# EVALUATION OF PITCHER IRRIGATION TECHNOLOGY FOR THE PRODUCTION OF LETTUCE (*Lactuca sativa*) CROP IN SAMARU, NIGERIA


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## DECLARATION

I hereby declared that, this dissertation has been written by me and that it is a record of my own research work. It has not been presented in any previous application for a higher degree. All quotations are distinguished by quotation marks and the sources of information are specifically acknowledged by means of references.

Signature:____________________________ Date:__________________________

MUSA YAKUBU

## CERTIFICATION

This dissertation titled “Evaluation of Pitcher Irrigation Technology for Production of Lettuce (*Lactuca sativa*) Crop in Samaru, Nigeria” by Yakubu Musa meets the regulations governing the award of the degree of Masters Degree (Agricultural Engineering) of Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation.

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## DEDICATION

I dedicate this project work to my late father, Sgt. Musa K. Diwa (Rtd), who despite his low level of education, ensures that we get the best education affordable within his means. May his gentle soul continue to rest with the Lord, Amen.

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**ABSTRACT**

Pitchers, in their simplest form, consist of unglazed baked earthen pots, which are buried to their neck in the soil and filled with water, directly feeding the roots of the plants with a steady supply of moisture. Pitcher irrigation system is one of the most efficient traditional irrigation systems. Water seeps out of a buried pitcher due to the pressure head gradient across the walls of the pitchers directly into the root zone of the irrigated crop. The pressure gradient results from positive pressure head inside the pitcher and negative pressure head on the outer surface of the pitcher which is in contact with the soil. The experiment was conducted to determine ways of reducing the volume of water use in crop production in the study area. Two sets of pitchers, one set 10mm thick (six in number, replicated three times) and the other set 15mm thick (six in number, replicated three times) were constructed, with each pitcher having a varying proportions of sand or sand and sawdust incorporated into the clay during construction, to enhance the release of moisture into the surrounding soil, and each pitcher also serves as a treatment in the experiment. All the pitchers have a depth of 24cm and an internal diameter of 28cm. The capacity of the pitchers is approximately 12 litres (12,000cm$^3$). Results from the experiment show that, the amount of water released by the 1.0cm thick pitchers (6.75a) is significantly higher than the amount of water released by the 1.5cm thick pitchers (5.81b). Pitcher composition also played a significant role in the release of moisture to the crops, where pitchers with 70% clay, 25% sand and 5% sawdust (T11/T12) releases significantly higher volume of water (7.68$^b$) than all the other pitcher compositions. Significantly higher yield was produced by treatments T11/T12 (134.32$^a$) over the other treatments. While, significantly lower crop yield was recorded in treatments T1/T2 (88.48$^b$). The average total volume of water used to produce lettuce crop in the experiment is 1,739.4m$^3$/ha and the average yield recorded was 13,843kg/ha. The volume of water use to produce lettuce crop in the experiment is much less than the volume of water use in producing the same crop using both micro sprinkler (2,227m$^3$/ha) and drip (1,782m$^3$/ha) irrigation systems. The average yield recorded in the experiment is less than that obtained in both micro sprinkler (21,700kg/ha) and drip (18,150kg/ha) irrigation systems. This is as a result of the challenges faced during the conduct of the experiment. Extension and agricultural research institutions should work closely with the farming community in order to identify develop and smoothly promote a range of locally appropriate technological options, such as the clay pitcher irrigation system.

# TABLE OF CONTENTS

**CHAPTER TWO**

**LITERATURE REVIEW**

**CHAPTER THREE**

**MATERIALS AND METHODS**

## CHAPTER FOUR

## RESULTS AND DISCUSSION



## CHAPTER FIVE

## SUMMARY, CONCLUSION AND RECOMMENDATIONS

| Table | List of Tables | Page |
|---|---|---|
| 3.1 | Metrological Data of IAR Research Field | 24 |
| 3.2 | Physical Properties of Soil of the Experimental Site | 25 |
| 3.3 | Chemical Properties of Soil of the Experimental Site | 26 |
| 4.1 | Compositions and Dimensions of the Fabricated Pitchers | 41 |
| 4.2 | Atterberg Limits | 42 |
| 4.3 | Hydraulic Conductivity of 10mm Pitchers | 44 |
| 4.4 | Hydraulic Conductivity of 15mm Pitchers | 44 |
| 4.5 | Experimental Results of 10mm Pitchers | 45 |
| 4.6 | Experimental Results of 15mm Pitchers | 46 |
| 4.7 | Effect of Pitcher thicknesses and Compositions on Seepage Crop Height, Crop Yield and Hydraulic conductivity | 50 |
| 4.8a | Effect of Sawdust on the 10mm Pitchers | 53 |
| 4.8b | Paired Sample Test on the Effect of Sawdust, 10mm Pitchers | 53 |
| 4.9a | Effect of Sawdust on the 15mm Pitchers | 54 |
| 4.9b | Paired Sample Test on the Effect of Sawdust, 15mm Pitchers | 54 |
| 4.10 | Yields of the Control and the Treatments | 55 |

| Plate | List of Plates | Page |
|---|---|---|

# CHAPTER ONE

# INTRODUCTION

## 1.1 Background to the Study

The continuous increase in world population has resulted in greater demand for food and fiber. Meeting the growing demand requires optimizing agricultural production per unit volume of water application (Ashrad *et al*, 2016), particularly in arid and semiarid regions of the world. Although modern irrigation methods such as micro sprinkler and subsurface drip irrigation systems may save up to about half of the water presently used for surface irrigation, technical, economic, and socio-cultural factors hinder the adoption of these technologies especially in the rural areas. Thus, developing traditional low-cost, water-saving technologies for sustainable crop production, particularly in semiarid and arid areas, remains a major challenge in science and engineering.

Pitcher irrigation is an ancient technique that has been practiced in many parts of the arid world including Iran, India, African and South American countries (Hegazi, 2018). The technique is simple, cheap and has large water-saving potential. Pitcher irrigation systems use clay pots, which are designed and constructed to produce walls of the desired porosity. The porosity of the pitcher wall depends on the manufacturing materials, usually a mixture of clay and sand at various ratios. Pitchers are buried up to their neck in the soil and filled with water at various time intervals to keep soil water at a level favorable to plant growth (Siyal *et al* 2013,). Water gradually seeps out into the root zone in the soil due to the pressure head gradient across the wall of the pitcher resulting from the positive pressure head inside the pitcher and the conditions on the outside. Daka (2011) found that using clay pots could save up to 70% of water when compared to basin or sprinkler irrigation.

Hegazi (2018) indicated that seepage rate of pitchers buried in the soil is affected by evapotranspiration rate, hydraulic conductivity at saturation of pitcher wall material and pitcher surface area. He discovered that in some cases a great increase in pitcher's seepage has been observed due to increased evapotranspiration demand. Balkrishna (2014) showed that the seepage rate of 14 pitchers produced in Jordan is affected by their conductance, defined as the product of the hydraulic conductivity at saturation multiply by surface area and divided by the wall thickness.

Despite its apparent advantages, the reasons and factors influencing the performance of pitcher irrigation have not been satisfactorily described and proven. For the practical application of the system and its efficient use there is need for basic information on the design criteria for pitcher irrigation.

Pitcher irrigation technology will contribute largely to the agricultural development in areas of water scarcity and where irrigation water is saline. Under these conditions, when no crop can be grown by existing methods (sprinkler or basin), this provides an alternative to grow crops, as it requires much less water. This method also holds promise because of its non-technical nature such that it can be easily popularized among the farmers. In spite of numerous developments made in irrigation development, the scarcity of water and problem of saline irrigation water are still a reality in many areas of Nigeria. Pitcher irrigation could be used to overcome this problem of water scarcity, because it could be used for small-scale irrigation in places where water is either scarce or expensive, and where crops are grown on uneven terrain that is difficult to level. It is also useful in places where the water is salty and not good for traditional kinds of irrigation, such as flood irrigation, (Ashrad, 2016).

## 1.2 Statement of the Research Problem

The irrigated agricultural sector of Samaru in the Northern Guinea Savannah of Nigeria is facing increasing challenges in the face of a rapidly growing population, decreasing availability of irrigable land and immense competition for scarce water resources. Improved agricultural water control is the key to meeting the growing food need of the people in the study area in particular and the country at large (Adakole, 2012).

Development in drip and micro-sprinkler irrigation technology in agricultural crop production has accelerated the world over in recent years, to meet food security requirement under conditions of increasing population. However, the initial and maintenance costs of these modern irrigation systems and the requirement for highly qualified people for management may hinder the use of these high technology systems in the study area, because of poverty and low level of education of most irrigation farmers in the study area. There is therefore the need to adopt a traditional method of irrigation that is low-cost, simple, locally-made and farmer friendly that could have similar efficiency to that of the drip and micro-sprinkler systems and this could only be found in pitcher irrigation technology.

Locally available selected clay soils are often use to make clay pitchers in the study area, but these type of pitchers could not be used for irrigation because of low porosity of the pitchers and lack of awareness about the technology on the part of the populace, hence the need to construct pitchers with increased saturated hydraulic conductivity and seepage rates, by incorporating materials such as sand, cow-dung and/or saw-dust into the clay. Thinner pitchers are very fragile and difficult to handle while; thicker pitchers tend to reduce the permeability of the pitchers hence, the need to construct pitchers with optimum wall thickness.

Altaf, *et al* (2009), in their work "Performance of Pitcher Irrigation System", construct three sets of pitchers. The first set having a volume of 20 litres, tagged as large. The second set having a volume of 15 litres, tagged as medium, and the last set with a volume of 11 litres, tagged as small. All the three sets of pitchers have a wall thickness of 1.0cm. The researchers, at the end of their experiment, discovered that, hydraulic conductivity of the pitchers decrease with increase in size. The problem with the larger pitchers is occupying more space thereby decreasing the cropping area even though they have lower hydraulic conductivity.

Hegazi (2018), in their work, “Hydraulic Characteristics of Pitchers Produced in Jordan”, constructed pitchers of various wall thicknesses, ranging between 0.7cm and 0.8cm. At the end of the experiment, it was discovered that, the hydraulic conductivity of the pitchers increases with increase in wall thickness of the pitchers. The problem with the thinner pitchers is that, though they have lower hydraulic conductivity, they are very fragile and have to be handled with extreme care.

Zenebe (2015), observed that, as with any other system, pitcher irrigation is not as well a perfect solution that can be applied without any limitations. Consequently, some of the precautionary measures that need to be given due attention includes:

- At times, the dependency of some plants on the pitcher as their only water source have prevent them from developing the actual deep-rooting systems to as much a level as their potentials. Under such circumstances, wicks of appropriate size may be used to improve the situation.
- During installation or removal of the pitchers, they need to be handled with care to avoid breakage
- The buried clay pots may clog up over time, especially if left dry for a long time. If this happens, they need to be removed from the soil and scrubbed, or soaked to clean out the pores
- The clay mixture, firing time and temperature and choice of clay need to be right and ascertained way ahead to be sure that the pitcher pot will be good enough for the purpose.

- If silty or muddy water is used, it may block the tiny holes in the clay pot and stop it from working efficiently. Hence the water should be clean enough, or else filtered using narrow meshed materials or cloths in advance of filling it into the pots.

### 1.3 Aims and Objectives

The general objective of this study is to evaluate the performance of pitcher irrigation technology for production of a vegetable crop in Samaru, Nigeria. The specific objectives are to:

i. Fabricate earthen pots of selected wall thicknesses and material compositions for irrigation of lettuce crop.
ii. Conduct laboratory and field study of the hydraulic properties of the fabricated earthen pots.
iii. Determine growth, yield and crop-water use indices of lettuce (*Lactuca sativa*) crop under the pitcher irrigation technology.
iv. Compare the amount of water used in the production of lettuce between pitcher irrigation system with other irrigation systems.

### 1.4 Justification

Population increase in the study area has put more pressure on the land and available water resources, coupled with the effect of global warming which rapidly depletes the available water resources, such as dams, rivers and groundwater, which are often use for irrigation farming, (Alina, 2017). Water sources like the Kapagi stream, that use to flow throughout the year now flow for only three to four months after the rainy season, which brings about scarcity of irrigation water in the study area, and this situation brings about serious competition, which sometimes ends in conflicts ( Adakole and Abolude, 2012). Thus, the need to construct a simple, low-cost and locally made water-saving technique, in the form of pitcher irrigation, which has been used around the globe, to tackle similar situation as is obtainable in the study area. Unfortunately, in the study area, there is presently no much study into such irrigation technique.

Thus, this study is aimed at contributing to the solution of water scarcity problem in the area of irrigation in the Northern Guinea Savannah of Nigeria, through the introduction of a simple, locally made, water-saving irrigation technique, in the form of specialized pitchers constructed with adequate permeability to release enough moisture to satisfy the irrigation needs of crops planted around them.

### 1.5 Scope of the Study

The main focus of this project was the design and fabrication of a traditional water pitcher (clay pots) of different wall thickness from mixture of clay, fractional percentages of sand or sand and sawdust; evaluation of the hydraulic characteristics of the fabricated pots; use of the clay pots to irrigate lettuce crop during the dry season of 2018.

## CHAPTER TWO

## LITERATURE REVIEW

### 2.1 Introduction

Agriculture is the largest consumer of the earth freshwater, responsible for taking around 70% of all freshwater withdrawals. As water resources shrink and competition for water from other sectors grows, the agricultural sector faces a complex challenge: producing more food of better quality while using less water and ensuring environmental sustainability (FAO, 2012).

Conservation and use of water is very important, especially for farmers in developing countries like Nigeria where water is often a major limiting aspect of agricultural production and development. In order to take advantage of the potential year-round growing seasons of the tropics and the resulting increased production, a low-cost, water-saving and efficient irrigation system is very essential and pitcher irrigation system is among the affordable irrigation system that satisfies this requirement.

### 2.2 Irrigation

Irrigation is the controlled application of water to arable lands in order to supply crops with the water requirements not satisfied by natural precipitation. In arid climates, adequate food and fibres cannot be produced without irrigation. Because of the potential for low crop yields and risk of crop failure due to variations in rainfall, irrigation in semiarid regions is needed most of the time.

#### 2.2.1 Types of irrigation systems

i) **Aerial irrigation (sprinkle irrigation system)**

Aerial irrigation is an irrigation in which the water is applied in form of rainfall over the earth surface. Sprinkle irrigation systems are the main systems use in aerial irrigation. A sprinkle irrigation system uses pressure to form and distribute ‘rain-like’ droplets over the land surface. Water in sprinkle system is conveyed from source (by the help of a pump) under pressure through a network of pipes called mainlines and sub-mains to one or more pipes fitted with sprinklers called laterals. The sprinklers distribute the water over the land surface.

**ii) Surface irrigation**

Surface irrigation is the irrigation in which water is conveyed from a source and applied directly on to the surface of the earth, through diversion facilities. Water for surface irrigation is conveyed through lined or unlined open channels and pipelines. Surface irrigation system is the cheapest irrigation system, except in situations where extensive land smoothing is needed.

Methods of surface irrigation

The followings are the major methods of applying water in surface irrigation:

a. Flooding (water spreading) – this involves turning a stream of water onto a relatively flat field and allowing the water to spread naturally. This method is very inefficient.
b. Border irrigation – this involves construction of parallel ridges about 3 to 30m apart called borders which guide a sheet of flowing water across a field. The length of a border is normally 100 to 800m. Borders should be slightly graded to enhance the movement of water. Borders irrigation is less efficient than basin irrigation but more efficient than water spreading (flooding).
c. Basin irrigation – basin irrigation involves dividing the field into small units call basins, by dikes. Gated outlets, siphon tubes, spiles etc. conduct water from delivery channels or pipelines into each basin. Basin may be either level or graded. In level basins, water is introduced into the basin as rapidly as

possible. High application efficiency is achieved with basin irrigation because it minimizes runoff and unnecessary deep percolation.

d. Furrow irrigation – this involves construction of furrows across or along a slope. The end of the slope is blocked so that water accumulates in the furrow and seeps laterally into the root zone of the plants.

**iii) Sub-surface irrigation system**

Subsurface irrigation systems are systems designed to apply water directly into the root zone of the plants. This is effected through perforated pipes buried within the root zone, or through tricklers connected to a pipe, in which each trickler supply water to a particular crop.

### 2.2.2 Advantages of irrigation systems

Apart from supplying crop with irrigation water, irrigation systems have the following advantages:

a. Crop and soil cooling:- when the atmospheric temperature is high, the rate of evapotranspiration increases and the plants losses a lot of water during the process. Sprinkling water into the atmosphere cools the air, the crop and the soil, thereby reducing the rate of evapotranspiration. cooling the soil by sprinkling also protects burning off of young seedlings.
b. Prevention of wind erosion:- wet soils are more resistant to erosion, therefore wetting a bare soil surface helps in preventing wind erosion.
c. Chemical application:- applying chemical such as fertilizers, pesticides, herbicides, defoliants etc. with irrigation water saves the farmer excess labour and equipments.
d. Frost protection:- sprinkling water on crops during radiation frost protect the crop from freezing damage.

e. Delaying bud development:- cooling of buds resulting from the evaporation of sprinkler spray, slows down bud growth and delay blossoming.
f. Improved yield and crop quality:- improved yield and crop quality have been associated with trickle irrigation system because, the crop have not been stressed at any stage of their development.
g. Trickle irrigation system:- Trickle irrigation system eliminates run offs and reduces deep percolation and evaporation to the barest minimum, since only a portion of the potential root zone is irrigated.
h. Trickle irrigation increase application efficiency since, almost all the water supplied by the system is used by the crop.
i. Trickle irrigation system unlike sprinkle irrigation system, wets only the root portion of the crop, leaving the above-ground portion completely dry, thereby reducing the activities of bacteria, fungi and other pests and diseases that depend on a moist environment.
j. Irrigation system increase food sufficiency by making it possible for the farmer to cultivate crops all year round.

