resources Planning Board.

Hargreaves, G. H.; and Samani, Z. A.; Reference crop evapotranspiration from temperature. Transaction of ASAE 1 (2); 96–99.

Harrold, L. L. (1996). Measuring evapotranspiration by lysimetry. In: Evapotranspiration and its role in water resources management. Proc. ASAE, St. Joseph, Michigan, P. 28-33.

Harrold, L. L. and Dreibelbies, F. R. (1967). Evaluation of Agricultural Hydrology by Monolith Lysimeters tech. Bull No; 1367 US: Dept. of Agric. Washington D. C. pp.123.

Howell T. A.; McComick, R.L.; Phene, C.J. (1985). Design and installation of large weighing lysimeters. Trans. ASAE 28:106-112, 117.

Howell T. A.; Schneider A.D.; Jensen, M. E (1991). History of lysimeter design and use for evapotranspiration measurements. In proceedings of the conference on lysimeter for evapotranspiration and environmental measurements. IR Div/ ASCE/Honolulu 23-25 July, pp.1-9.

Howell T. A. Schneider, A.D.; Dusek, D. A.; Marek, T. H.; and Steiner, J. C. (1995). Calibration and scale performance of Bushland weighing lysimeters. Trans. ASAE 38 (4): 1019-1024.

Hylckama, V. (1980). Weather and evapotranspiration studies in a Salteeder Thicket Arizona. US. Geological Survey Professional Paper 491 – E p 30.

Kang, S; Gu, B.; Du, T.; and Zhang, J. (2003). Crop coefficient and ratio of transpiration to evapotranspiration of winter

wheat and maize in a semi humid region. Agricultural Water Management 59 (1): 239-254.

Kaspyap. P.S.; and Panda, R. K. (2001). Evaluation of Evapotranspiration methods and development of crop coefficients for potato crop in a sub-humid region. Agricultural Water Management 50: 9-25.

Kauffman, C. S.; and Weber, L. E. (1990). Grain Amaranth. Advances in new crops. Timmber Press, Portland. OR pp 127-139.

King, K. M.; Tanner, B.; and Suomi, V.E (1956). A floating lysimeter and its evaporation recorder, Trans. Geophys. Union, 37, 738-743.

Kirkham. R.R.; Gee, G.W.; Jones, H. (1984). Weighing lysimeter for long term water balance investigations at remotes sites. Soil Sci. Soc. Am J48: 1203–1205.

Klocke, N.L.; Heerman D.F.; Duke H. R. (1985). Measurement of evaporation and transpiration with lysimeters. Transaction of ASAE pp. 183-192

Klocke, N. L.; Todd, R. W.; Herget, G. W.; Watts, D. G.; Parkhurst, A. M. (1993). Design, installation and performance of percolation lysimeters for water quality sampling. Trans. ASAE 36: 426-435.

Kohnke, H.; Dreibelbies, F. R.; Davidson, J. M. (1940). A survey and discussion of lysimeters and a bibliography on their construction and performance. Misc. Publ. No 372 US Dept. of Agric. Washington DC. Pp 68.

Kosa, P. (2003). The effect on temperature on actual evapotranspiration based on landsat 5 TM satellite imagery.(www.interchopen.com/download/paf/pafsid/14187)

Linsley, R. K.; Kohler, M. A.; and Paulhus, J. L. H. (1982). Hydrology for engineers. McGraw-Hill International Book Company. 3rd Edition.

Malone, R.W.; Bonta, J.V.; Stewardson, D.J.; Nelson, T. (2000). Error analysis and quality improvement of the coshcton weighing lysimeters. Trans ASAE 43: 271-280.

Marek, T.H.; Schneider, A.D.; Howell, T.A.; Ebeling, L. L. (1988). Design and construction of large weighing monolithic lysimeters. Trans. ASAE Vol. 31, No 2 pp. 477 - 484.

Marek, T. H.; Piccinni, G.; Schneider, A. D.; Howell, T. A.; Jett, M.; Dusek, D. A. (2006) Weighing lysimeters for the determination of crop water requirements and crop coefficients. Appl Eng. Agric 22: 851-856.

