CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Variation and change in climate has become an issue in recent time because of its impact on natural eco-systems, and agriculture is one of the most likely operations affected by this climate change (Adamgbe and Ujoh 2013). Climate variability remains one of the most critical determinants of inter-annual crop output, including high yield (Kang et al, 2009). Changes in temperature and precipitation as a result of global climate change could have severe implication on hydrologic cycle processes, water resources accessibility, irrigation water use and hence upsetting agricultural production and output (Abeysingha et al., 2016).

Water availability has been identified as one of the threats to crop production and food security (Kang et al, 2009). Relatively, only a four percent of the total arable land in sub-saharan Africa is irrigated (ACPC, 2011). This means that agriculture is predominantly rain-fed which makes the sector particularly vulnerable to the vagaries of climate variability and change. Agriculture is the main source of livelihood and Gross Domestic Product in some African countries and is the most vulnerable to climate change and variability (Mendelson et al., 2008).
Climate change has been a threat to sustainable development in South Eastern Nigeria in general. Gornall et al (2010) also stated that climate change is expected to threaten agriculture and established farming systems. Agriculture being the main stay of our national development is sensitive to climate change. Anyadike (2009) said that climate change is a situation in which a change in climate continues in one direction, at rapid rate and for an unusual long period of time. Climate change has been defined by the intergovernmental panel on climate change (IPCC) in Eboh (2009) as statistically significant variations that persist for an extended period typically

decades or longer and it includes shifts in the frequency and magnitude of sporadic weather events as well as the slow continuous rise in temperature. These changes occur due to variations in different climate parameters such as temperature and precipitation. Eboh (2009) highlighted that climate change could manifest in a number of ways viz: changes in average climate conditions – some regions may become drier or wetter on average, changes in climate variability of rainfall events may become more erratic in some regions. Ozor (2009) explained that with increasing incidences of flooding, erosion, bush burning, pest and diseases, increased temperature, erratic rainfall and drought, it becomes pertinent that agricultural productivity under these circumstances will be very low. The low yield will change the supply and demand pattern, and thus commodity prices, the profitability of farming and affordability of food and food security.

The major impact of climate variation on agriculture will come from changes in temperature, rainfall, ultra violet radiation and carbon dioxide levels (Adamgbe and Ujoh, 2013). Long term shifts in seasonal climatic patterns and increases in the intensity of weather extremes are already disrupting agriculture. It is also observed that variability in rainfall characteristics has the chance to significantly influence crop production (Adamgbe and Ujoh, 2013). With this, regions of Nigeria like the Southeastern region with predominantly rural economies and low levels of agricultural diversification are at greater risk. A large proportion of the region depends on rain-fed agriculture with poor technology, low finance and low political and social capacity to adapt to the changing climatic conditions. Agricultural production pace in Nigeria has not met up with food production in decades and there is chance for further decrease in food production. This decline is caused by many factors especially climatic factors (Chikezie et al 2015). Climate change is a global issue and its impact is more serious in developing countries considering the regions limited human, institutional and financial capacity (UNFCC, 2007). Climate change is marked with increased intensity of storms, drought and flooding, altered hydrological cycles and precipitation variance and these have implications for future food availability (FAO, 2007).