### 2.2.3 Disadvantages of irrigation systems

a) The use of pipes for conveying and application of water which restrict erosion and minimize evaporation is very expensive and could not be afforded by many farmers.
b) Surface irrigation which is affordable to most farmers is susceptible to erosion, especially when the canals are not lined.
c) A lot of water is lost during storage, conveyance and application in surface irrigation, through deep percolation, lateral seepage, evaporation and runoffs.
d) The emitters in trickle irrigation system are easily blocked by particles, and if they are not noticed on time, the crops are adversely affected.

e) The roots of plants irrigated through trickle irrigation system are concentrated in one place, that is, they do not withstand wind velocity.

f) Plants irrigated by trickle irrigation system do not resist water stress when there is system malfunction.

g) Spreading water into the atmosphere as in sprinkle irrigation system increase the rate of evaporation, which leads to excessive loss of water.

h) Weed growth within unlined canals could not be prevented completely. The seeds of such weeds are conveyed with irrigation water into the farm and this constitute excessive weed control problem.

**2.3 Pitcher Irrigation**

Most commonly, pitchers in their simplest form, consist of unglazed baked earthen pots, which are buried to their neck in the soil and filled with water, directly feeding the roots of the plants with a steady supply of moisture (Zenebe, 2015). They are essentially recognized as simple, low-cost or cost-effective solution of controlled irrigation for dry-land farming. The reasons for these properties are believed to lie in their high auto-regulative capabilities, which arise from the close interaction between the pitchers and their environments, namely the soil, climate and plants (Daka, 2011).

Pitchers are round earthen containers often used in rural areas for water storage, ranging from 10 to 20 litres in capacity. Functionally, they are similar to the drip systems, but very much less expensive to install. They are one of the most efficient traditional systems of irrigation known and are well suited for small farmers in many dry land areas of the world.

Pitchers are very efficient irrigation systems used to grow a wide range of annual and perennial plants in many arid and semiarid regions around the globe such as Pakistan, India, China, Iran, Mexico, Morocco, Algeria, Tunisia, Indonesia, and Brazil (Mondal, 1984; Setiawan et al., 1998; Siyal, 2013). The system is particularly known to be ideal for spreading plants such as gourd, pumpkin, and melon because few pitchers are needed per unit area. It is also very good for rooting cuttings, promoting deep root growth of saplings, for other vegetables such as tomatoes and okra, and landscape gardening such as growing plants in containers.

As reported by Rajshekar (2009), eucalyptus trees planted in communal woodlots in Burkino Faso are watered through buried clay pots; in Zambia experiments have shown that fruit tree seedlings watered through buried clay pots grow faster and healthier than tree seedlings watered from above; and in Pakistan and the deserts of the USA, clay pots have been found very effective in reforestation programs. Owing to such amiable qualities, the pitcher technology is generally recommended for dry-land areas with less than 500 mm rainfall per annum (Altaf, 2009).

### 2.3.1 Importance of pitcher irrigation

The rapid increase in world population has resulted in a greater demand for food and nutrition security. Meeting the growing demand primarily requires optimizing agricultural production per unit area of land as well as unit volume of water application. However, water for irrigation is a very scarce resource in most parts of the world, more particularly in the northern part of Nigeria where there are extreme temperatures, uncertain rainfall, fast-depleting water resources and high rate of evapotranspiration (Bainbridge, 2011).

In the alternative, under such circumstances, some dry-land countries have adopted certain water saving technologies like drip and micro-sprinkler systems to irrigate their crops so that their scarcely available water resources will not be depleted. Here again, although such irrigation methods are known to save about half of the water presently used for surface or furrow irrigation, their technical, economical (high investment and operational costs), and socio-cultural factors have remained a serious hindrance from adoption, especially by small-scale farmers (Murwira, 2014).

The use of such techniques such as surface, drip and micro-sprinkler has thus been limited to commercial farms and to those areas with relatively plain landscapes or topographies that are relatively located in closer proximity to water points. As such, the large majority of smallholder farmers in those areas are still by and large deprived of irrigated farming and so much exposed to food and nutrition insecurity. Understanding the situation, some dry-land countries have adopted certain locally appropriate water efficient technologies such as the clay pot pitcher irrigation system mainly to ensure crop production at household levels indiscriminately across all landscapes and topographic regimes in other to address household food and nutrition security.

### 2.3.2 Benefits of pitcher irrigation system

Written about in Chinese texts 2000 years ago, utilized by the Romans, and now employed across Latin America, Africa, and Asia, clay pitcher irrigation is a low-technology solution that is helping thousands of communities in arid regions of the world cultivates farmland during dry seasons of the year (Balkrishna, *et al*., 2014). These buried, pitchers allow water to seep through the clay's micro-pores and into the surrounding soil at a rate that is limited by the soil and the plant's water uptake. This subsurface irrigation eliminates water losses to surface evaporation and percolation through the soil, improving water savings by up to 70% over conventional surface irrigation methods. Furthermore, productivity is often increased since the plant's energies are diverted from developing root mass needed for acquiring water, to increasing overall plant yield. Further benefits include decreased soil crusting and erosion, reduction in weeds, and improved efficiency in chemical fertilizers and insecticides applied through the pot. Clay pitcher irrigation is also beneficial in regions where soil salinity is a problem, (Sandeep *et al*, 2017).

### 2.3.3 Auto-regulative capacity of clay pots

Studies have shown that pitchers used for pitcher irrigation are capable of adjusting their seepage rates according to changes in evaporation or crop water demands. In some cases, an increase of seepage rates of up to 200% were observed. This is determinate by the following three main interaction components: the hydraulic conductivity of the pitcher material, the size of the surface area and the wall thickness of the pitcher, (Sandeep *et al*, 2017).

Study of the performance of the system with respect to seepage rates and "reaction capability" can be conducted using the interaction between the pitcher properties. This interaction allows a qualitative assessment of the interplay of the pitcher properties. Soil-pitcher interaction is also very important and should be taken into consideration.

Increase in root growth around pitchers minimises the interaction potentiality over time. Hence the seepage rates and "reaction capabilities" decrease with the length of the irrigated crop grown. Under practical irrigation conditions, both the seepage rate and "reaction capability" should be taken as being much lower than is potentially possible.

### 2.3.4 Problems of pitcher irrigation system

The manufacture and installation of the pitchers requires a lot of labour work. The use of clay pitchers can also be more labour intensive than traditional methods of watering crops, and may have difficulty in coping with providing adequate water for crops with high water requirements. Also, the porosity of pitchers decreases with time, and they have to be replaced at intervals. Pitchers lifespan are greatly reduced by the use of turbid water with a high silt and clay content. The silt accumulates in the pores, effectively sealing the pitchers' pores.

### 2.3.5 Previous studies on Picher Irrigation

Neelkanth and Beldev (2017) use an 11 litre pitcher for the production of vegetable crops and he discovers that, these types of pitchers (small pitchers) are adequate for most vegetables. The wetting pattern was like balloon and extended to a horizontal distance of 25 cm and a depth of 70 cm from ground level. These type of pitchers are ideal for shallow rooted vegetable crops (up to 30 cm depth) such as; celery, lettuce, onions, potatoes, radish and moderately deep rooted (30 – 60 cm depth) vegetable crops such as; broccoli, beans, cabbage, carrot, cauliflower, cucumber, muskmelon, pepper, tomatoes and zucchini.

The Benefit-Cost ratio from small sized pitcher irrigation was 136.82% higher than the Benefit-Cost ratio from large sized pitcher irrigation. The experimentation confirmed the fact that, this indigenous method can be successfully employed even for unfavourable land and water. The cost to be incurred for adopting this, is quite less in comparison to drip irrigation and thus, can be adopted by small and medium scale farmers.

Altaf et al (2009) construct pitchers of various sizes by mixing donkey dung or ricr husks with the clay. Three sizes of pitchers (having different volume) were produced. They were identified as large (20 litres), medium (15 litres) and small (11 litres). The thicknesses of the pitchers were 1 cm. Results shows that, the hydraulic conductivities of the pitchers is quite low ranging between 0.07 and 0.14 cm/day.

Sandeep (2017) discovers that, the number of pitchers needed per hectare varies with the type of crop. A creeping crop such as bitter gourd requires 2,000 – 2,500 pitchers per hectare. Upright crops or crops producing canopy around the pots require more pots, up to 4,000 – 5,000 pots per hectare. Pitchers use for this purpose should have good seepage ability (minimum 15% in 24 hours) in an open air. He also found that 6 – 12 litres pots are sufficient to grow most vegetable crops and pitcher irrigation is ideal for sandy to loamy soils with good porosity and for small scale farmers, and it is more profitable where:

i. Water is scarce or very expensive,

ii. Fields are difficult to level such as under uneven terrain and

iii. In remote areas where vegetables are expensive and hard to come by.

Zenebe (2015) reported that pitcher irrigation is more efficient than most other irrigation systems in terms of crop production per unit application of water. A corn yield of 2.5 – 6.0 kg/plant/$m^3$ of water was recorded in pitcher irrigation, compared to 1.4 kg with drip irrigation, 0.9 kg with sprinklers and 0.7 kg with basin irrigation system. He also suggested the use of 1/3 of compost or aged manure to be mixed with the soil that was removed from the hole and lined the hole before putting the pitcher in a heavy soil and the use of gypsum was advised in case of saline or alkaline soil.

Studies indicates that, most vegetable crops need pots of between 6 – 12 litres capacity while, bigger ones are for fruit trees, (Patil *et al*, 2013). Soluble fertilizers water filtered compost or manure can also be mixed with the water and applied through the pitchers, (Margaret and Kimberly, 2017).

Setiawan and Nurhidayat, (2011) construct a pitcher with a hole at the bottom. A wig is passed out through the hole and buried deep under the pitcher so that the crop root does not become localized around the pitcher. This system is mostly employed with fruit trees that need deeper root system. Alternatively, pitchers with three small holes on one side of the pitcher were constructed to be use for the production of fruit trees. Two pitchers were to be buried with the plant between them. This is also to avoid localization of the plant's root system.

Arunabha *et al,* (2020) reported the effect of pitcher irrigation on crops cultivation thus: subsurface irrigation using clay pipes was particularly effective in improving yields, crop quality and water use efficiency as well as being cheap, simple and easy to use. Comparing the field experiment conducted by Murata, (2019), it was found that yield of pitcher pot irrigated melon in India was 25 t ha-1 using only 2 cm water ha-1 whereas the yields of melon was 33 t ha-1using 26 cm of water with flood irrigation. Beinbridge et al., (2011) conducted a detailed study of cucumber production which showed that irrigation of 1.9 mm ha-1 with pitcher pots provided yields comparable to 7.3 mm ha-1 by hand irrigation.

Pachpute (2010) also concluded that the increase in total yield due to package of water management practices including pitcher irrigation method is 203 per cent and water use efficiency obtained is 12.06 kg m-3. Saha et al., (2005) conducted an experiment with pumpkin (C. moschata) involving three methods of irrigation (drip irrigation by direct pitcher, drip irrigation by pipe from pitcher and basin system of irrigation). The direct pitcher method recorded significantly higher values for vine length, number of nodes per vine, stem girth and significantly lower values for inter node length compared to the other two methods of irrigation at all stages of plant growth.

Effect of Pitcher Irrigation with Saline Water: The stable soil moisture maintained by pitcher pot irrigation enables crops to be grown in very basic or saline soil or with saline water under conditions in which conventional irrigation would fail (Daka, 2011).

### 2.4 Lettuce (*Lactuca sativa,* Family-*Compositae*)

Lettuce belongs to the Compositae (sunflower or daisy family). *Lactuca sativa*. It is an annual plant native to the Mediterranean area. Its cultivation may have started as early as 4500 BC, perhaps initially for the edible oil extracted from its seeds. Salad lettuce was popular with the Ancient Greeks and Romans. Cultivated lettuce was probably derived from the so called wild or prickley, lettuce *Lactuca sierriola*. The primitive forms of lettuce were loose and leafy. Firm heading forms became well developed in Europe by the 16th Century. Oak leaved and curled-leaf types of various colors were described in the 16th and 17th centuries in Europe. There are 5 types of lettuce:

(1) Crisp-head

(2) Butter-head

(3) Cos or Romaine

(4) Loose leaf or bunching and

(5) Stem lettuce (celtuce).

Lettuce color for commercial cultivars varies from a yellow-green to dark red and all colors in between (Maynard *et al*, 2019).

Lettuce is a cool-weather annual crop, which is not badly damaged by winter cold, and light frosts, although differences in tolerance to cold (or heat) may vary appreciably among cultivars. Heavy frosts will however, severely scorch the leaves, especially mature heads. It grows best under short-day conditions, but the greatest demand is for use in salads during the summer. The most favourable temperatures for optimum growth and development are daily means between 15°C and 18°C, with monthly means between 7°C and 24°C. Day temperatures ranging from about 17°C to 27°C, and night temperatures between 2°C and 12°C, are most suitable. Many cultivars will produce only small, inferior heads under hot summer conditions. Certain diseases are more prevalent in hot weather. High temperatures, especially with young plants, may also induce this annual crop to bolt, i.e. run to seed prematurely. Any growth stress, such as that caused by a lack of water, will intensify the problem of bolting. Temperature and soil moisture, together with cultivar, are probably the most important factors affecting the success of lettuce production (Cantliffe and Karchi, 2012).

The crop is fairly tolerant of soil type, and will do well on soils varying from light sand to heavy clay, provided the nutritional and water status is good. Best results are obtained on fertile loams, well supplied with organic matter. Soils which crust badly are less suitable, particularly when the crop is direct-seeded. The most favourable pH appears to be between 5.0 and 6.5. Whereas the deep, well-drained soils are suitable for most crops, including lettuce, the latter, with its shallow root system, can be grown quite successfully on relatively shallow soils, provided a favourable soil moisture regime can be maintained.

In many areas of the country, and particularly when grown on a large scale under good growing conditions, lettuce is often sown directly in the production field. The seeding rate is generally about 1.5 kg per hectare, but is sometimes as high as 3 kg. Sowing depth varies between 10 and 15 mm. The seedlings are later thinned out to the desired spacing - a time – consuming and labour-intensive operation. Such thinning are occasionally used for transplanting, where necessary, but these transplants tend to extend the harvesting season unduly. The practice of direct seeding should be considered only under cooler, more favourable climatic conditions, where frequent, light irrigations can be applied, and on relatively weed-free lands. As lettuce seed is small, the soil should not be subject to crusting. It should be worked to a fine tilth, without clods. It should also be as level as possible, to ensure a more even plant emergence. The seedlings may be transplanted, and may thus be raised in seedbeds, but seedbeds are seldom used in commercial practice. Roughly 500 g of seed is needed to raise sufficient plants for one hectare when using seedbeds, whereas about 300 g is generally adequate when seed-trays are used. Plants are normally ready for transplanting after about 5 weeks (Maynard *et al*, 2019).

Seedlings will emerge within 2 to 7 days at soil temperatures of between 10°C and 30°C, above which the seed is subject to a temperature-induced dormancy period, and plants will emerge poorly, or not at all. At temperatures approaching freezing-point, germination is greatly delayed.

### 2.4.1 Spacing and plant populations

Spacing and plant populations can have a marked effect on total yield and on head size. The total yield tends to increase with an increase in plant population. However, as the inter-plant competition increases with higher density plantings, head size becomes smaller. Head size is a very important quality factor, with the larger heads normally commanding the higher prices. Plant spacing vary from about 200 mm to 300 mm apart in rows drawn 300 mm to 400 mm apart, rarely up to 600 mm. Plant populations vary from about 60,000 to 100,000 plants per hectare (Maynard *et al*, 2019).

### 2.4.2 Fertilization

It is not possible to make accurate fertilizer recommendations without a soil analysis. However, the approximate absorption of nutrients by a very good crop of 40 tons per hectare are 110 kg nitrogen (N), 14 kg phosphorus (P) and 190 kg potassium (K). Care should be taken not to over-apply nitrogen, because it tends to make the crop more susceptible to various diseases or disorders. This shallow-rooted crop responds well to organic manuring.

As a general guide, fertilizer mixture such as 2:3:4 (30) at a rate of 500 to 1000 kg per hectare should be used, depending on soil fertility. Follow this with a side-dressing of 150 to 250 kg/ha at 4 weeks (Hochmuth and Smajstrla, 2017).

### 2.4.3 Water requirement of lettuce

Soil moisture is one of the most important factors that determine the success of lettuce production. The moisture requirements of the crop are generally high, and no more than 50% of the available water in the root-zone should be depleted before an irrigation, (FAO, 2012).

The greater proportion of the roots penetrates the soil to a depth of only 300 mm, which infers that the nutrient and water requirements of the crop should be confined to this relatively small volume of soil. Wetting the soil to a greater depth is wasteful of water and will also lead to higher losses of nutrients by leaching.

The amount of available soil moisture to a depth of 300 mm is relatively small, and varies from about 18 mm, on very sandy soils, to about 50 mm, on very heavy clay soils. This implies that more frequent, but lighter, irrigations are necessary for lettuce than for many other vegetable crops (Hochmuth and Smajstrla, 2017).

Tudor and Diana (2015), in their work, “Irrigation Regime and Water Consumption for Lettuce Cultivated in Protected Areas” using drip and micro sprinkler irrigation system, discovers that, water rates applied to lettuce in autumn are lower for both drip and micro sprinkler, than water rates applied in spring. They also discovered that, during vegetation period, lettuce water consumption oscillated in accordance with the development state of the crop, water rates and watering methods, recording low values at the beginning and the end of vegetation period and maximal values at the middle of the vegetation period.