Marthaler, H. P.; Vogelsanger, W.; Richard, F.; and Wierenga, J. P. (1983). A pressure transducer for field tensiometers. Soil Science Society of America Journal. 47 pp 624-627.

McFarland, M. J.; Worthington, J. W.; Newman, J. S. (1983). Design, installation and operation of a twin weighing lysimeter for fruit trees. Trans, ASAE 26: 1717–1721.

Mclay, C.D.A.; Cameroon, K. C.; McLaren, R.G. (1992). Influence of soil structure on sulphate leaching from a silt loam. Australian Journal of Soil Research 30. 443 – 455.

Meissner R.; Rupp, H.; Seeger, G.; Oilesch G.; and Gee, G. W. (2010). A comparison of water flux measurement; passive wick samplers verus drainage lysimeter. European Journal of Soil Science Willey. Online library.

Meshkat, M.; Warner, R. C.; Walton L. R. (1999). Lysimeter design, construction and instrumentation for assessing evaporation from a large undisturbed soil monolith. Appl. Eng. Agric. 15: 303 -308.

Michael, A. M. (1985). Irrigation theory and practice. Vikas Publishing House PVT. Ltd. New Delhi, India.

Moyer, J. W.; Saporito, L. S.; Jank, R. R. (1996). Design, construction, and installation of an intact soil core lysimeter. Agron. J. 88: 253–256.

Nathan, E. D; Raymond, E. K; and Bruce, R. M. (2002). Construction and Performance of Large Soil Core Lysimeters. Department of Soil Science, North Dakota State University, Fargo, ND53 105-5638.

Nwaakwa, C. I. (1985). Consumptive Use of Plantain. Unpublished Thesis. Department of Agricultural Engineering, University of Nigeria.

Obioma, C. P. (2014). Comparative Analysis of Direct and Four Indirect Method for Determination of Evapotranspiration of Water Leak (Talium Triangulare) Unpublished Thesis, Agricultural Engineering Department, Federal University of Technology, Owerr.

Piccinni, G.; Marek, T.; Jett. M.; Schneider, A.; Dusek, D.; and Howell, T. (2002). Construction of three weighing lysimeters for the determination of crop coefficients for

improving water use efficiency and managing irrigation of row and vegetable crops in the winter garden. UREC - 02-019. Texas A & M Agricultural Research and Extension Centre at Uvalde.

Puritt, W. O.; and Angus D. E. (1960). Large weighing lysimeter for measuring evapotranspiration. Trans. of ASAE 3:13–15.

Schneider, A. A.; Ayars, E. E.; Phene, C. I. (1996). Combining monolithic and repacked soil tank for lysimeters from high water table sites. Appl. Eng. Agric 12:649 – 654.

Schneider, A. A.; Howell, T. A.; Moustafa, A. T. A.; Evett, S. R.; Abou – Zeid, W. (1998). A simplified weighing lysimeter for monolithic or reconstructed soils. Appli. Eng. Agric. 14:267–273.

Schwarb, G. O.; Fangmeier, D. D.; Elliot, E. T.; Fravert, R. K. (1981). Soil and water conservation engineering 4th edition published by John Walley and Sons Inc. New York.

Seyfriedd, M. S.; Hanson, C. I.; Murdock, M. D.; Vanvactor S. (2001). Long term lysimeter data base. Reynolds Creek experimental watershed. Idaho, United States Water resources Res 37:2853–2856.

Shirish, S. (1996). Changes in the photosynthetic rate, transpiration rate, stomatal conductivity and water use efficiency of vitis varieties grown under different temperature and light conditions. Science Bulletin of the Faculty of Agriculture, Kyushu University. Vol. 51 (1–2) pp 33–38.

Shulka, J.; Fouad, J.; Saurabl, S.; James K. (2007). Water use and crop coefficient for water meter in Southeast Florida Southwest Florida Research and Education Center, Immokalee. Final Report No. WRP-LY-009. Institute of Ford Agricultural Science (IFAS) University of Florida FL 34142.

Stallknecht, G. F.; and Schultz-Schaeffer, J. R. (1993). Amaranth rediscovered. New crops. Willey, New York. pp. 211-218.

Tacket, J. L.; Burnet, E.; and Fryrear, D. W. (1965). A rapid procedure for securing large, undisturbed soil cores. Soil Sci. Soc. AM Proc. 29:218–220.