Relevant studies by Nwaiwu et al., (2014), Nwajiuba and Onyeneke (2010) and Odjugo (2010) show that there is variability in Nigerian rainfall and temperature. Amel (1992) is of the opinion that variations in climate may affect changes in rainfall distribution, which will have significant effect in agricultural production. FAO (2006) estimated 25% loss of cereals in developing world as a result of weather conditions. Crop yield in Africa may fall by 10-20% by 2050 or even up to 50% due to climate change (FAO, 2006). With the above statistics, climate change is indeed a worldwide issue, and portends capacity to reduce agricultural production. Hence it is important to address sustainable development in agriculture in Nigeria especially the southeast where agriculture is largely rainfed. Higher temperature and changing precipitation are unfavourable for agricultural production, especially crops (Yesuf et al 2008). According to (Grace, 2009), agricultural production is sustainable when it produces food using natural resources and farming techniques that protect the environment. The main changes in climate parameters in Nigeria are the late onset and early cessation of rainfall, and rising temperatures. These have consequences for farmers decision and management including eneterprise choice and management. These are postulated to have implications on choice of crops to be planted, date of planting and harvesting. There have been numerous studies of climate change, the bulk of these were conducted in temperate and highly industrialized countries. Developing countries like Nigeria do not contribute much to climate change but there is evidence of the impact on the countrys agricultural productivity. Climate change will make the task of increased production especially in sub-saharan Africa difficult. A 2°C rise which is median, will lead to unusual changes in agricultural production and available water. The challenge is to produce more but in ways that will protect the environment, especially soil and water, while minimizing agricultural contributions to climate change. While temperature is the most critical climate determinant of the length of growing in the temperate region environment (Ayoade, 2002), in the tropical region like Nigeria, rainfall is the determinant Heavier than normal rainfall and drought in south eastern part of the country have in time past led to destruction of crops in the field leading to greater post harvest losses, loss of arable land and increased growth of weeds. The affordability of the crops become a very big problem to the farmers and the consumers at a large.

Soil structure also affects soil performance which in turn leads to poor crop yield. Soil physical properties like least limiting water range, bulk density, particle density are used in determining soil compaction which is mainly caused by improper use of farm machinery. Soil bulk density, penetration resistance and water movement in the soil are all indices of soil compactness and porosity and they depend on the depth and method of tillage (Jabro et el., 2010), they also stated that Assessing the effect of tillage depth and method on these soil physical properties may explain variability in crop growth, crop development, crop yield and quality. Tillage has been part of most agricultural systems throughout history because it achieves many agronomic objectives, but excessive tillage affects soil quality, crop productivity and environment by affecting soil structure (Kahlon and Singh 2014)

Compaction from farm machinery and other implements has led to poor soil structure which affect water storage and this in turn affects soil moisture content, soil temperature and crop yield. There is need for proper soil treatment to correct poor soil structure through soil compaction indices like the least limiting water range, maintaining the moisture content in this range leads to good crop yield in a poor soil structure.

1.2 Statement of the problem

Optimum crop yield will help solve food and poverty problem especially in Southeastern Nigeria. Year round farming through rain-fed Agriculture and cost effective irrigation system has helped reduce poverty in developed parts of the world. Optimum crop yield is mainly as a result of two factors; adequate climatic factor, (precipitation and temperature), and good soil structure, which gives rise to good soil quality. Good soil structure improves aeration, infiltration, water storage and transport of nutrients in the soil and reduces runoff and erosion which leads to high crop yield.

In Southeastern part of Nigeria, mostly rainfed agriculture is practiced, little irrigation is in practice and this has resulted in loss of agricultural products through drought and flooding. Poor soil structure as a result of compaction caused most times by agricultural implements has also reduced soil quality, leading to erosion, poor infiltration and poor crop yield.

With the problem above, there is need to develop a drip irrigation system for dry season farming and also obtain the irrigation parameters for the desired water needed for plant growth without waste. Soil physic-chemical properties are also necessary to repair damaged soil structure, in a situation where the damaged soil structure cannot be repaired, there is need to maintain the range of soil moisture content necessary for crop growth.

1.3 Aim and Objectives

The aim of this study is to model the effects of different soil treatments (tillage, irrigation and NPK fertilization) on crop yield. The objectives of the study are:

1. To develop and evaluate a simple PVC drip irrigation system and obtain the irrigation parameters.
2. To evaluate the effects of soil treatments under different tillage practices and soil depths on soil physico-chemical properties, yield components and the interactions and spatio temporal dynamics of important parameters relevant for crop growth and productivity.
3. To evaluate the least limiting water range under different tillage practices and soil depths.
4. To optimise the process parameters of the variables (Irrigation deficit, NPK application rate and tillage) and responses (crop yield, soil moisture content and soil temperature) using response surface methodology.