### 2.4.4 Weed control

Weed control, particularly when the crop has been direct seeded, but also in the early stages of growth after transplanting, is very important for this short-statured crop. Due to the close spacing adopted, mechanical weed control is generally confined to the period before planting, and in the very early growth stages. Reliance needs to be placed on hand-hoeing or hand-pulling of weeds, especially between plants in the rows.

The only herbicide registered for use on lettuce is propyzamide, which is sold as Kerb or Kerb 50. Propyzamide has a long residual effect in the soil - up to 12 months and longer - and can harm susceptible follow-up crops. It is not used in any intensive vegetable enterprise (Tudor and Diana, 2015).

### 2.4.5 Harvesting

Head lettuce is harvested when the heads are fully grown and firm. The loose-leaf types are harvested when the leaves have attained the required size. Under warm growing conditions the crop may be ready for harvest within 11 to 13 weeks when direct seeded, or at 7 to 9 weeks from transplanting. Under cooler growing conditions, or with late-maturing cultivars, the growing season may be extended for a further 4 or 5 weeks. In harvesting, the plants are cut off just above the soil surface to retain most of the wrapper leaves around the head. Loose, discoloured, damaged or diseased leaves are removed, and the butt ends cut cleanly for packing. To avoid damage by excessive handling, they are often packed into the marketing crates or cartons directly on the land, but they may be transported to a packing shed for packing. They should in any event be moved into a cool, shady spot as soon as possible after picking.

It is advisable not to harvest directly after rain, or while the plants are still wet, because leaves that have absorbed much water are particularly crisp and brittle, and thus break easily. Wet foliage is also more likely to commence rotting in transit (Old farmer’s Almanac, 2017).

Lettuce is highly perishable and wilts easily under hot or windy conditions, thus detracting from its appearance. Harvesting early in the day before the product has built up field heat, and then keeping it as cool as possible, will contribute towards its keeping quality. Directly after harvest the product should be moved into a cool, airy, shady spot protected from strong winds.

In transporting the crop to market, travelling should preferably be done in the evening (lower temperatures) and the crop must be protected from the drying breezes caused by movement. Lettuce of good quality is firm, fresh, clean and crisp, and free of any signs of wilting, seeding or bitter taste. A mean yield of 20 tons to 25 tons per hectare can be expected under normal growing conditions (Ogbodo, 2010).

**2.5 Deductions from Literature Review**

Most of the experiments conducted on pitcher irrigation use same composition and same thickness pitchers, only pitcher sizes were altered. The experiments also use a single material incorporated into the clay fraction that is, either donkey dung or sand. The parameters considered in those experiments will not inform the farmer the right pitcher composition and thickness for a particular crop type.

This dissertation has taken into consideration the effect of wall thickness on the water seepage and hydraulic conductivity of the pitchers. It also took into consideration different material compositions use for the construction of the pitchers and came up with the best pitcher thickness and material composition for a particular crop, and it has open doors for further studies to determine the best pitcher compositions and thickness for other crops.

Pitcher irrigation is not widely accepted due to lack of adequate and specific information on the irrigation system. Some farmers could used pitcher irrigation successfully with a particular crop but, another farmer may use the same type of pitcher for a different crop and be disappointed, hence the need for specific information on the irrigation system.

# CHAPTER THREE

# MATERIALS AND METHODS

## 3.1 Study Location

The study was carried out in the experimental field of Institute for Agricultural Research (I.A.R.), Ahmadu Bello University, Zaria, and in laboratories, all located in Samaru, Zaria of Kaduna State, Nigeria. Zaria is located within the Northern Guinea Savannah ecological zone of Nigeria, and it is characterized by three distinct seasons; the hot dry season from March to May, the warm rainy season from June to September and the cold season from November to February.

The engineering characteristics (Hydraulic conductivity) of the pots were determined at the Irrigation Laboratory, Department of Agricultural and Bio-resources Engineering while, the Atterberg limits and texture of the clay use in ,making the pots were determined in the Soil Laboratory of the Department of Civil Engineering, both in the Faculty of Engineering, Ahmadu Bello University Zaria. Samaru is located on latitude $11^0$ 10'N and longitude $7^0$ 38'E, and 722m above sea level (getamap.net, 2018).

The field experiment was carried out at the experimental field of Institute for Agricultural Research (I.A.R.), Ahmadu Bello University, Zaria located at $11^0$ 08'N, $7^0$ 46'E and 686m above sea level (Geoview.info, 2016).

### 3.1.1 The weather records of the experimental field

The experimental field as presented in Table 3.1, were obtained from the daily weather records of the metrological unit of I.A.R. The mean maximum and minimum monthly temperatures, the mean monthly humidity (at 10:00 a.m. and 4:00 p.m.) and the mean monthly precipitation were calculated from the daily weather records thus, the mean maximum monthly temperatures range between 30.13$^0$C and 37.90$^0$C, while the mean minimum monthly temperature ranges between 14.74$^0$C and 23.32$^0$C during the period of the study. The humidity level in the study area ranges between 15.06% and 46.71% in the mornings (10:00am) and between 14.97% and 25.74% in the evening (4:00pm) Table 3.1. The rainfall pattern in the study area is bimodal with peaks in the months of July and August but the rainfall record was zero within the period of study.

**Table 3.1:Meteorological Data of IAR Research Field**

| | Mean Monthly Temperature ($^0$C) | | Relative Humidity (%) | | Rainfall (mm) |
|---|---|---|---|---|---|
| Month | Max. | Min. | 10:00am | 4:00pm | |
| January | 30.13 | 14.74 | 15.06 | 14.97 | 0.00 |
| February | 33.00 | 17.87 | 19.26 | 13.48 | 0.00 |
| March | 37.90 | 20.00 | 26.42 | 18.23 | 0.00 |
| April | 35.10 | 23.32 | 46.71 | 25.74 | 0.00 |
| Total | 136.13 | 75.94 | 107.45 | 72.42 | 0.00 |
| Maean | 34.03 | 18.98 | 26.86 | 18.10 | 0.00 |

IAR Research Field 2018

The average annual rainfall in the study area is 1150 mm, however, the research work was done during dry season with no direct effect of rainfall on the work. The mean maximum temperature (34.03$^o$C) and the mean minimum temperature (18.98$^o$C) were generally too high for optimum production of lettuce crop. The crop is of temperate origin and usually produced at high altitude with a cool temperature. Lettuce is reported to perform optimally at a temperature range of between 15 – $20^{0}$C (Ogbodo et al., 2010). The high temperature has, to a great extent, hinders the optimum performance of the lettuce crop. The mean relative humidity of the study area is low (18%). This low humidity coupled with the high temperature aggravated the poor performance of the crop.

### 3.1.2 Soil physical properties

The physical properties of the soil used for the lettuce production in the research field were determined at I.A.R. soil laboratory. Three soil samples were taken from nine locations at depths of 0 – 15cm, 15 – 30cm and 30 – 45cm. Subsequently, hydrometer method was used to determine the soil texture. The soil texture of the experimental site was recognized to be sandy clay-loam at 0 – 15cm, clay-loam at 15 – 30cm and clay at 30 – 45cm depths. Table 3.2 summarizes some physical properties of the soil at the experimental field.

**Table 3.2: Physical Properties of Soil at the Experimental Site**

| Depth (cm) | Bulk Density ($g/cm^3$) | Particle Size Analysis, Corrected to $20^{0}$C | | | Soil Texture (USDA) |
|---|---|---|---|---|---|
| | | (%) Clay | (%) Silt | (%) Sand | |
| 0-15 | 1.41 | 29.33 | 16.00 | 54.67 | scl |
| 15-30 | 1.59 | 39.33 | 34.00 | 26.67 | cl |
| 30-45 | 1.59 | 41.33 | 33.67 | 25.33 | c |

Scl=sandy clay-loam, cl=clay loam, c=clay IAR Research Field 2018

Dry bulk density was determined by the cone method. Total porosity was calculated from the dry bulk density as the fraction of total volume not occupied by soil assuming a particle density of 2.65mg $m^{-3}$. The major soil physical constraints observed include, high bulk density, low porosity and high soil temperature. The high bulk density (1.53 $g/cm^3$) particularly led to reduced pore space, aeration and water infiltration, appendix I. This situation was even more aggravated by the high soil temperature which created heat flux, leading to increased moisture evaporation from the soil. All these observed physical problems constitute great constraints to the performance of the crops in the study area.

### 3.1.3 Soil chemical properties

The chemical properties of the composite soil sample taken at various depths were analyzed at I.A.R. soil laboratory for N, P, K, Ca, Mg pH SOC and CEC. Total nitrogen was determined by the macro Kjeldahl method. Available phosphorus was determined using Bray II method as outlined in Page *et al.* and Organic Carbon by the Walkely and Black method. Soil pH in water (2:1) was determined by the glass electrode pH meter. The exchangeable bases were extracted using the ammonium acetate method. Potassium was determined with a flame photometer, and Calcium and Magnesium were measured by atomic absorption spectroscopy. The soil CEC was determined by the method of Tel and Rao are shown in Table 3.3.

**Table 3.3: Chemical Properties of Soil at the Experimental Site**

| Depth (cm) | Soil pH | Percentage (%) | | | Available, P (mg/kg) | Exchangeable Bases (Meq/100g) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | S.O.C. | S.O.M. | N | | K | Na | Ca | Mg |
| 0-15 | 5.63 | 0.54 | 0.94 | 0.068 | 2.95 | 0.29 | 0.85 | 2.20 | 0.67 |
| 15-30 | 5.88 | 0.37 | 0.63 | 0.054 | 1.60 | 0.19 | 0.52 | 2.67 | 0.80 |
| 30-45 | 6.00 | 0.36 | 0.62 | 0.054 | 1.20 | 0.14 | 0.66 | 3.53 | 1.06 |

IAR Soil Laboratory, 2018

The levels of the essential nutrients were below the standard required for optimum lettuce crop production (appendix II). The low level of organic matter in the research field affected the Cation Exchange Capacity (CEC), nutrient availability and retention in the soil.

### 3.2 Description of Experimental Treatments (Pots)

Two set of six types of pitchers were fabricated; one set has a thickness of 10 mm while, the other set has a thickness of 15 mm. The first pitchers in both sets has 85% clay and 15% sand, second pitchers has 80% clay and 20% sand, third pitchers has 75% clay and 25% sand, fourth has 80% clay, 15% sand and 5% sawdust, fifth has 75% clay, 20% sand and 5% sawdust and, sixth has 70% clay, 25% sand and 5% sawdust.

Each of the twelve pitchers is a treatment in the experiment. All the pots have the same internal diameter (28cm) and depth (24cm) with approximate volume of 12,000cm$^3$. Three set of pitchers were produced for each treatment, thus the experiment was replicated three times, Table 4.1.

#### 3.2.1 Design criteria

The pots' dimensions of 24 cm depth and 28 cm internal diameter were carefully chosen to provide enough moisture for production of lettuce. Lettuce needs 0.2 – 2.7mm from germination to head; 2.7 – 3.7mm from head to maturity (Tushar, 2016). These dimensions will produce pots with 12 litres capacity. This volume of water will provide 3mm depth of water in a 1m by 1m plot as used in the experiment, which is sufficient for lettuce crop production. This dimension will also not occupy too much space, but large enough to give a reasonable irrigation interval. Some of the pots were 1.0 cm thick while others were 1.5 cm thick, in order to determine the effect of the pots' thicknesses on the seepage rate of the pots. The most common thicknesses used for pitcher irrigation were 10mm and below.

Some percentage of sand or sand and sawdust were incorporated into the clay before constructing the pots to increase the porosity of the pots, so that they could comfortably sustains plant growth and development. The percentage of sand incorporated into the clay ranges between 15% and 25%. Additional 5% sawdust was incorporated in some cases to further increase the porosity of the pots as explained in section 3.5, Description of Experimental Treatments.

Unlike the ordinary pots, these pots were designed with curved base and straight circular sides, that is, the diameter of the pots is the same from the centre to the sides and the bottom of the pots as shown in plate 3.1. This pitcher shape, unlike the conventional pot gives a more or less uniform thickness. The curved portion just before the mouth opening of conventional pots is always much thicker than the other parts of the pot.

**Plate 3.1:** Pot samples

### 3.2.2 Material selection

The materials used in the construction of the pots were selected to conform to the design criteria. Fine sand and fine sawdust were used so that they could easily blend with the clay. The fineness of the materials has also decreased the incidence of leakage, especially after firing. Clean water was also used in order to minimize the effect of dirt in dirty water on the cohesiveness of the clay. The water being provided in the experimental field is clean and it was ensured that the pitchers were clean before commencing the experiment. The pitchers were always kept closed; they are only opened during refill. The refill is done using measuring cylinder placing the water directly into the pitcher as seen in Plate 3.7.

### 3.2.3 Fabrication of the pots

A skilled potter fabricated the pots using clay and sand or clay, sand and sawdust in varying proportions to represent the various treatments. Four moulds of the same dimensions were used to construct the pots. Therefore, after measuring out the clay and sand or the clay, sand and sawdust fractions (i.e. 85% clay, 15% sand and 0% sawdust for treatment one, 80% clay, 20% sand and 0% sawdust for treatment two, etc.) the various components were thoroughly mixed together by the potter and the mixtures were used to construct the pots, using the available moulds. After about fifteen to twenty minutes, the pots were removed from the moulds by two people and placed under a shade. The procedures were repeated for other pots. After moulding and arrangement of the pots in the shade, the potter goes into the shade and trims the edges of the pots where they held them as they remove them from the mould, and to also ensure the right dimensions of the pots in terms of depth and wall thickness. The pots were allowed to remain in the shade for about five days to dry, before firing. The firing of the pots was done in a kiln behind the shade. The pots were arranged in a heap in the kiln and covered with a special type of grass, and ash was sprinkled on the grass before setting the grass on fire, so that the fire will burn steadily and gradually to avoid breakage of the pots due to sudden expansion of the pitchers. The fire burns at a temperature between $497^0$C for about eight hours before it died down, and it took another eight hours for the pots to cools down sufficiently to be carried out of the kiln.

## 3.3 Laboratory Characterization of the Clay Pots

The soil textures of the clay and sand used in the construction of the pots were determined at the soil laboratory of the Institute for Agricultural Research (I.A.R.) while, the Atterberg limits (Liquid limit, Plastic limit, Linear shrinkage, Liquidity index and Plasticity index) tests were carried out at the Soil Laboratory of the Department of Civil Engineering. The dimensions (Internal diameter, Depth and Thickness of the pitchers) and the hydraulic properties (Hydraulic conductivity) of the pots were carried out at the Irrigation Laboratory of the Department of Agricultural and Bio-resources Engineering.

### 3.3.1 Particle size analysis

Particles size analysis of the clay and sand used in constructing the pitchers was carried out at the Soil Laboratory of the Institute for Agricultural Research (I.A.R.). this was obtained using hydrometer method.

### 3.3.2 Determination of atterberg limits of the clay

Laboratory tests to determine the Atterberg limits of the clay use in constructing the pots were conducted at the Soil Laboratory of the Department of Civil Engineering, Ahmadu Bello University, Zaria. The following limits were determined; the liquid limit, the plastic limit, linear shrinkage, liquidity index and plasticity index.

**a) Liquid limit**

The liquid limit (LL) is arbitrarily defined as the water content in percent at which a pat of soil in a standard cup and cut by a groove of standard dimensions, will flow together at the base of the groove for a distance of 13mm (0.5’) when subjected to 25 shocks from the cup being dropped 10mm in a standard liquid limit apparatus operated at a rate of two shocks per second, (plate 3.2).

**Equipment:** Liquid limit device, porcelain (evaporating) dish, flat grooving tool, eight moisture cans, weighing balance, glass plate, spatula, wash bottle filled with distilled water and a drying oven set at $105^0$C (Benjamin, 2019).

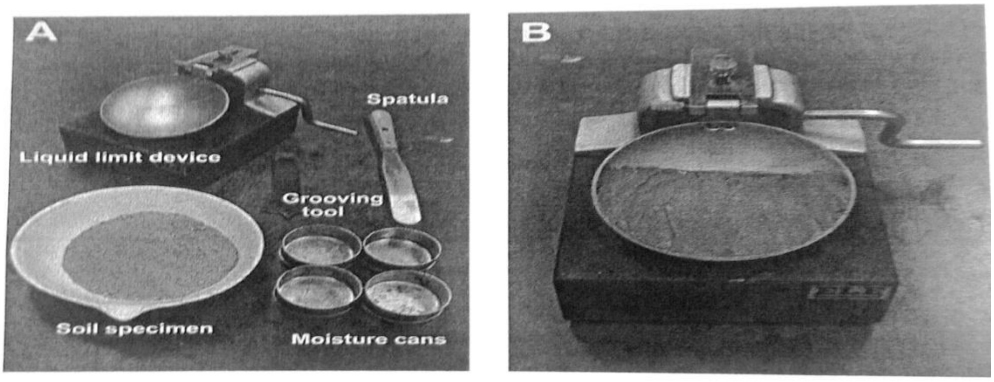



**Plate 3.2:** Liquid limit apparatus

**Procedure for determining Liquid limit**

i. About three quarter of the soil sample was placed into a porcelain dish and thoroughly mixed with small amount of distilled water ***kg/g, until it becomes a smooth uniform paste. The dish was covered with cellophane to prevent moisture from escaping.

ii. Four empty moisture cans with their lids were numbered and weighed, and the weights recorded in a table (Appendix II).

iii. The height of drop of the cup of the liquid limit apparatus was adjusted to 10mm, using the grooving tool whose handle is 10mm in width. The rotation of the crank was adjusted so that the cup drops approximately two times per second.

iv. A portion of the earlier mixed soil was placed into the cup of the liquid limit apparatus. The soil was squeezed to eliminate air pockets before spreading it inside the cup to a depth of 10mm at its deepest point (Plate 3.2).

v. The grooving tool was carefully used to cut a clean straight groove down the centre of the soil in the cup (Plate 3.3).

vi. The crank of the apparatus was turned at approximately two drops per second and the number of drops taken to make the two halves of the soil pat to come together at the bottom of the groove along a distance of 13mm was recorded as N.

vii. Soil sample was taken on both sides of the groove where the soil comes together. The sample was placed in a moisture can and covered. The moisture can was then weighed and recorded in a data sheet. The lid was removed and the can placed in an oven for at least 16 hours, after which the can was brought out, covered and weighed, and the weight recorded in the data sheet, (Appendix III).

viii. Steps iv to vii were repeated for three more samples, with increasing amount of distilled water, so as to have a decreasing number of drops to cover the groove.