Tood, R. W.; Evett, S. R.; Howell, T. A.; Kloche, H. I (2006). Soil temperature and water evaporation of small steel and plastic lysimeters replaced daily. Soil Sci. 165:890-895.

Tyagi, N. K.; Sharma, D. K.; and Luthra, S. K. (2000). Determination of Evapotranspiration and crop coefficient of rice and sunflower with lysimeter. Elsevier. Agricultural Water Management 45 (2000) 41-54.

Uguru, M. I. (1996). Crop Production tools, techniques and practice. Published by Fulladu Publishing Company. B Umeano Estate Nsukka, Nigeria.

Uma, Cordelia Chika (2004). Seasonal Quality Status of Groundwater and Its use as Irrigation Water in Imo State. Unpublished Thesis. Department of Agricultural Engineering, Federal University of Technology, Owerri.

US National Research Council Committee on opportunities in the hydrologic science (1991). Water Science technology Board. National Academy Press. Washington D. C.

Van der Ploeg and Beese (1977). Model calculation for the extraction of soil water by ceramic and plates. Soil Science Society of America Journal Vol. 14 pp. 466–470.

Weber, L. E. (1990). Amaranth grain production guide. Rodale Press Emmaus, P. A. 28p.

Weihermneler, L.; Siemens, J.; Deurer, M.; Knoblanch, S. Rupp, H.; Ceottein, A.; Puetz, T. (2007). In situ water extraction. A review, Journal of Environmental Quality 36. pp. 1735–1748.

Wellings, S. R.; Bell, J. P.; and Raynor, R. J. (1985). The use of Gypsum Resistance Blocks for measuring soil water potential in the field. Report No. 92, Institute for Hydrology, Wallingford. United Kingdom.

Xiao, H.; Messner, R.; Seeger, J.; Rupp, H.; and Borg, H. (2009). Testing the precission of a weighable gravitation lysimeter. Journal of Plant Nutrition and Soil Science. 172. 194–200.

Yang, J.; Li, B.; and Liu, S. (2000). A large weighing lysimeter for evapotranspiration and soil water and ground water exchange studies. Hydrological processes. 14: 1887-1897.

Young, M. H.; Wierenga, P. L.; and Mancino, C. F. (1997). Monitoring near-surface soil water storage in turf grass using time domain reflectometory and weighing lysimeter. Soil Sci. Soc Am J. 61: 1138 – 1146.

www.fao.org/docrep/x490e/x0490e ob.html.

Library.wrds.uwyo.edu/wrp/84-09/84-09.html.

Days	Irrigation	Rainfall (mm)	Total Application (mm)	Drainage (mm)	ETc (mm)
1	9.17	--	9.17	8.33	0.84
2	7.15	--	7.15	6.18	0.97
3	5.28	--	5.28	4.44	0.84
4	6.04	--	6.04	4.58	1.46
5	6.67	--	6.67	3.75	2.92
6	6.07	--	6.07	3.19	2.88
7	6.67	--	6.67	2.64	4.03
8	6.11	--	6.11	1.94	4.17
9	6.32	--	6.32	2.08	4.24
10	7.22	--	7.22	2.74	4.48
11	7.05	19.83	26.88	16.26	10.62
12	--	8.26	8.26	6.47	1.79
13	--	18.44	18.44	11.25	7.19
14	--	28.40	28.40	18.01	10.39
15	--	--	--	3.58	--
16	--	--	--	2.09	--
17	6.39	--	6.39	2.50	3.89
18	7.81	9.72	17.53	6.30	11.23
19	7.92	--	7.92	2.33	5.59
20	--	16.45	16.45	4.93	11.52
21	--	17.06	17.06	4.31	12.75
22	9.47	--	9.47	1.46	8.01
23	--	16.96	16.96	8.72	8.24
24	--	16.25	16.25	6.91	9.34