1.4 Justification/ Significance of the Study

Variations in climatic factors which are mainly from excessive or little precipitation and temperature affect crop yield and this can lead to extreme events like drought and flooding, which in turn leads to runoff, erosion, poor aeration, poor infiltration and the end product is poor crop yield. Poor soil structure from compaction caused by vehicular movements also affects the soil physical properties, leading to poor soil quality which increase runoff and erosion, reduces infiltration, poor transport of nutrients in the soil with a resultant effect of poor crop yield. The study helped to obtain the exact amount of water needed for crop growth without wastage through determination of irrigation parameters using developed drip irrigation. Soil physico-chemical properties was also obtained to know the extent of damage caused by compaction from vehicular and other movements, this was done at different tillage methods, different NPK application rate and different irrigation management allowable depletion and the best management practice was also obtained from the interactions of the factors.

1.5 Scope and limitation of the study

The research essentially covers;

1. Use of three tillage methods (conventional, conservative and no tillage for the study area.
2. Installation of drip irrigation for the determination of irrigation parameters using *Zea maize L* variety Oba super 13 as test crop.
3. Using the critical energy of soil moisture to determine the least limiting water range of the area.
4. Obtaining the soil physico-chemical properties for the area
5. The study was carried out in one year, hence it has the limitation of giving different results if continued for over a period of 5 years because of variation in climatic factors.

CHAPTER TWO

LITERATURE REVIEW

2.1 Irrigation and Types of Irrigation Scheme

Irrigation is the application of water to the land to provide adequate moisture for crop production. Phocaides (2007) also defined irrigation as the application of water, supplementary to that supplied by precipitation for the production of crops. Man cannot depend solely on rainfed Agriculture for his activities without supplementary application of water hence the need of artificial application of water cannot be underestimated in achieving a sustainable agriculture. Agriculture is the greatest user of water resources in the world totalling 70% of total withdrawals and over 80% of the consumptive use of water (Baudequine and Molle, 2003). Notably, there are large regional variations from 88% in Africa to less than 50% in Europe. Ascough and Kiker (2002) stated that irrigated agriculture is the largest user of water resources in South Africa accounting for 53% of the total annual amount used.

In dry areas, rainfall is not enough for most crops hence irrigation makes up for the shortage. Crops suffer from moisture shortage even in areas of high seasonal rainfall for short period (USDA, 1984). These brings the importance of irrigation for great yield in crop production. Irrigation has its limitations hence there is need for calibration and irrigation scheduling for proper use of water. According to Phocaides (2007), there are two basic types of irrigation systems, namely open canal systems and pressurised piped systems. Sherer (2005) also stated that there are four basic methods of applying water, they are subsurface irrigation, surface irrigation, drip irrigation and sprinkler irrigation.

2.1.1 Surface irrigation

Surface irrigation is applying water over the land surface by gravity. It is the most common type of irrigation and is practiced all over the world virtually unchanged for thousand, of years. At times, surface irrigation is referred to as flood, were water is not controlled and water is not always enough. There are three major types of surface irrigation; basin, furrow and border.

Basin irrigation has been used in small areas having level surfaces that are surrounded by earth banks. In basin irrigation, water is applied in the whole area and allowed to infiltrate. Basins can be linked together so that excess water from water basin can drain into another. A closed type basin is one that water is not allowed to drain from one basin to another. Basin irrigation is favoured in soils with low infiltration rates.

Furrow irrigation is carried out by creating small parallel channels along the field length in the direction of the predominant slope, water is then applied at the top end of each furrow and flows down the field under gravity. Application of water may be through the help of gated pipe, siphon and head ditch. Slope, surface roughness and shape of the furrow determines the speed of water movement but most importantly by the inflow and infiltration.