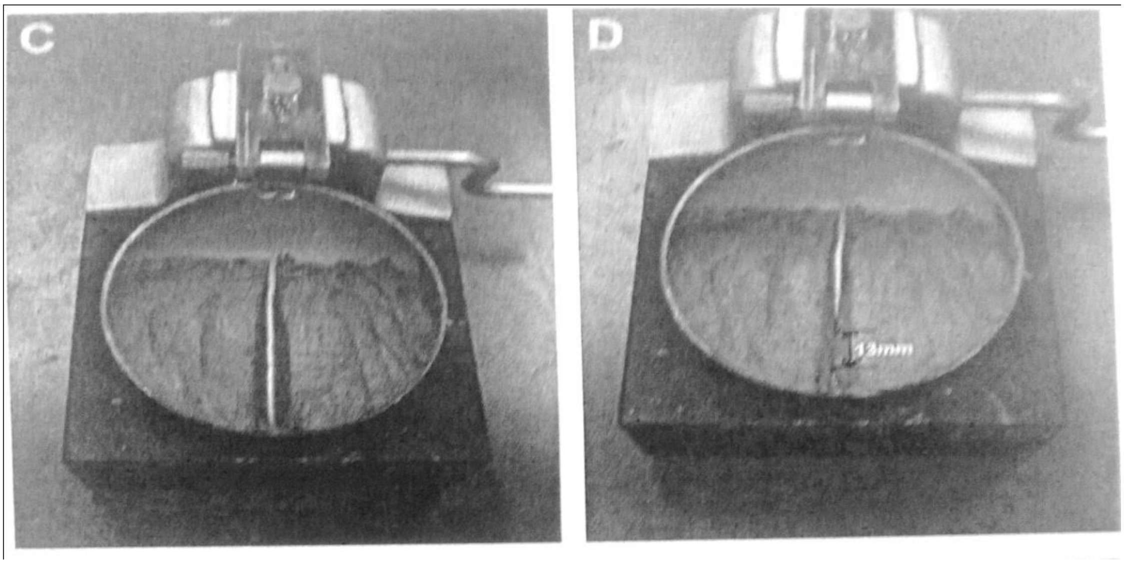



**Plate 3.3:** Grooving the soil sample

**b) Plastic limit**

The plastic limit (PL) is the water content in percent, at which a soil can no longer be deformed by rolling into 3.2mm (0.125') diameter threads without crunching (plate 3.4).

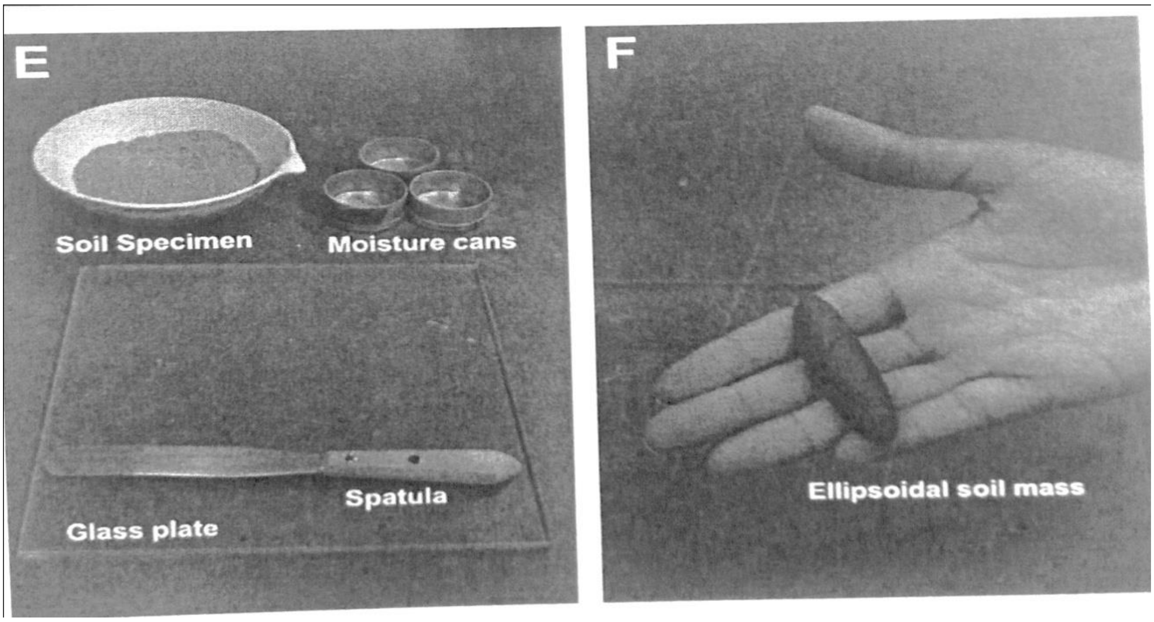



**Plate 3.4:** Plastic limit apparatus

**Procedure for determining Plastic limit**

i. Another set of cans were weighed and numbered, and recorded in a data sheet (Appendix IV).

ii. The remaining one quarter of the original sample was mixed with distilled water until the soil is at a consistency where it can be rolled without sticking to the hand.

iii. The rolled soil was kneaded and rolled again to a thread of 3.2mm diameter. This process was repeated several times until the soil could not be rolled to a thread of 3.2mm.

iv. Portions of the crumbled soil were gathered and placed into the moisture can and covered. The can was then weighed and recorded. The lid was removed and the can placed in an oven for 24 hours, after which the can is weighed and recorded again.

v. Steps three and four were repeated two more times. The water content from each trail was determined as presented in (appendix IV).

**c) Linear shrinkage**

Linear shrinkage (LS), was obtained using the following equation:

$$LS = \frac{\Delta L}{L} * 100\% \tag{3.1}$$

Where: LS=Linear shrinkage

ΔL=Change in length

L=Original length

**d) Liquidity index**

Liquidity index (LI) was obtained using the following equation:

$$LI = \frac{(w-PL)}{(LL-PL)} \tag{3.2}$$

Where: LI = Liquidity index

w = Water content

PL = Plastic limit

LL = Liquid limit

**e) Plasticity index (PI)**

Plasticity index (PI) = the difference between liquid limit and plastic limit

$$PI = LL - PL \tag{3.3}$$

Where: PI = Plasticity index

LL = Liquid limit

PL = Plastic limit

***Source of equations:*** *American Standard Test Method (ASTM) for Liquid limit, Plastic limit and Plasticity Index of Soils.*

### 3.3.3 Dimensions and Hydraulic Properties of the Pots

The dimensions and hydraulic properties of the pots were determined at the Irrigation Laboratory of the Department of Agricultural and Bio-resources Engineering, Ahmadu Bello University, Zaria.

A) **Dimensions:** the thicknesses of the pots were measured using a micrometer screw gauge, while the depth, the height, the internal diameter and the external diameters measured using a meter rule.

B) **Hydraulic Conductivity (Kh):** the Hydraulic Conductivities of the pots were determined using the Darcy's equation:

$$Q = Av$$

$$= AKi$$

$$= AK\Delta H/d$$

Also, $Q = V/t$

Thus, $AK\Delta H/d = V/t$

Therefore, $$K = \frac{\mathrm{V\ x\ d}}{\mathrm{t\ x\ A\ x\ \Delta H}} \qquad (3.4)$$

Where:

Q = rate of seepage ($cm^3/s$)

A = surface area of the pot ($cm^2$)

$v$ = velocity of flow (cm/s)

$d$ = thickness of the pot (cm),

$i$ = hydraulic gradient

$K$ = hydraulic conductivity,

$V$ = volume of water that seeps through the pot material in time $t$,

$t$ = time taken for water level to fall from $h_0 - h_1$

$\Delta H$ = change in water level from $h_o$ to $h_{1.}$

## 3.4 Field Experimentation

### 3.4.1 Field layout

Three blocks A, B and C each consisting of thirteen plots (twelve treatments and control) with each plot measuring 1 m by 1 m, were prepared. The plots were separated by a space of 0.5 m, while the blocks were separated by a space of 1 m. At the centre of each plot a pitcher of particular composition and specific thickness was buried, with the exception of the control plot, using Randomized Complete Block Design (RCBD) as shown in Plate 3.5.

**Plate 3.5:** Field layout

### 3.4.2 Planting and transplanting

Lettuce is a cool-season crop that grows well in rainy and dry seasons in most regions. Lettuce seedlings can even tolerate a light frost. Temperatures of between $15^{0}$CF and $20^{0}$C are considered ideal for the production of lettuce crop (Ogbodo, 2010 and Jansen, 1994). At high temperatures, growth is stunted, the leaves may be bitter and the seed stalk forms or elongates rapidly. There are five distinct varieties of lettuce: leaf (also called loose-leaf lettuce), Cos or romaine, crisp-head, butter-head and stem (also called asparagus lettuce).

The variety of lettuce use for this study was the butter-head, and these varieties are generally small, loose-head types that have tender, soft leaves with a delicate sweet flavour. The lettuce seeds were planted on a raised seedbed in Kurmin Bomo village, on 29th January, 2018, and transplanted first on the 17th February, 2018 and then on the 24th February, 2018, (Plate 3.6).

**Plate 3.6:** Transplanted crops

About twenty seedlings were planted in each plot in double lines around the pitchers. The crops were planted, 30cm apart along the plot (i.e. four seedlings in each row) and 20cm apart across the plots (i.e. five seedlings in each row), plate 3.6b.

### 3.4.3 Crop evapotranspiration (ETc)

Weather parameters, crop characteristics, soil characteristics, management and environmental aspects are the major factors affecting crop evapotranspiration (Siyal, 2013). Direct measurement procedures are laborious and time consuming, but currently CROPWAT model is widely used. CROPWAT model is a computer program for irrigation planning and management, developed based on the FAO Penman-Moneith (Siyal, 2013).. Its basic function includes the calculation of reference evapotranspiration, crop water requirement and crop and scheme requirement. Reference evapotranspiration can be calculated from the actual temperature, humidity, sunshine/radiation and wind speed data, according to FAO penman-Monteith method.

$$ET_c = K_c ET_o$$

Where, $ET_c$= Crop evapotranspiration

$ET_o$ = Reference ET

$K_c$ = Crop coefficient

$ET_o$ could either be potential or reference crop ET, potential ET is the maximum rate at which water if available can be removed from soil and plant which varies from day to day. Reference crop ETo is the potential ET for a specific crop (usually either grass or alfalfa) and set of surrounding conditions.

### 3.4.4 Fertilizer application and weeding

First fertilizer (NPK) application was done on 10th March, 2018, it was at the rate of 350 kg/ha, using broadcast application method. First weeding operation was done on 19th March, 2018. Second fertilizer (Urea) application was done on 11th April, 2018 at the rate of 100 kg/ha, inside the water in the pitchers. A second weeding operation was done on 13th April, 2018.

### 3.4.5 Taking readings

The treatments were imposed on 17th March, 2018, by filling the pitchers with water and covering them up. The irrigation interval was set at four days interval (because it is the minimum number of days taken for the first pitcher to almost dry-out), therefore the first readings (i.e. volume of water use, growth parameter of the crops, and moisture contents around the pitchers) were taken on 21st Mach 2018. The volume of water use was obtained as follows; the pitchers were filled to the brim with water and covered with an airtight lid made up of palm-leaf plate (pai-pai) and covered with viva polythene bag. After four days, the pitchers were filled to the brim again with a measured quantity of water using a measuring cylinder, and the amount of water use to refill the pitchers was recorded, being the same quantity of water that seeps out through the walls of the pitchers, into the soil surrounding the pitchers in each plot. This procedure was repeated after every four days until the crop was harvested (plate 3.7).

Crop height were measured, when the crops were well established, using a meter ruler, on every irrigation day. The heights of the crops at the highest point were measured and recorded in a special format.

**Plate 3.7:** Taking readings of seepage rate

### 3.4.6 Harvesting

The crops were harvested eighty six days after planting, on the 25th April, 2018. This is in line with the recommendation of FAO (2012) of between 75 and 140 days. The crops were harvested at this time because they started bolting, due to high temperature regime. The crops were harvested plot by plot using hoe. The crops in each plot were numbered 1 to 20. Each crop was harvested and weighed until the harvest was completed in all the three blocks.

### 3.5 Data Analysis

The data collected from the experiment were subjected to statistical analysis, using Analysis of Variance (ANOVA). The Software employed for the analysis was S.A.S.

The rates of seepage between pots of different compositions were evaluated and compared with the effect of pot composition. The relationship of the height of the crops and moisture distribution for each treatment were determined and inferences drawn from the results.

# CHAPTER FOUR

# RESULTS AND DISCUSSION

## 4.1 Fabrication of the Earthen Pots (Pitchers)

The pitchers compositions and dimensions are presented in Table 4.1. Treatment 1 and 2 have the same composition of clay and sand but different thickness as seen in Table 4.1, so also Treatment 3 and 4, Treatment 5 and 6 up to Treatment 11 and 12. Treatments 1 to Treatment 6 have only clay and sand composition, while Treatments 7 to Treatment 12 has clay, sand and sawdust.

**Table 4.1: Compositions and Dimensions of the Fabricated Pitchers**

| Name | Label | Treatments | Internal Diameter (cm) | Depth (cm) | Thickness (cm) | Clay (%) | sand (%) | saw-dust (%) |
|---|---|---|---|---|---|---|---|---|
| Control | Ctrl | - | - | - | - | - | - | - |
| Treatment 1 | T1 | $Th_{10}C_{85}S_{15}$ | 28 | 24 | 1.0 | 85 | 15 | 0 |
| Treatment 2 | T2 | $Th_{15}C_{85}S_{15}$ | 28 | 24 | 1.5 | 85 | 15 | 0 |
| Treatment 3 | T3 | $Th_{10}C_{80}S_{20}$ | 28 | 24 | 1.0 | 80 | 20 | 0 |
| Treatment 4 | T4 | $Th_{15}C_{80}S_{20}$ | 28 | 24 | 1.5 | 80 | 20 | 0 |
| Treatment 5 | T5 | $Th_{10}C_{75}S_{25}$ | 28 | 24 | 1.0 | 75 | 25 | 0 |
| Treatment 6 | T6 | $Th_{15}C_{75}S_{25}$ | 28 | 24 | 1.5 | 75 | 25 | 0 |
| Treatment 7 | T7 | $Th_{10}C_{80}S_{15}Sd_{5}$ | 28 | 24 | 1.0 | 80 | 15 | 5 |
| Treatment 8 | T8 | $Th_{15}C_{80}S_{15}Sd_{5}$ | 28 | 24 | 1.5 | 80 | 15 | 5 |
| Treatment 9 | T9 | $Th_{10}C_{75}S_{20}Sd_{5}$ | 28 | 24 | 1.0 | 75 | 20 | 5 |
| Treatment 10 | T10 | $Th_{15}C_{75}S_{20}Sd_{5}$ | 28 | 24 | 1.5 | 75 | 20 | 5 |
| Treatment 11 | T11 | $Th_{10}C_{70}S_{25}Sd_{5}$ | 28 | 24 | 1.0 | 70 | 25 | 5 |
| Treatment 12 | T12 | $Th_{15}C_{70}S_{25}Sd_{5}$ | 28 | 24 | 1.5 | 70 | 25 | 5 |

Th=Thickness, C=Clay, S=Sand, Sd=Sawdust and subscript=percentage composition/thickness

### 4.1.1 Atterberg limit of the clay used in making the pitchers

The results of the Atterberg limit tests on the clay use for the construction of the pitchers are presented in Table 4.2.

**Table 4.2: Atterberg Limits**

| Items | Result |
|---|---|
| Sample No | 11 |
| Liquid Limit (LL) | 47.0% |
| Plastic Limit (PL) | 14.33 |
| Liquidity Index (LI) | 0.88% |
| Plasticity Index (PI) | 32.7% |
| Linear Shrinkage (LS) | 11.68% |
| Description of Soil | Clay |

The parameters used to describe the response of cohesive soils to stress or pressure are the consistency or Atterberg limits (shrinking, plastic and liquid limit) and the plasticity index, respectively. Water content has an important influence on the behaviour of a cohesive soil. In the remoulded state, the consistency of the soil is largely governed by the water content. As water is added to a clayey soil, the consistency changes from solid to semi-solid to plastic, and finally to liquid. The liquid limit *LL* is the water content at which the soil–water mixture changes from a liquid to a plastic state. As the water content decreases, the soil passes into a semi-solid state at the plastic limit *PL*, and to a solid state at the shrinkage limit *SL*. Soil shrinks as moisture is gradually lost from it. With continuing loss of moisture, a stage of equilibrium is reached at which more loss of moisture will result in no further volume change. The moisture content, in percent, at which the volume of the soil mass ceases to change is defined as the shrinkage limit (Wagner, 2013). The difference in water content between plastic and liquid limit is called the plasticity index $I_p$ ($I_p = w_L - w_p$).

The knowledge of Atterberg limits and plasticity is often used to determine the amount of silt and clay in a fine-grained soil, as plasticity generally increases with higher clay content. A high liquid limit normally indicates a high compressibility and a high shrinkage/swelling potential. A high-plasticity index $I_p$ generally results in a low shear strength. However, the greater the plasticity, the greater is the shrinkage on drying (Lagali and Dekany, 2013).