Appendix I

ETc COMPUTED FROM WATER BALANCE OF THE LYSIMETER

25	8.50	--	8.50	1.22	7.28
26	--	1.41	1.41	0.11	1.30
27	--	2.82	2.82	0.28	2.54
28	--	18.58	18.58	6.08	12.50
29	--	27.28	27.28	10.02	17.26
30	9.23	--	9.23	0.04	9.19
31	9.50	--	9.50	0.09	9.41
32	--	29.35	29.35	18.38	10.97
33	--	10.60	10.60	1.11	9.49
	132.57 7.37mm/day	241.41 16.09mm/day	373.98 12.06mm/day	172.23 5.20mm/day	207.33 6.69mm/day

Note:

Days above represent day after transplanting

Appendix II

Climatic data collected during the study period

Days	Temperature		Relative Humidity	Sunshine Hours	Radiation
	Maximum	Minimum			
1	36.0	25.3	76	6.3	6.5
2	36.5	25.9	75	5.1	6.3
3	34.3	25.7	75	4.6	6.3
4	36.2	23.7	71	6.0	4.9
5	36.5	24.6	72	3.2	5.5
6	33.4	24.5	77	5.6	6.5
7	35.2	24.6	69	7.4	1.0
8	36.0	26.0	68	3.6	7.1
9	35.0	25.0	75	6.6	6.8
10	35.8	23.0	71	5.7	3.7
11	35.0	25.5	74	6.0	4.9
12	35.3	21.2	81	6.4	4.5
13	34.2	24.3	76	5.2	5.4
14	30.3	21.7	83	7.0	0.6
15	33.0	25.4	82	5.4	4.7
16	33.0	25.2	75	8.6	3.7
17	34.2	25.0	69	6.2	7.9
18	34.2	25.0	83	4.8	5.4
19	33.9	24.2	84	2.1	5.6
20	33.0	24.0	80	3.4	3.0
21	33.4	21.2	87	5.0	3.9
22	31.7	24.5	78	5.2	35
23	32.7	25.2	87	6.2	3.5
24	33.3	22.5	96	0.0	5.1
25	32.5	24.9	79	4.4	6.1
26	32.8	25.1	84	4.4	3.9
27	31.8	22.0	80	7.1	6.2
28	34.0	21.6	88	8.7	8.2
29	33.0	21.8	95	9.2	6.0
30	33.7	25.2	85	9.8	5.1
31	34.0	25.4	75	7.6	3.8
32	34.5	22.2	68	7.1	2.7
33	31.8	21.6	90	4.1	5.0
	1120.2 33.95	793 24.03	2608 79.03	188.1 5.69	163.3 4.94

Appendix III

Cost of Materials for Lysimeter Construction

S/N	Item	Specification	Quantity	Unit Cost ₦	Amount ₦
1	Metal sheet	Mild steel 2mm	4	1500	60000
2	U-bend joint	Metallic joint	2	600	1200
3	Galvanized pipe	Circular metal pipe (2m)	1	15000	1500
4	Sand		1	9000	9000
5	Electrodes	Packets	3	1000	3000
6	Anti-Rust	Tins	2	1000	2000
7	Paint	Tin (oil paint)	1	1500	1500
8	Wire mesh	Stainless w/m	1	200	200
9	Cement	Bags (50kg)	3	2200	6600
10	Container	Plastic	2	300	600
11	Sealant		1	300	300
12	Tap		1	1000	1000
13	Hose	2cm diameter hose	1	700	700
14	Clip		3	150	450
15	Aluminum sheet		1	300	300
16	Gravel			3000	3000
Total					**₦91,350**

Appendix IV

Cost of Labour and Transportation as at February 2012

S/N	Item	Specification	Amount ₦
1	Transport	Transporting of materials to the workshop	1800
2	Transport	Transporting the constructed lysimeter from the workshop to the site	2500
3	Transport	Transporting cement	150
4	Block moulding	3 bags	1500
5	Excavation	3x2x2 (Lysimeter)	8000
6	Excavation	2x2x2 (receiving vessel)	6000
7	Installation	Lysimeter installation	2500
8	Refilling	Refilling the lysimeter	5000
9	Plumbing	Plumbing work for irrigation	4500
10	Water	Water supply for block moulding, mansonry and irrigation	10,500
11	Mason	Labour	3000
12	Sundry expenses		1750
Total			**₦47,200**

The total cost of construction and installation of the lysimeter is 91,350 + 47,200 = **₦138,550.**