The result of the Atterberg limit test done on the clay use for the fabrication of the pitchers reveals that the clay is an inorganic clay of medium plasticity (LL=47%, PL=14.33% & PI=32.7%), based on the classification of fine-grained soils in the 'United Soil Classification System (USCS)' plasticity chart, (Appendix V). Plasticity give the clay its ability to form and retain the shape by an outside force (stickiness). Clays with high plasticity shrinks much more than non plastic clays, (Jannifer, 2011).

Inorganic clay of medium plasticity was used because; clays of high plasticity were found to be too sticky, while non plastic clays could not form and retain shapes easily. Additionally, high plasticity clays also shrink excessively.

## 4.2 Hydraulic Properties of the Fabricated Earthen Pots (Pitchers)

The hydraulic conductivity of the 10 mm pitchers ranges between 0.92cm/hr and 1.25cm/hr while, hydraulic conductivity of the 15 mm pitchers ranges between 1.45cm/hr and 2.63cm/hr which agrees with Henry and Japheth (2013) findings, that the hydraulic conductivity of pitchers made from pure clay was 2.07cm/hr, clay pipes made from 95% clay and 5% sand was 3.08cm/hr while clay pipes made from 90% clay, 5% sand and 5% sawdust was 4.80cm/hr. The hydraulic conductivity of amalgamated clay use in this experiment is much higher than the hydraulic conductivity of pure clay, (Tables 4.3 and 4.4).

**Table 4.3: Hydraulic Conductivity of 10mm Pitchers**

| Treatments | Ave. Vol./day V ($cm^3$) | Thickness of pitcher d (cm) | Time t (hr) | Surface area A ($cm^2$) | Change in water depth ΔH (cm) | Hydaulic conductivity K (cm/hr) |
|---|---|---|---|---|---|---|
| T1 | 1442.00 | 10 | 24 | 205.72 | 2.34 | 1.25 |
| T3 | 1226.67 | 10 | 24 | 175.72 | 2.00 | 1.45 |
| T5 | 1710.00 | 10 | 24 | 244.30 | 2.78 | 1.05 |
| T7 | 1831.00 | 10 | 24 | 261.44 | 2.97 | 0.98 |
| T9 | 1894.00 | 10 | 24 | 270.01 | 3.07 | 0.95 |
| T11 | 1964.67 | 10 | 24 | 280.01 | 3.18 | 0.92 |

**Table 4.4: Hydraulic Conductivity of 15mm Pitchers**

| Treatments | Ave. Vol./day V ($cm^3$) | Thickness of pitcher d (cm) | Time t (hr) | Surface area A ($cm^2$) | Change in water depth ΔH (cm) | Hydaulic conductivity K (cm/hr) |
|---|---|---|---|---|---|---|
| T2 | 1034.33 | 15 | 24 | 147.15 | 1.67 | 2.63 |
| T4 | 1129.33 | 15 | 24 | 161.44 | 1.83 | 2.39 |
| T6 | 1312.67 | 15 | 24 | 187.15 | 2.13 | 2.06 |
| T8 | 1587.67 | 15 | 24 | 227.15 | 2.58 | 1.69 |
| T10 | 1766.67 | 15 | 24 | 252.87 | 2.87 | 1.52 |
| T12 | 1860.67 | 15 | 24 | 265.73 | 3.02 | 1.45 |

Volume of water released by the pitchers increases with increased porosity in both the 10mm and the 15 mm pitchers. The hydraulic conductivity of both thicknesses tends to decrease with increased volume of water released by the pitchers as shown in the tables above. The average hydraulic conductivity of the 15 mm pitchers (1.96cm/hr) is much higher than the average hydraulic conductivities of the 10 mm pitchers (1.10cm/hr). The hydraulic conductivity obtained during the experiment is comparable to those obtained by Altaf *et al* 2016, (1.75cm/hr).

The saturated hydraulic conductivity of pitchers is considered the most important factor affecting the outflow rate from pitchers. Sandeep *et al*, (2017) conduct hydraulic conductivity tests with fourteen pitchers selected from local producers in Jordan, with varying size, shape and production temperatures using the falling head method. They discovered that their hydraulic conductivities range between 0.219 and 2.37 cm/hr and tend to increase with increase wall thickness. This result tallies with the result obtained in this study which shows that an increase in the wall thickness of the pitchers significantly increases the hydraulic conductivity of the pitchers. The average hydraulic conductivity of the 15 mm pitchers (1.96cm/hr) is much higher than the average hydraulic conductivities of the 10 mm pitchers (1.10cm/hr).

Altaf et al, (2016), also discovered that, wall thickness significantly affects the hydraulic conductivity of the pitchers. A pitcher with 8.1mm wall thickness has a hydraulic conductivity of 1.04mm/day while the same type of pitcher with wall thickness 7.9mm has a hydraulic conductivity of 0.96mm/day, another set of the same type of pitcher with thicknesses 8.1mm and 7.7mm have hydraulic conductivities of 0.12mm/day and 0.11mm/day respectively.

### 4.3 Water Use, Crop Height and Yield of Lettuce.

Tables 4.5 and 4.6 presented the water used, crop height and yield of lettuce irrigated using the clay pots.

**Table 4.5: Experimental Results of the 10mm Pitchers**

| Treatments | Vol. of water ($cm^3$) | Change in height of crop (cm/day) | Yield (kg/ha) | Hydraulic Conductivity (cm/hr) |
|---|---|---|---|---|
| Ctrl | 240000 | 0.2066 | 8738 | |
| T1 | 158627 | 0.1885 | 11799 | 1.25 |

| | | | | |
|---|---|---|---|---|
| T3 | 164120 | 0.2485 | 11257 | 1.45 |
| T5 | 171807 | 0.3407 | 11461 | 1.05 |
| T7 | 185960 | 0.2999 | 15801 | 0.98 |
| T9 | 188180 | 0.2401 | 11739 | 0.95 |
| T11 | 190670 | 0.4501 | 17237 | 0.92 |

**Table 4.6: Experimental Results of the 15mm Pitchers**

| Treatments | Vol. Of water ($cm^3$) | Change in height of crop (cm/day) | Yield (kg/ha) | Kh(cm/hr) |
|---|---|---|---|---|
| Ctrl | 240000 | 0.2066 | 8738 | |
| T2 | 157210 | 0.1573 | 10559 | 2.63 |
| T4 | 160603 | 0.3104 | 10634 | 2.39 |
| T6 | 167203 | 0.2790 | 8936 | 2.06 |
| T8 | 177103 | 0.2844 | 11583 | 1.69 |
| T10 | 183640 | 0.3240 | 10449 | 1.52 |
| T12 | 186933 | 0.2836 | 11471 | 1.45 |

### 4.3.1. Water released by the pitchers

The porosity of the pitchers increases from treatment 1 to treatment 11 in the 1.0 cm pitchers and also from treatment 2 to treatment 12 in the 1.5 cm pitchers, and the seepage rates also increase accordingly, based on the compositions of the pitchers. This could be deduced by the total volume of water used for the production of lettuce in the two sets of pitchers i.e., between 158,627cm3 and 190,670cm3 for the 1.0cm pitchers, and between 157,210cm3 and 186,933cm3 for the 1.5cm pitchers. Tables 4.5 & 4.6

The average amount of water released by each pitcher for the production of lettuce ranges between 157210 $cm^3$ (1572.1$m^3$/ha) and 190670 $cm^3$ (1906.7$m^3$/ha), which is much less than the amount of water use by Tudor and Diana (2015) at Napoca, Romania, using both drip and micro sprinkler irrigation systems (the two most common systems of irrigation used to save water) to raise lettuce. In their experiment the amount of water use for drip irrigation ranges between 167400 $cm^3$ (1674$m^3$/ha) and 189000 $cm^3$ (1890$m^3$/ha) and for micro sprinkler irrigation is between 216000 $cm^3$ (2160$m^3$/ha) and 229500 $cm^3$ (2295$m^3$/ha). At the time of the experiment, the average relative humidity at 00:00 – 06:00 hrs was 55% and at 12:00 – 06:00 hrs was 28%; mean maximum temperature was 20.32$^0$C and mean minimum temperature was 14.26$^0$C. This shows that, pitcher irrigation is much more economical, in terms of water use, than basin, drip and micro-sprinkler systems of irrigation.

The seepage rates of the pitchers range between 1.44mm/day and 1.86mm/day at temperature 34.03$^0$C and relative humidity 26.86%. Seepage rates of pitchers are greatly influenced by temperature and humidity, as reported by Siyal, (2013). Siyal discovered that, at temperature of 20$^0$C and relative humidity of 79%, the mean seepage rate of pitchers of sizes 11, 15 and 20 litres was 0.13mm/day, while the mean seepage rate of the same pitchers at a temperature of 45$^0$C and relative humidity of 40% was 1.02mm/day.

The reference evapotranspiration ETo in the study area was found (using CROPWAT model: Max. Temp.=34.03$^0$C, Min. Temp.=18.98$^0$C, Humidity=26.86%, Rad.=24.6, 2013 – 2018) to be 4.2mm/day and the crop coefficient of lettuce at early, mid and late stages were 0.7, 1.0 and 0.95 respectively. Therefore, the crop evapotranspiration at early, mid and late stages were also 2.94, 4.2 and 3.99 mm/day respectively.

### 4.3.2. Crop height

The growth responses of the lettuce in terms of height increase are presented in Tables 4.5 and 4.6. The highest average increase of plant's height increase occurred in the late stage of the crop's development and is in T11 (0.4501cm). The lowest plant's height increase was observed in T2 (0.1567cm), and occurred in the early stage of the crop's development.

The growth rates of the crops did not follow a particular order but tends to increase for some time then decrease. It increases again a second time, then decrease. These periods of increase coincided with the periods of first and second dose of fertilizer applications (appendix VII). The first application was done on the $10^{th}$ March, 2018 (NPK) and the second on $11^{th}$ April, 2018 (Urea).

### 4.3.3 Yield per hectare.

The lettuces yields in kg/ha are presented in Tables 4.5 and 4.6. Treatment 11 with a composition of 70% clay, 25% sand and 5% sawdust recorded the average highest yield of 17237 kg/ha, while, Treatment 3, with 80% clay and 20% sand recorded the average lowest yield of 11257 kg/ha, under the 10 mm pitchers Table 4.5. Treatment 8 with 80% clay, 15% sand and 5% sawdust had the average highest yield of 11583 kg/ha, while Treatment 10 with 75% clay, 20% sand and 5% sawdust has the average lowest yield of 8936 kg/ha under the 15 mm pitchers, Table 4.6. Pitchers with 1.0 cm thickness tended to produce more yield than similar pitchers with 1.5 cm thickness.

Generally there was increase in yield of the crop as more water was supplied by the pitchers. Despite the challenges of high temperature and shortage of water during the production period, the average yield of the lettuce ranges between 8,936 and 17,237 kg/ha, which were similar to the findings of Ogbodo *et al.*, (2010); who reported yields between 12000 – 32000 kg/ha in an experiment conducted at Abakaliki Southern guinea Savannah, similarly, Patil *et al.,* (2013) reported an average yield of 11,896 kg/ha. However, these results were below the potential yield of 47,700 kg/ha as reported by Hochmuth and Smajstrla, (2017).

The comparably lower crop yield in this experiment was as a result of the observed poor soil physical and chemical properties (Tables 3.2 & 3.3; appendix I & II). High temperature and high bulk density contributed to the low performance of the crops. The high bulk density

(1.53g/cm$^3$) must have restricted the crops' root growth, and reduced the ability of the plants to mobilize nutrients for optimum performance. Bulk density of 1.40g/cm$^3$ is considered ideal for crops root growth (Appendix I).

High temperature has also negatively affected the yield of the lettuce, this agrees with the findings of Cantliffe and Karchi (2012) who in their experiment shows that adverse soil temperature causes stunted growth in lettuce, inducing bitterness and poor quality of lettuce leaves. Warm and dry conditions promote flowering and seed formation (bolting). Bolting occurs where temperatures over 20$^0$C are maintained day and night for a week or more, (Maynard *et al*, 2019).

Low organic matter was another factor that negatively affects the yield of the crops in the study area. Soil Organic Matter (S.O.M.) in any soil meant for crop production should not fall below 1% and should not go above 6%, (Department of Primary Industries and Regional Development, 2017 & Wikipedia, 2018). The average S.O.M. in the study area was 0.73%, which was considered low for lettuce crop production, (Table 3.3).

The experimental field also suffers low Soil Organic Carbon (S.O.C.). The percentage of SOC for crop production should not fall below 0.7% and should not be above 4.0% (Wikipedia, 2018). The average SOC in the study area was found to be 0.42%, which is also low for lettuce crop production, (Table 3.3).

The nitrogen, phosphorus and potassium contents of the study are, 0.059%, 1.92 mg/kg and 0.21 Meq/100g respectively and are very low for lettuce crop production, (Table 3.3 & Appendix II).

Despite all the challenges faced during the experiment, the yield recorded was much higher than the one recorded by Murata *et al.,* (2019), who recorded a yield of 11,560.5kg/ha and

10,645.5kg/ha for sub-surface pipe and pitcher irrigations respectively. The yield is also comparable to drip irrigation systems (18,150kg/ha) as reported by Santosh *et al.,* (2017) and micro sprinkler irrigation systems (21,700kg/ha) as reported by Tejaswini *et al.,* (2013).

### 4.4 Analysis

The results were analyzed using Analysis of Variance (ANOVA). The Software employed for the analysis was S.A.S. and the results obtained were presented in Tables 4.7.

**Table 4.7: Effect of pitcher Thicknesses and Compositions on Seepage, Crop Height, Crop Yield and Hydraulic Conductivity**

| Symbols | Thickness (cm) | Seepage (L) | Crop Height (cm) | Yield (g) | Hydraulic Conductivity (cm/hr |
|---|---|---|---|---|---|
| **$T_{1.0}$** | 1.0 | $6.75^{a}$ | 1.18 | 114.91 | $1.10^{b}$ |
| **$T_{1.5}$** | 1.5 | $5.81^{b}$ | 1.09 | 102.78 | $1.95^{a}$ |
| **S. E.** | | 0.243 | 0.096 | 5.759 | 0.118 |
| | **Composition** | | | | |
| **$T_1$ & $T_2$** | $C_{85}S_{15}Sd_0$ | $4.99^{d}$ | $0.69^{b}$ | $88.48^{b}$ | $1.94^{a}$ |
| **$T_3$ & $T_4$** | $C_{80}S_{20}Sd_0$ | $4.72^{d}$ | $1.12^{ab}$ | $100.93^{b}$ | $1.92^{a}$ |
| **$T_5$ & $T_6$** | $C_{75}S_{25}Sd_0$ | $6.08^{cd}$ | $1.24^{ab}$ | $121.13^{ab}$ | $1.56^{ab}$ |
| **$T_7$ & $T_8$** | $C_{80}S_{15}Sd_5$ | $6.89^{bc}$ | $1.17^{ab}$ | $106.02^{ab}$ | $1.34^{ab}$ |
| **$T_9$ & $T_{10}$** | $C_{75}S_{20}Sd_5$ | $7.34^{bc}$ | $1.13^{ab}$ | $102.18^{ab}$ | $1.24^{ab}$ |
| **$T_{11}$ & $T_{12}$** | $C_{70}S_{25}Sd_5$ | $7.68^{b}$ | $1.47^{a}$ | $134.32^{a}$ | $1.19^{b}$ |
| **Cntl.** | Control | $12.00^{a}$ | $0.83^{b}$ | $93.73^{b}$ | $0.50^{c}$ |
| **S. E.** | | 0.421 | 0.166 | 9.974 | 0.204 |

#### 4.4.1 Volume of water released by the pitchers

The control uses significantly higher volume of water than all the treatments ($12.00^{a}$). The amount of water released by the 1.0cm thick pitchers ($6.75^{a}$) is significantly higher than the amount of water released by the 1.5cm thick pitchers ($5.81^{b}$). Pitcher composition also played a significant role in the release of moisture to the crops, where pitchers with 70% clay, 25% sand and 5% sawdust ($T_{11}/T_{12}$) releases significantly higher volume of water ($7.68^{b}$) than all the other pitcher compositions. Treatments $T_7/T_8$ is statistically the same to treatments $T_9/T_{10}$ ($6.89^{bc}$ and $7.34^{bc}$ respectively) in terms of moisture release. Treatments $T_1/T_2$ 85% clay, 15% sand and 0% sawdust and $T_3/T_4$ with 80% clay, 20% sand and 0% sawdust are statistically the same and they releases significantly lower volume of water than all the other pitcher compositions ($4.99^{d}$ and $4.72^{d}$ respectively). Treatments $T_1/T_2$, $T_3/T_4$, and $T_5/T_6$ are statistically similar ($4.99^{d}$, $4.72^{d}$, $6.08^{cd}$ while, treatments $T_1/T_2$, $T_1/T_2$ and $T_1/T_2$ are also statistically similar ($6.89^{bc}$, and $7.34^{bc}$).

### 4.4.2 Crops height increase

There is no significant difference in crop height increase between pitchers with 1.0cm thickness and pitchers with 1.5cm thickness (1.18 and 1.09 respectively). The crops' height increase in treatments $T_{11}/T_{12}$ ($1.47^{a}$) is significantly higher than all the other treatments. Treatments $T_1/T_2$, and the control are statistically the same ($0.69^{b}$ and $0.83^{b}$ respectively) while, treatments $T_3/T_4$, $T_5/T_6$, $T_7/T_8$ and $T_9/T_{10}$ are also statistically the same ($1.12^{ab}$, $1.24^{ab}$, $1.17^{ab}$, and $1.13^{ab}$ respectively). The first and the second sets are statistically similar but, the second set produce significantly higher crop height increase than the first set.

### 4.4.3 Crop yield produced by the different pitcher compositions

Crop yield did not vary significantly between 1.0cm thick and 1.5cm thick pitchers (114.91 and 102.78 respectively). Significantly higher yield was produced by treatments $T_{11}/T_{12}$ ($134.32^{a}$) over the other treatments. A significantly lower crop yield was recorded in treatments $T_1/T_2$, $T_3/T_4$ and control ($88.48^{b}$, $100.93^{b}$ and $93.73^{b}$ respectively) which are statistically the same in terms of yield. Treatments $T_5/T_6$, $T_7/T_8$ and $T_9/T_{10}$ ($121.13^{ab}$, $106.02^{ab}$ and $102.18^{ab}$ respectively) are also statistically the same in terms of crop yield, but they produced significantly higher yield than treatments $T_1/T_2$ and $T_3/T_4$.

### 4.4.4 Hydraulic conductivity of the pitchers

The hydraulic conductivity of 1.5cm thick pitchers is significantly higher than the hydraulic conductivity of 1.0cm thick pitchers ($1.95^{a}$ and $1.10^{b}$ respectively). Treatments $T_1/T_2$ and $T_3/T_4$ ($1.94^{a}$ and $1.92^{a}$) are statistically the same in terms of hydraulic conductivity and also have significantly higher hydraulic conductivity than the other pitcher compositions. Treatments $T_5/T_6$, $T_7/T_8$ and $T_9/T_{10}$ ($1.56^{ab}$, $1.34^{ab}$ and $1.24^{ab}$ respectively) are also statistically the same and produce significantly lower hydraulic conductivity than treatments $T_1/T_2$ and $T_3/T_4$. The lowest hydraulic conductivity was recorded in the control ($0.50^{c}$). Treatments $T_5/T_6$, $T_7/T_8$ and $T_9/T_{10}$ are statically similar with $T_1/T_2$ and $T_3/T_4$, so also treatments $T_5/T_6$, $T_7/T_8$ and $T_9/T_{10}$ and treatments $T_{11}/T_{12}$.

### 4.4.5 Effect of incorporating sawdust into the material composition of the pitchers

Results in Table 4.10b indicates that, there are no significant variations in terms of volume of water released, height increase, yield of crop and hydraulic conductivity of the pitchers due to addition of sawdust in the material compositions of the 10 mm pitchers.

**Table 4.8a: Effect of sawdust on the 10mm Pitchers**

| Vol ($cm^3$/day) | | Ht (cm/day) | | Yld (kg/ha) | | Kh (cm/hr) | |
|---|---|---|---|---|---|---|---|
| **Sand** | **Sand/SD** | **Sand** | **Sand/SD** | **Sand** | **Sand/SD** | **Sand** | **Sand/SD** |
| 1227 | 1831 | 0.2485 | 0.2999 | 11257 | 15801 | 1.46 | 0.98 |
| 1710 | 1894 | 0.3407 | 0.2401 | 11461 | 11739 | 1.05 | 0.95 |

**Table 4.8b: Paired Samples Test on the Effect of sawdust on the 10mm Pitchers**

| | | Paired Differences | | | | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference Lower | Upper | | | |
| Pair 1 | VCsand - VCsand/sd | -270.00 | 127.28 | 90.0 | -1413.56 | 873.56 | -3.00 | 2 | .205 |
| Pair 2 | HCsand - HCsand/sd | 0.02 | 0.11 | 0.08 | -0.94 | 0.99 | 0.32 | 2 | .801 |
| Pair 3 | YCsand - YCsand/sd | -2411.00 | 3016.5 | 2133.0 | 29513.33 | 24691.33 | -1.13 | 2 | .461 |
| Pair 4 | KCsand - KCsand/sd | 0.29 | 0.27 | 0.19 | -2.12 | 2.70 | 1.53 | 2 | .369 |

SD=Sawdust, V=volume of water, H=height increase, K=hydraulic conductivity, Csand=clay/sand comp., Csand/sd=clay/sand/sawdust comp.

Results in Table 4.8b indicates that, there are no significant variations in terms of volume of water released, height increase, yield of crop and hydraulic conductivity of the pitchers due to addition of sawdust in the material compositions of the 10 mm pitchers.

**Table 4.9a: Effect of sawdust on the 15mm Pitchers**

| Vol ($cm^3$/day) | | Ht (cm/day) | | Yld (kg/ha) | | Kh (cm/hr) | |
|---|---|---|---|---|---|---|---|
| **Sand** | **Sand/SD** | **Sand** | **Sand/SD** | **Sand** | **Sand/SD** | **Sand** | **Sand/SD** |
| 1129 | 1588 | 0.3104 | 0.2844 | 10634 | 11583 | 2.38 | 1.69 |
| 1312 | 1767 | 0.2790 | 0.3240 | 8936 | 10449 | 2.06 | 1.52 |

**Table 4.9b: Paired Samples Test on the Effect of sawdust on the 15mm Pitchers**

| | | Paired Differences | | | | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference: Lower | Upper | | | |
| Pair 2 | HCsand - HCsand/sd | -.01 | .05 | .04 | -.46 | .44 | -.27 | 2 | .834 |
| Pair 3 | YCsand - YCsand/sd | -1231.00 | 398.81 | 282.0 | -4814.15 | 2352.15 | -4.37 | 2 | .143 |
| Pair 4 | KCsand - KCsand/sd | .62 | .11 | .08 | -.34 | 1.57 | 8.20 | 2 | .077 |

SD=Sawdust, V=volume of water, H=height increase, K=hydraulic conductivity, Csand=clay/sand comp., Csand/sd=clay/sand/sawdust comp.

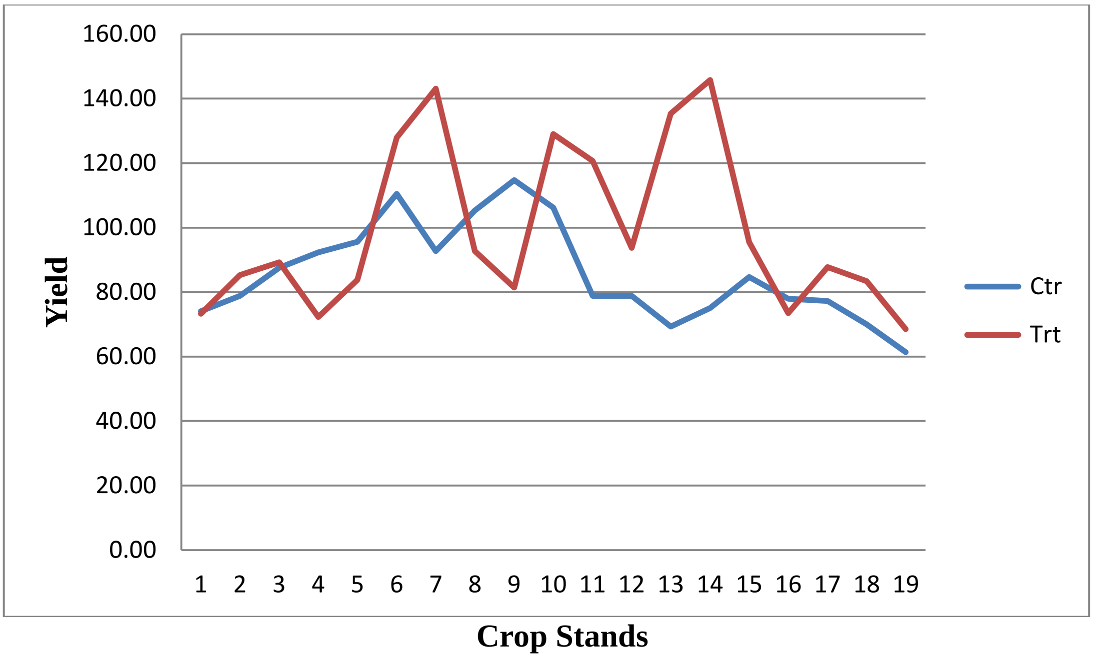
Results in Table 4.9b indicates that, there are no significant variations in terms of volume of water released, height increase, yield of crop and hydraulic conductivity of the pitchers due to addition of sawdust in the material compositions of the 15 mm pitchers.

### 4.4.6 Yield comparison between treatments and control

The results show that, crop for crop the treatments produced much higher yields than the control, despite the fact that the control uses much more water than the treatments, Tables 4.5 and 4.6. Secondly, the crops that were much further away from the pitcher produced much less than those closer to the pitcher. The same thing happens with the control, the crops in the periphery did not do very well.

**Table 4.10: Yield of the Control and Yield of the Treatments**

| Yield | |
|---|---|
| **Ctr** | **Trt** |
| 74.05 | 73.24 |
| 78.84 | 85.26 |
| 87.60 | 89.25 |
| 92.30 | 72.29 |
| 95.60 | 83.76 |
| 110.45 | 127.92 |
| 92.67 | 143.12 |
| 105.30 | 92.69 |
| 114.77 | 81.40 |
| 106.20 | 129.02 |
| 78.84 | 120.73 |
| 78.84 | 93.75 |
| 69.30 | 135.39 |
| 75.10 | 145.78 |
| 84.67 | 95.48 |
| 77.95 | 73.48 |
| 77.20 | 87.74 |
| 70.00 | 83.37 |
| 61.40 | 68.49 |




**Plat 4.1:** Yields of Crop between Treatments and Control

# CHAPTER FIVE

# SUMMARY, CONCLUSION AND RECOMENDATIONS

## 5.1 Summary

The experiment, "Evaluation of Pitcher Irrigation Technology for Production of Lettuce (*Lactuca sativa*) Crop in Samaru, Nigeria," was conducted at the Institute for Agricultural Research (I.A.R.), research field, Ahmadu Bello University (A.B.U.), Zaria, Nigeria.

The experiment was conducted using twelve treatments and a control, replicated three times, that is replicates 1, 2 and 3. Each treatment consists of a pitcher of clay and sand or clay, sand and sawdust compositions in various proportions. Each replicate consist of 12 treatments and control arranged in a randomized complete block design, and each treatment is buried in the centre of a 1m x 1m plot. Twenty Lettuce plants were planted in each plot, with a spacing of 30 cm (0.3m) inter-row and 20 cm (0.2m) intra-row. The crops were irrigated after transplanting using surface irrigation method. After the crops became established, the treatment was imposed, that is, the pitcher in each plot is filled to the brim with water and covered with an airtight cover. The water in the pitcher was then allowed to seep naturally into the root zone of the crops. The pitchers were re-filled every four days, throughout the period of the experiment.

Analysis and comparison of results show that, the depth of water supplied by the pitchers ranged between 0.99 mm/day to 2.04 mm/day, the growth rate of the crops ranges between 0.11cm to 0.57cm per day and the yield ranges between 6,316 kg/ha to 24,313 kg/ha.

The volume of water released by the pitchers generally increase as the volume of sand and, the volume of sand and sawdust increased in the clay used for the construction of the pitchers, appendix VI. The rate of height increase of the crops fluctuates in line with fertilizer applications, appendix VII. There is also significant variation in yield between the treatments, but the yield of the treatments is significantly higher than the yield in the control.

**5.2 Conclusion**

Results of the experiment show that, wall thickness significantly affects the volume of water released by the treatments. Thinner pitchers ($6.75^{a}$) tend to release significantly more water than thicker pitchers ($5.81^{b}$).

Incorporation of sand or sand and sawdust into the clay use for the construction of the pitchers significantly affect the volume of water released by the pitchers. The higher the amount of sand or sand and sawdust incorporated into the material composition of the pitchers, the higher the volume of water released by the pitchers.

The control uses the highest volume of water to produce lettuce crop in the experiment ($12.00^{a}$) but produce significantly lower yield than the other treatments ($93.73^{b}$). Treatment $T_{11}/T_{12}$ release significantly higher volume of water, greater crop height increase and higher crop yield ($7.68^b$, $1.47^a$, and$134.32^a$ respectively) than all the other pitcher compositions, but treatment $T_{11}$ has a thickness of 1.0cm therefore, it is better than treatment $T_{12}$ and all the other treatments in terms of lettuce crop production in Samaru Nigeria.

**5.3 Recommendations**

The following recommendations were drawn with the vision of promoting the production of vegetables across all dry-land parts of Africa in general and Nigeria in particular:

1. Farmers should be enlightened on pitcher irrigation technology, because a lot of farmers, especially the local farmers, have never heard of pitcher irrigation technology, let alone adopting it.
2. Extension and agricultural research institutions should work closely with the farming communities in order to identify, develop and smoothly promote a range of locally appropriate technological options, such as the clay pitcher irrigation system.
3. Pitchers with 70% clay, 25% sand and 5% sawdust is the best pitcher for the production of lettuce crop in the study area
4. Plots of 1m by 1m are recommended for this type of pitcher irrigation, considering the evapotranspiration rate of the crop and the amount of moisture released by the pitcher.
5. Irrigation interval of four days was recommended in order not to unnecessarily stress the crops by the complete drying-out of the water in the pitchers and also reduce the frequency of irrigation.
6. Clay pitcher irrigation can be made more useful to small scale farmers when combined with small water harvesting techniques such as rainwater catchment systems.
7. The use of locally manufactured clay pitcher not only provides a sustainable source of inexpensive pots for irrigation purposes, but also offers an outlet for promoting

income and skill development opportunities more inclusively across the rural communities.

8. Further research needs to be undertaken to improve the design, durability and overall efficiency of the existing clay pot pitchers.

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## APPENDICES

**Appendix I: Relationship between bulk density and root growth based on soil texture**

| Soil Texture | Ideal Bulk Density for Plant Growth | Bulk Density that restricts root growth |
|---|---|---|
| Sandy | < 1.60 | >1.80 |
| Silty | < 1.40 | >1.65 |
| Clayey | < 1.10 | >1.47 |

East National Technology Support Center, 2011

**Appendix II:** Fertility level of crop production soil

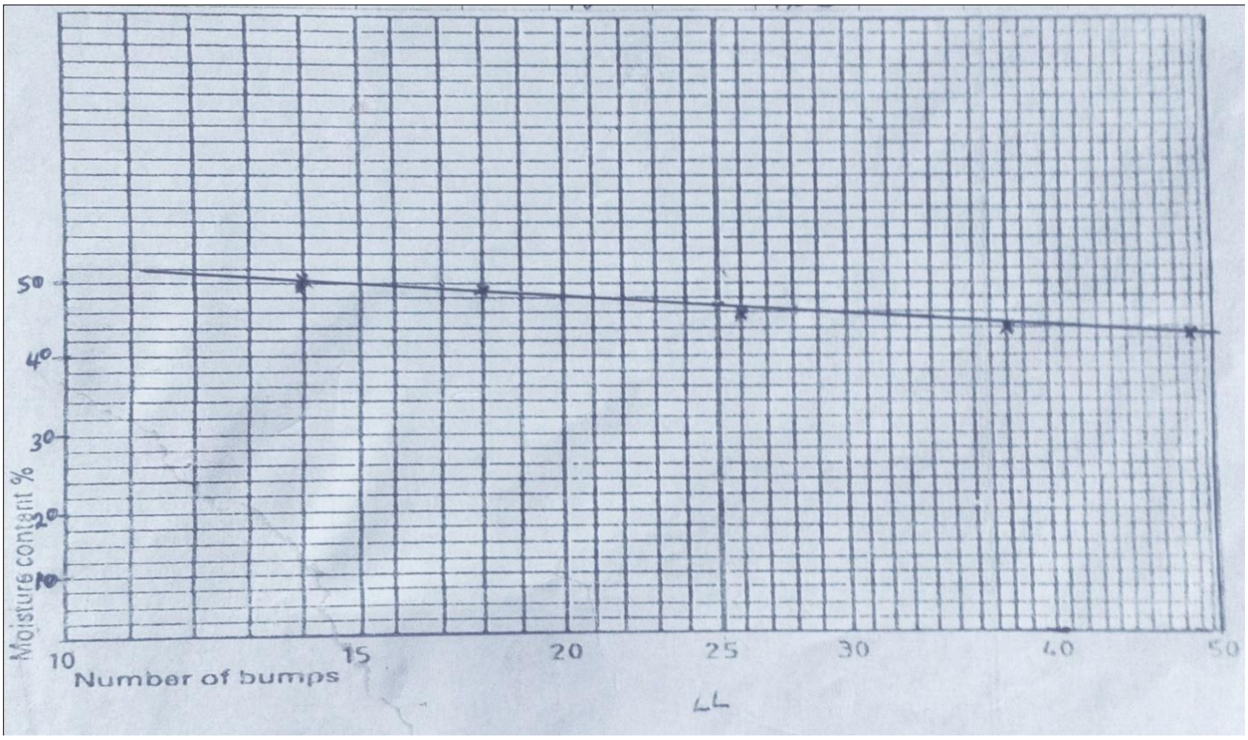
| | N (mg/kg) | P (mg/kg) | K (mg/kg) |
|---|---|---|---|
| Low | 0 - 15 | 0 - 25 | 0 - 60 |

| | | | |
|---|---|---|---|
| Medium | 15 - 30 | 25 - 50 | 60 - 100 |
| High | 30+ | 50+ | 100+ |

Source: Jove.com Science Education, 2017

## Appendix III: Liquid Limit

| Test Type | LL | LL | LL | LL | LL |
|---|---|---|---|---|---|
| No of blows (N) | 48 | 38 | 26 | 18 | 14 |
| Container No | L4 | N47 | N90 | R38 | A10 |
| Wt. of wet soil & cont. (g) | 26.7 | 28.8 | 35.9 | 41.2 | 43.3 |
| Wt. of dry soil & cont. (g) | 21.3 | 22.7 | 27.4 | 30.7 | 31.7 |
| Wt. of container (g) | 8.8 | 9.0 | 9.0 | 9.4 | 8.6 |
| Wt. of dry soil (Wd) g | 12.5 | 13.7 | 18.4 | 21.3 | 23.1 |
| Wt. of moisture (Ww) g | 5.4 | 6.1 | 8.5 | 10.5 | 11.6 |
| Moisture content (g) w | 43.2 | 44.5 | 46.2 | 49.3 | 50.2 |

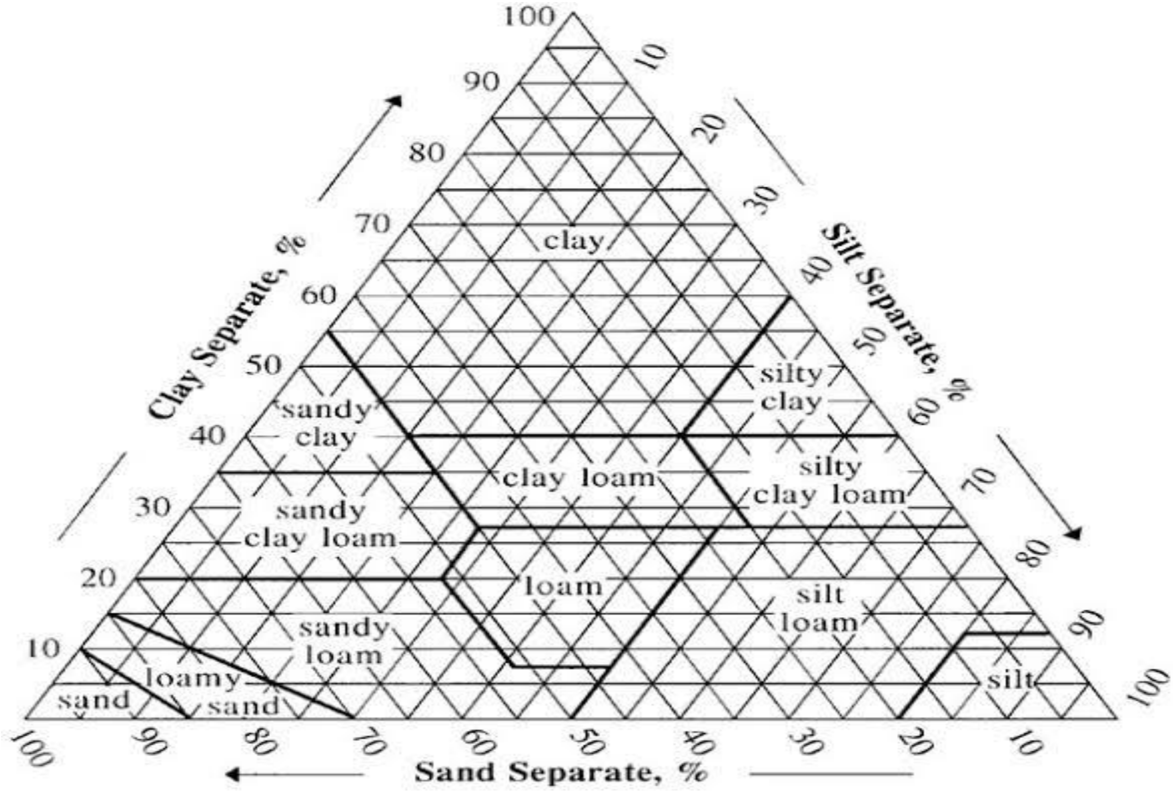


**Appendix IV: Plastic Limit**

| Test Type | PL | PL | PL |
|---|---|---|---|
| No of blows (N) | - | - | - |
| Container No | R3 | N35 | A19 |
| Wt. of wet soil & cont. (g) | 10.1 | 10.2 | 10.5 |
| Wt. of dry soil & cont. (g) | 9.9 | 10.0 | 10.3 |
| Wt. of container (g) | 8.3 | 8.9 | 8.7 |
| Wt. of dry soil (Wd) g | 1.6 | 1.1 | 1.6 |
| Wt. of moisture (Ww) g | 0.2 | 0.2 | 0.2 |
| Moisture content (g) w | 12.5 | 18.0 | 12.5 |

**Appendix V. Reference Values for Consistency Limits of Cohesive Soils (Dahms and Fritz, 1998)**

| **Soil** | **Liquid limit $w_L$ (%)** | **Plastic limit $w_p$ (%)** | **Plasticity $I_p$ (%)** |
|---|---|---|---|
| Silt, low plasticity | 25–35 | 20–28 | 4–11 |
| Silt, medium plasticity | 35–50 | 22–23 | 7–20 |
| Clay, low plasticity | 25–35 | 15–22 | 7–16 |
| Clay, medium plasticity | 40–50 | 18–25 | 16–28 |
| Clay, high plasticity | 60–85 | 20–35 | 35–55 |




## Appendix VI: Rate of Irrigation by the pitchers (L)

| BLK | DATE | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | T9 | T10 | T11 | T12 | Ctrl |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Wed. 21-03-18 | 3.27 | 3.86 | 4.26 | 4.64 | 7.22 | 4.46 | 6.76 | 6.47 | 8.80 | 7.90 | 7.87 | 8.30 | 12.00 |
| | Sun. 25-03-18 | 4.27 | 3.94 | 4.97 | 4.62 | 8.20 | 4.26 | 7.71 | 7.16 | 8.48 | 8.90 | 8.38 | 8.10 | 12.00 |
| | Thu. 29-03-18 | 3.45 | 3.65 | 4.62 | 4.37 | 10.46 | 4.55 | 7.21 | 7.00 | 7.51 | 7.93 | 7.40 | 7.29 | 12.00 |
| | Mon. 02-04-18 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 12.00 |
| | Fri. 06-04-18 | 5.14 | 5.02 | 6.44 | 2.25 | 10.46 | 5.70 | 7.59 | 7.45 | 8.14 | 8.35 | 8.20 | 8.33 | 12.00 |
| A | Tue. 10-04-18 | 3.72 | 4.43 | 6.01 | 5.55 | 7.95 | 5.16 | 4.79 | 7.43 | 7.11 | 8.14 | 8.52 | 7.92 | 12.00 |
| | Fri. 13-04-18 | 4.00 | 4.45 | 5.52 | 4.43 | 7.03 | 4.70 | 6.44 | 6.40 | 7.11 | 6.52 | 7.41 | 6.85 | 12.00 |
| | Tue. 17-04-18 | 5.15 | 5.48 | 6.73 | 4.86 | 9.24 | 6.05 | 8.39 | 7.40 | 8.38 | 7.73 | 8.52 | 9.92 | 12.00 |
| | Sat. 21-04-18 | 4.54 | 3.31 | 4.79 | 4.13 | 10.91 | 5.39 | 6.60 | 5.63 | 7.49 | 6.81 | 8.50 | 7.49 | 12.00 |
| | Wed. 25-04-18 | 6.56 | 4.71 | 6.26 | 4.74 | 9.45 | 6.52 | 9.31 | 7.33 | 9.40 | 7.90 | 8.76 | 6.56 | 12.00 |
| | Total | 40.10 | 38.85 | 49.60 | 39.59 | 80.92 | 46.79 | 64.80 | 62.27 | 72.42 | 70.18 | 73.56 | 70.76 | 120.00 |
| | Ave./Irr | 4.46 | 4.32 | 5.51 | 4.40 | 8.99 | 5.20 | 7.20 | 6.92 | 8.05 | 7.80 | 8.17 | 7.86 | 13.33 |
| | Ave./Day | 1.114 | 1.079 | 1.378 | 1.100 | 2.248 | 1.300 | 1.800 | 1.730 | 2.012 | 1.949 | 2.043 | 1.966 | 3.333 |
| B | Wed. 21-03-18 | 8.10 | 3.11 | 3.88 | 3.87 | 4.57 | 4.22 | 7.34 | 5.26 | 8.05 | 7.20 | 8.90 | 8.03 | 12.00 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Sun. 25-03-18 | 9.00 | 3.41 | 3.82 | 4.87 | 4.04 | 3.60 | 7.18 | 6.33 | 8.32 | 5.93 | 8.04 | 7.70 | 12.00 |
| | Thu. 29-03-18 | 9.07 | 3.94 | 4.21 | 3.41 | 4.62 | 4.00 | 7.73 | 7.49 | 7.12 | 7.43 | 7.90 | 7.83 | 12.00 |
| | Mon. 02-04-18 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 12.00 |
| | Fri. 06-04-18 | 10.93 | 4.94 | 4.75 | 6.62 | 8.55 | 4.94 | 8.87 | 7.50 | 5.65 | 7.63 | 8.42 | 8.54 | 12.00 |
| | Tue. 10-04-18 | 9.18 | 3.56 | 3.84 | 4.25 | 6.01 | 4.50 | 8.04 | 5.83 | 7.09 | 6.64 | 7.41 | 7.65 | 12.00 |
| | Fri. 13-04-18 | 8.87 | 4.50 | 3.86 | 3.52 | 7.45 | 4.30 | 7.16 | 5.70 | 8.09 | 6.20 | 6.57 | 6.73 | 12.00 |
| | Tue. 17-04-18 | 6.57 | 4.26 | 4.88 | 5.61 | 6.14 | 5.35 | 7.94 | 6.37 | 7.23 | 7.36 | 7.71 | 7.00 | 12.00 |
| | Sat. 21-04-18 | 7.13 | 3.87 | 3.75 | 4.17 | 4.43 | 4.86 | 6.61 | 5.90 | 7.81 | 7.15 | 6.65 | 6.07 | 12.00 |
| | Wed. 25-04-18 | 9.70 | 5.64 | 4.89 | 4.65 | 6.45 | 6.63 | 7.99 | 6.24 | 7.60 | 7.50 | 7.90 | 7.99 | 12.00 |
| | Total | 78.55 | 37.23 | 37.88 | 40.97 | 52.26 | 42.40 | 68.86 | 56.62 | 66.96 | 63.04 | 69.50 | 67.54 | 120.00 |
| | Ave./Irr | 8.73 | 4.14 | 4.21 | 4.55 | 5.81 | 4.71 | 7.65 | 6.29 | 7.44 | 7.00 | 7.72 | 7.50 | 13.33 |
| | Ave./Day | 2.182 | 1.034 | 1.052 | 1.138 | 1.452 | 1.178 | 1.913 | 1.573 | 1.860 | 1.751 | 1.931 | 1.876 | 3.333 |
| C | Wed. 21-03-18 | 3.29 | 3.53 | 4.54 | 3.98 | 4.87 | 5.11 | 7.32 | 5.11 | 7.40 | 6.37 | 8.50 | 7.66 | 12.00 |
| | Sun. 25-03-18 | 3.78 | 4.15 | 4.87 | 4.71 | 5.54 | 5.29 | 7.61 | 5.29 | 7.20 | 6.45 | 8.39 | 6.53 | 12.00 |
| | Thu. 29-03-18 | 3.52 | 4.20 | 4.95 | 3.93 | 5.84 | 4.80 | 8.09 | 4.80 | 7.12 | 6.51 | 8.19 | 7.06 | 12.00 |
| | Mon. 02-04-18 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 12.00 |
| | Fri. 06-04-18 | 4.71 | 4.70 | 6.36 | 5.71 | 6.61 | 6.62 | 7.49 | 6.62 | 8.78 | 7.36 | 8.67 | 8.07 | 12.00 |
| | Tue. 10-04-18 | 3.50 | 3.84 | 5.76 | 5.18 | 5.88 | 6.60 | 7.08 | 6.60 | 6.47 | 6.37 | 7.21 | 7.00 | 12.00 |
| | Fri. 13-04-18 | 4.16 | 4.34 | 5.24 | 4.58 | 5.18 | 5.75 | 6.53 | 5.75 | 6.04 | 5.07 | 6.35 | 6.20 | 12.00 |
| | Tue. 17-04-18 | 4.98 | 4.04 | 4.95 | 4.95 | 6.14 | 6.71 | 7.25 | 6.71 | 7.80 | 6.85 | 7.27 | 6.88 | 12.00 |
| | Sat. 21-04-18 | 4.57 | 2.80 | 3.49 | 3.49 | 4.51 | 5.52 | 5.75 | 5.52 | 5.70 | 5.95 | 7.15 | 5.88 | 12.00 |
| | Wed. 25-04-18 | 4.64 | 3.95 | 4.72 | 4.72 | 6.78 | 6.02 | 7.10 | 6.02 | 8.65 | 6.77 | 7.22 | 7.22 | 12.00 |
| | Total | 37.15 | 35.55 | 44.88 | 41.25 | 51.35 | 52.42 | 64.22 | 52.42 | 65.16 | 57.70 | 68.95 | 62.50 | 120.00 |
| | Ave./Irr | 4.13 | 3.95 | 4.99 | 4.58 | 5.71 | 5.82 | 7.14 | 5.82 | 7.24 | 6.41 | 7.66 | 6.94 | 13.33 |
| | Ave./Day | 1.03 | 0.99 | 1.25 | 1.15 | 1.43 | 1.46 | 1.78 | 1.46 | 1.81 | 1.60 | 1.92 | 1.74 | 3.33 |

## Appendix VII: Crop Growth Rate per Irrigation (cm)

| Blck | Trts<br>Par/<br>Readings | T1<br>ΔHt<br>(cm) | T2<br>ΔHt<br>(cm) | T3<br>ΔHt<br>(cm) | T4<br>ΔHt<br>(cm) | T5<br>ΔHt<br>(cm) | T6<br>ΔHt<br>(cm) | T7<br>ΔHt<br>(cm) | T8<br>ΔHt<br>(cm) | T9<br>ΔHt<br>(cm) | T10<br>ΔHt<br>(cm) | T11<br>ΔHt<br>(cm) | T12<br>ΔHt<br>(cm) | Ctrl<br>ΔHt<br>(cm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 1st | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 2nd | 0.88 | 0.09 | 0.09 | 1.45 | 1.40 | 0.99 | 1.63 | 0.95 | 0.65 | 1.19 | 1.13 | 0.90 | 0.54 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **3rd** | 1.95 | 1.35 | 1.01 | 2.04 | 2.18 | 2.60 | 2.66 | 1.90 | 1.78 | 1.76 | 1.24 | 1.16 | 0.70 |
| | **4th** | 1.71 | -0.14 | 1.24 | 1.01 | 0.82 | 1.88 | 0.23 | 1.39 | 1.52 | 1.21 | 1.24 | 1.40 | 0.95 |
| | **5th** | 0.30 | 0.21 | 0.80 | 0.70 | 1.90 | 1.11 | -0.25 | 0.71 | 0.67 | 0.99 | 1.03 | 0.71 | 1.30 |
| | **6th** | 0.49 | 0.77 | 1.05 | 1.39 | 1.95 | 1.66 | 1.21 | 1.21 | 1.03 | 1.75 | 1.27 | 1.06 | 0.83 |
| | **7th** | 0.83 | 0.75 | 2.78 | 2.36 | 2.15 | 1.44 | 1.49 | 2.23 | 1.28 | 2.40 | 2.39 | 1.19 | 1.05 |
| | **8th** | 1.07 | 0.31 | 2.24 | 2.28 | 2.10 | 0.94 | 1.80 | 1.65 | 0.64 | 1.87 | 1.90 | 1.73 | 1.37 |
| | **9th** | 0.84 | 0.51 | 1.09 | 1.49 | 1.75 | 1.91 | 2.41 | 0.42 | 0.58 | 2.79 | 4.76 | 0.95 | 1.42 |
| | **10th** | 0.47 | 0.10 | 0.72 | 1.82 | 1.33 | 3.08 | 1.53 | 0.63 | 0.58 | 2.35 | 4.35 | 1.22 | 0.92 |
| | **Total** | **8.54** | **3.95** | **11.01** | **14.54** | **15.58** | **15.60** | **12.70** | **11.09** | **8.73** | **16.30** | **19.29** | **10.32** | **9.08** |
| | **Ave./Irr** | 0.95 | 0.44 | 1.22 | 1.62 | 1.73 | 1.73 | 1.41 | 1.23 | 0.97 | 1.81 | 2.14 | 1.15 | 1.01 |
| | **Ave./Day** | 0.24 | 0.11 | 0.31 | 0.40 | 0.43 | 0.43 | 0.35 | 0.31 | 0.24 | 0.45 | 0.54 | 0.29 | 0.25 |
| | **1st** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | **2nd** | 0.60 | 0.90 | 0.23 | 1.20 | 0.71 | 1.53 | 1.05 | 0.81 | 0.26 | 1.19 | 1.61 | 0.50 | 0.95 |
| | **3rd** | 1.33 | 1.30 | 0.61 | 1.61 | 2.54 | 2.63 | 2.28 | 1.20 | 1.08 | 1.36 | 2.89 | 1.61 | 0.93 |
| | **4th** | 1.34 | 1.08 | 1.36 | 1.28 | 1.88 | -0.29 | 1.26 | 1.98 | 1.30 | 2.28 | 2.59 | 2.34 | 0.99 |
| **B** | **5th** | 0.90 | 0.89 | 0.99 | 1.08 | 0.89 | 1.05 | 0.71 | 0.95 | 1.20 | 0.98 | 1.38 | 1.39 | 0.81 |
| | **6th** | 0.69 | 0.60 | 1.38 | 1.36 | 1.18 | 0.82 | 1.12 | 1.73 | 1.16 | 1.78 | 2.07 | 1.57 | 0.84 |
| | **7th** | 0.78 | 1.09 | 1.58 | 1.64 | 1.59 | 1.46 | 1.25 | 2.78 | 2.26 | 1.93 | 2.64 | 2.15 | -0.61 |
| | **8th** | 0.87 | 1.28 | 1.38 | 0.86 | 2.30 | 0.83 | 1.35 | 1.82 | 1.36 | 1.47 | 1.74 | 1.51 | 0.79 |
| | **9th** | 0.51 | 0.59 | 1.14 | 0.77 | 0.98 | 0.72 | 0.93 | 0.79 | 1.41 | 0.55 | 2.74 | 0.79 | 1.03 |
| | **10th** | 0.37 | 0.56 | 0.95 | 0.16 | 0.85 | 0.75 | 0.82 | 0.41 | 1.52 | 0.84 | 3.02 | 0.86 | 0.54 |
| | **Total** | **7.38** | **8.28** | **9.61** | **9.95** | **12.91** | **9.49** | **10.77** | **12.47** | **11.55** | **12.38** | **20.68** | **12.72** | **6.27** |
| | **Ave./Irr** | 0.82 | 0.92 | 1.07 | 1.11 | 1.43 | 1.05 | 1.20 | 1.39 | 1.28 | 1.38 | 2.30 | 1.41 | 0.70 |
| | **Ave./Day** | 0.21 | 0.23 | 0.27 | 0.28 | 0.36 | 0.26 | 0.30 | 0.35 | 0.32 | 0.34 | 0.57 | 0.35 | 0.17 |
| | **1st** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | **2nd** | 0.54 | 1.06 | 0.69 | 0.93 | 0.55 | 0.75 | 0.86 | 0.28 | 1.04 | 0.89 | 0.96 | 1.16 | 0.51 |
| | **3rd** | 0.68 | 0.79 | 0.89 | 1.13 | 1.15 | 0.87 | 1.47 | 1.20 | 0.97 | 0.96 | 1.15 | 1.24 | 0.70 |
| **C** | **4th** | 0.40 | 0.57 | 0.97 | 1.17 | 1.14 | 0.94 | 1.10 | 1.75 | -0.23 | 0.91 | 1.13 | 1.04 | 0.91 |
| | **5th** | 0.25 | 0.64 | 0.70 | 0.71 | 0.77 | 0.21 | 0.72 | 0.66 | 0.81 | 0.58 | 0.87 | 0.72 | 0.98 |
| | **6th** | 0.66 | 0.39 | 0.78 | 0.91 | 1.31 | 0.81 | 1.06 | 0.74 | 0.92 | 0.81 | 1.29 | 0.94 | 0.89 |
| | **7th** | 0.76 | 0.32 | 0.83 | 1.29 | 1.90 | 0.18 | 1.13 | 0.83 | 0.92 | 0.85 | 1.54 | 0.99 | 0.96 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **8th** | 0.26 | 0.25 | 0.52 | 1.14 | 0.65 | 0.55 | 1.05 | 0.74 | 0.45 | 0.48 | 0.65 | 0.79 | 0.99 |
| **9th** | 0.41 | 0.37 | 0.52 | 1.02 | 0.40 | 0.30 | 0.72 | 0.34 | 0.59 | 0.43 | 0.62 | -0.51 | 0.72 |
| **10th** | 0.49 | 0.37 | 0.32 | 0.73 | 0.43 | 0.43 | 0.81 | 0.62 | 0.19 | 0.40 | 0.42 | 1.22 | 0.31 |
| **Total** | **4.44** | **4.76** | **6.22** | **9.03** | **8.30** | **5.05** | **8.92** | **7.15** | **5.66** | **6.32** | **8.64** | **7.59** | **6.97** |
| **Ave./Irr** | 0.49 | 0.53 | 0.69 | 1.00 | 0.92 | 0.56 | 0.99 | 0.79 | 0.63 | 0.70 | 0.96 | 0.84 | 0.77 |
| **Ave./Day** | 0.12 | 0.13 | 0.17 | 0.25 | 0.23 | 0.14 | 0.25 | 0.20 | 0.16 | 0.18 | 0.24 | 0.21 | 0.19 |

## Appendix VIII: Crop Yield (g)

| **Blck** | **Trtm/ Crop std** | **T1** | **T2** | **T3** | **T4** | **T5** | **T6** | **T7** | **T8** | **T9** | **T10** | **T11** | **T12** | Ctrl |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | 0.0 | 50.9 | 0.0 | 0.0 | 0.0 | 0.0 | 72.6 | 85.5 | 65.5 | 53.6 | 0.0 | 0.0 | 75.8 |
| | **2** | 78.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 94.7 | 104.7 | 75.7 | 119.2 | 53.6 | 0.0 | 0.0 |
| | **3** | 76.3 | 66.1 | 54.2 | 0.0 | 0.0 | 72.3 | 86.4 | 67.1 | 0.0 | 0.0 | 0.0 | 102.0 | 0.0 |
| | **4** | 60.3 | 55.9 | 51.9 | 0.0 | 91.2 | 0.0 | 81.4 | 124.6 | 0.0 | 75.7 | 0.0 | 0.0 | 0.0 |
| | **5** | 94.2 | 68.7 | 74.4 | 0.0 | 0.0 | 0.0 | 76.7 | 99.8 | 69.7 | 128.5 | 0.0 | 0.0 | 0.0 |
| **A** | **6** | 110.8 | 98.7 | 174.2 | 0.0 | 148.3 | 0.0 | 128.6 | 152.7 | 118.2 | 178.5 | 108.2 | 0.0 | 0.0 |
| | **7** | 156.3 | 137.6 | 188.6 | 0.0 | 162.7 | 230.3 | 165.7 | 175.5 | 161.3 | 164.1 | 172.3 | 187.3 | 98.9 |
| | **8** | 79.0 | 0.0 | 70.9 | 63.4 | 93.1 | 0.0 | 0.0 | 119.2 | 67.3 | 103.8 | 0.0 | 0.0 | 105.3 |
| | **9** | 0.0 | 73.6 | 57.0 | 0.0 | 74.9 | 0.0 | 102.6 | 64.3 | 78.2 | 101.5 | 0.0 | 94.7 | 143.3 |
| | **10** | 160.5 | 126.4 | 164.3 | 152.1 | 0.0 | 268.2 | 165.4 | 225.7 | 139.6 | 0.0 | 116.4 | 0.0 | 0.0 |
| | **11** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | **12** | 97.5 | 67.6 | 128.4 | 0.0 | 86.3 | 0.0 | 159.9 | 126.8 | 61.1 | 130.2 | 193.2 | 174.5 | 0.0 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **13** | 0.0 | 0.0 | 68.6 | 0.0 | 0.0 | 0.0 | 140.2 | 140.3 | 77.8 | 117.5 | 0.0 | 0.0 | 0.0 |
| | **14** | 122.1 | 90.8 | 0.0 | 172.9 | 195.6 | 0.0 | 207.1 | 144.3 | 107.2 | 141.2 | 207.5 | 0.0 | 0.0 |
| | **15** | 103.4 | 91.2 | 162.6 | 172.5 | 120.5 | 188.8 | 116.1 | 157.6 | 197.3 | 149.6 | 182.3 | 0.0 | 0.0 |
| | **16** | 61.8 | 0.0 | 113.7 | 0.0 | 0.0 | 0.0 | 106.8 | 101.2 | 71.2 | 0.0 | 0.0 | 108.3 | 120.8 |
| | **17** | 71.8 | 55.1 | 51.3 | 82.3 | 60.4 | 60.5 | 92.5 | 0.0 | 0.0 | 85.2 | 98.6 | 0.0 | 0.0 |
| | **18** | 83.5 | 0.0 | 82.8 | 0.0 | 0.0 | 0.0 | 111.8 | 66.8 | 99.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| | **19** | 88.9 | 68.7 | 67.0 | 60.8 | 0.0 | 0.0 | 84.7 | 63.7 | 90.9 | 0.0 | 133.1 | 0.0 | 0.0 |
| | **20** | 0.0 | 63.1 | 54.1 | 0.0 | 84.5 | 0.0 | 0.0 | 69.7 | 0.0 | 68.1 | 52.9 | 84.9 | 0.0 |
| | **Total** | **1444.6** | **1114.4** | **1564.0** | **704.0** | **1117.5** | **820.1** | **1993.2** | **2089.5** | **1480.4** | **1616.7** | **1318.1** | **751.7** | **544.1** |
| | **Ave.** | **96.3** | **79.6** | **97.8** | **117.3** | **111.8** | **205.0** | **117.2** | **116.1** | **98.7** | **115.5** | **219.7** | **75.2** | **108.8** |
| | **%surv.** | **78.9** | **73.7** | **84.2** | **31.6** | **52.6** | **21.1** | **89.5** | **94.7** | **78.9** | **73.7** | **31.6** | **52.6** | **26.3** |
| | **%not sur.** | **21.1** | **26.3** | **10.5** | **47.4** | **36.8** | **73.7** | **10.5** | **5.3** | **21.1** | **26.3** | **57.9** | **47.4** | **73.7** |
| | **% died** | | | **5.3** | **21.1** | **10.5** | **5.3** | | | | | **10.5** | | |
| | **1** | 0.0 | 65.8 | 57.6 | 73.4 | 86.6 | 0.0 | 115.5 | 0.0 | 0.0 | 0.0 | 73.4 | 76.2 | 0.0 |
| | **2** | 75.7 | 0.0 | 0.0 | 72.5 | 0.0 | 67.7 | 0.0 | 60.2 | 92.3 | 0.0 | 113.1 | 113.5 | 0.0 |
| | **3** | 0.0 | 92.8 | 0.0 | 101.0 | 123.2 | 72.3 | 117.0 | 91.5 | 63.8 | 64.2 | 175.3 | 0.0 | 0.0 |
| | **4** | 80.6 | 0.0 | 0.0 | 104.1 | 0.0 | 0.0 | 55.9 | 0.0 | 57.8 | 77.4 | 0.0 | 71.8 | 0.0 |
| | **5** | 92.9 | 0.0 | 0.0 | 0.0 | 124.6 | 0.0 | 82.8 | 0.0 | 0.0 | 54.5 | 174.6 | 0.0 | 97.1 |
| | **6** | 121.5 | 105.3 | 0.0 | 119.6 | 164.6 | 98.7 | 0.0 | 195.6 | 82.3 | 0.0 | 203.5 | 103.2 | 112.3 |
| | **7** | 0.0 | 135.1 | 70.4 | 155.3 | 179.4 | 122.6 | 163.6 | 0.0 | 0.0 | 0.0 | 177.2 | 168.5 | 68.8 |
| | **8** | 85.2 | 0.0 | 0.0 | 132.1 | 120.7 | 91.2 | 115.6 | 0.0 | 0.0 | 0.0 | 91.3 | 105.8 | 0.0 |
| | **9** | 96.2 | 0.0 | 113.9 | 69.5 | 0.0 | 0.0 | 87.1 | 0.0 | 148.3 | 0.0 | 126.0 | 99.5 | 94.3 |
| **B** | **10** | 108.3 | 139.2 | 86.7 | 193.9 | 136.5 | 80.9 | 0.0 | 0.0 | 103.2 | 74.4 | 191.4 | 112.7 | 103.5 |
| | **11** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | **12** | 104.4 | 94.8 | 101.8 | 151.0 | 127.5 | 99.3 | 155.2 | 101.7 | 172.6 | 168.1 | 236.1 | 0.0 | 0.0 |
| | **13** | 0.0 | 0.0 | 72.4 | 0.0 | 126.1 | 71.3 | 89.6 | 0.0 | 53.2 | 0.0 | 0.0 | 78.7 | 0.0 |
| | **14** | 78.7 | 112.6 | 177.1 | 89.1 | 161.8 | 82.1 | 121.9 | 0.0 | 113.1 | 146.2 | 156.3 | 165.2 | 69.3 |
| | **15** | 103.4 | 107.0 | 0.0 | 212.2 | 169.3 | 155.6 | 233.6 | 128.7 | 81.7 | 0.0 | 207.7 | 0.0 | 78.0 |
| | **16** | 83.0 | 81.8 | 0.0 | 90.2 | 0.0 | 76.6 | 0.0 | 0.0 | 0.0 | 228.6 | 127.5 | 104.1 | 67.3 |
| | **17** | 95.6 | 0.0 | 0.0 | 0.0 | 53.5 | 0.0 | 75.2 | 59.2 | 60.0 | 0.0 | 63.0 | 116.2 | 71.7 |
| | **18** | 0.0 | 81.4 | 94.4 | 112.5 | 0.0 | 0.0 | 187.3 | 0.0 | 110.3 | 72.9 | 86.8 | 0.0 | 0.0 |
| | **19** | 81.4 | 0.0 | 78.5 | 73.1 | 0.0 | 73.2 | 113.6 | 0.0 | 0.0 | 0.0 | 163.6 | 73.0 | 0.0 |
| | **20** | 0.0 | 89.4 | 0.0 | 0.0 | 75.7 | 0.0 | 54.6 | 62.3 | 52.6 | 0.0 | 64.5 | 0.0 | 0.0 |
| | **Total** | **1206.9** | **1105.2** | **852.8** | **1749.5** | **1649.5** | **1091.5** | **1768.5** | **699.2** | **1191.2** | **886.3** | **2431.3** | **1388.4** | **762.3** |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Ave.** | **92.8** | **100.5** | **94.8** | **116.6** | **126.9** | **91.0** | **117.9** | **99.9** | **91.6** | **110.8** | **187.0** | **81.7** | **84.7** |
| | **%surv.** | **68.4** | **57.9** | **47.4** | **78.9** | **68.4** | **63.2** | **78.9** | **36.8** | **68.4** | **42.1** | **68.4** | **89.5** | **47.4** |
| | **%not sur.** | **31.6** | **36.8** | **52.6** | **21.1** | **31.6** | **36.8** | **21.1** | **63.2** | **21.1** | **57.9** | **31.6** | **10.5** | **47.4** |
| | **% died** | | **5.3** | | | | | | | **10.5** | | | | **5.3** |
| **C** | **1** | 80.4 | 58.0 | 66.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 58.1 | 52.6 | 0.0 | 0.0 | 72.3 |
| | **2** | 87.4 | 63.9 | 0.0 | 0.0 | 0.0 | 66.3 | 64.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | **3** | 0.0 | 0.0 | 63.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 87.6 |
| | **4** | 53.0 | 52.0 | 54.4 | 63.1 | 0.0 | 0.0 | 87.4 | 53.8 | 0.0 | 0.0 | 63.2 | 97.9 | 92.3 |
| | **5** | 0.0 | 0.0 | 59.7 | 0.0 | 0.0 | 0.0 | 0.0 | 61.3 | 0.0 | 0.0 | 68.1 | 75.6 | 94.1 |
| | **6** | 135.4 | 57.6 | 92.7 | 0.0 | 0.0 | 122.1 | 112.3 | 0.0 | 80.6 | 113.4 | 88.9 | 172.0 | 108.6 |
| | **7** | 90.6 | 0.0 | 89.5 | 93.4 | 125.2 | 102.1 | 107.4 | 0.0 | 112.4 | 105.4 | 93.3 | 152.5 | 110.3 |
| | **8** | 0.0 | 0.0 | 89.4 | 0.0 | 67.8 | 0.0 | 0.0 | 105.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | **9** | 68.5 | 91.8 | 0.0 | 71.5 | 79.1 | 0.0 | 0.0 | 0.0 | 58.6 | 0.0 | 0.0 | 0.0 | 106.7 |
| | **10** | 87.5 | 50.0 | 81.2 | 143.2 | 55.7 | 0.0 | 175.6 | 60.9 | 109.4 | 0.0 | 109.5 | 157.6 | 108.9 |
| | **11** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 103.4 |
| | **12** | 0.0 | 110.5 | 84.1 | 108.7 | 79.2 | 118.2 | 83.4 | 64.1 | 94.3 | 91.3 | 131.1 | 144.3 | 0.0 |
| | **13** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 92.1 | 94.7 | 0.0 | 0.0 | 0.0 | 96.3 | 0.0 | 0.0 |
| | **14** | 122.3 | 108.6 | 82.0 | 166.0 | 179.3 | 127.5 | 170.7 | 94.3 | 131.8 | 114.6 | 177.4 | 113.6 | 0.0 |
| | **15** | 104.3 | 95.3 | 0.0 | 90.7 | 0.0 | 0.0 | 83.0 | 0.0 | 107.4 | 0.0 | 169.3 | 157.5 | 72.2 |
| | **16** | 0.0 | 57.5 | 70.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 121.9 | 124.2 | 65.9 |
| | **17** | 0.0 | 56.7 | 0.0 | 0.0 | 0.0 | 83.6 | 0.0 | 95.0 | 0.0 | 0.0 | 93.7 | 0.0 | 84.2 |
| | **18** | 0.0 | 83.8 | 0.0 | 0.0 | 85.1 | 0.0 | 0.0 | 86.4 | 0.0 | 68.4 | 99.2 | 105.9 | 77.2 |
| | **19** | 58.8 | 0.0 | 63.3 | 0.0 | 0.0 | 0.0 | 0.0 | 65.0 | 97.6 | 85.9 | 109.9 | 0.0 | 70.0 |
| | **20** | 0.0 | 62.4 | 63.6 | 0.0 | 0.0 | 57.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 61.4 |
| | **Total** | **888.2** | **948.1** | **960.3** | **736.6** | **671.4** | **769.2** | **978.7** | **686.3** | **850.2** | **631.6** | **1421.8** | **1301.1** | **1315.1** |
| | **Ave.** | **88.8** | **72.9** | **73.9** | **105.2** | **95.9** | **96.2** | **108.7** | **76.3** | **106.3** | **90.2** | **142.2** | **100.1** | **87.7** |
| | **%surv.** | **52.6** | **68.4** | **68.4** | **36.8** | **36.8** | **42.1** | **47.4** | **47.4** | **42.1** | **36.8** | **52.6** | **68.4** | **78.9** |
| | **%not sur.** | **47.4** | **26.3** | **31.6** | **63.2** | **57.9** | **57.9** | **52.6** | **52.6** | **47.4** | **57.9** | **47.4** | **31.6** | **21.1** |
| | **% died** | | **5.3** | | | **5.3** | | | | **10.5** | **5.3** | | | |