The process of infiltration can be described using four phases. As water is applied to the top end of the field, it will flow over the field. The advance phase refer to length of time as water is applied to the top of the field and flows or advances over the field length. After the water reaches the end of the field, it will either runoff or start to pond. The period between the end of the advanced phase and the shutoff of the inflow is termed wetting, ponding or storage phase. As the inflow ceases, the water will continue to runoff and infiltrate until the entire field is drained. The depletion phase is that short period of time after cut-off when the length of the field is still submerged. The recession phase describes the time period while the water front is retreating towards the downstream end of the field. The depth of water applied to any point in the field is a function of the opportunity time, the length of time for which water is present on the soil surface.

2.1.2 Sprinkler irrigation

This is creation of artificial rainfall. Water is carried to the field through pressured pipes, sprinkler and rotating nozzles distribute the water

2.1.3 Drip irrigation

Africa experiences extensive period of drought and inadequacy in rainfall and these cause food shortage in the continent. There is need to create technology for efficient water usage to improve water management as nature cannot be controlled. Drip irrigation system is one type of technology for improvement of water supply management and food crisis. These systems use low flow rates and low pressures at the emitters and are typically designed to only wet the root zone and maintain this zone at or near an optimum level. This conserves water by not irrigating the whole area of land. Some advantages of the drip irrigation system are smaller wetted surface area, minimal evaporation and weed growth, and potentially improved water application uniformity within the crop root zone by better control over the location and volume of water application.

In recent years, low-pressure drip irrigation (LPDI) systems have been developed for smaller farming areas. For many subsistence farmers, a standard pressurised system is too expensive and complicated, as pressurized systems are intended for large areas of land, and therefore do not match the needs of small subsistence farming (Bustan and Pasternak 2008). This system works with gravity power and are low water pressure; there is no longer a need for operation by an outside power source, thus reducing the initial cost. With the bottom of water reservoir sitting at 1-2m above the ground, these systems can generate a flow of about $1m^3/h$ (Phocaides, 2007).

Drip systems provide not only the potential to irrigate more frequently but also the ability to more readily maintain specific moisture deficits at a level below field capacity either for part or all of the irrigation season. The potential water application efficiency of drip irrigation systems is often quoted as greater than 90%. The ability to achieve this high level of efficiency is a function of the design, installation and management practices. Losses of water through irrigation occur mainly through evaporation from the soil surface, surface runoff and deep drainage.

2.1.3.1 Advantages of drip irrigation

(1) Drip irrigation uses water efficiently: sprinklers waste a lot of water as a result of wind scattered spray, sun-powered evaporation, runoff, the evaporation of accumulated puddles, or deep leaching.

(2) It provides precise water control: every part of a drip irrigation system can be constructed with an exact flow rate. It is very easy to calculate what the total flow of the system amounts to and to match this with the plants needs.

(3) It can be used for slow, gradual application of tiny amounts of water on a frequent or daily basis. This maintains an ideal soil moisture level, promoting more abundant foliage, greater bloom, and higher yields of produce, fruits and nuts than those produced by any other irrigation approach.

(4) Provides better control of saline water, sprinklers apply water to the foliage, if water is saline, this can cause leaf burn, drip irrigation applies water only to the soil, and frequent applications with drip irrigation help to keep the salts in

solution so they don’t affect the roots adversely. Any salt crust buildup at the margins of the moist area can be leached away with occasional deep irrigation.

(5) The small moist spot around each emitter, where the water slowly dribbles out, covers only a fraction of the soils surface. The larger dry areas between emitters remain too dry for weed seeds to sprout.

(6) Drip irrigation systems eliminate tedious and inefficient hand watering. Automatic drip systems add the convenience of not even having to remember to turn valves on and off by hand. The initial installation of such a system, however, will take more time and effort than all other forms of irrigation except permanent sprinkler.

(7) Reduces disease problems, without the mist produced by sprinkler, a drip-irrigated plants are less likely to develop water-simulated diseases such as powdery mildew, leaf spot, shot-hole fungus, fire-blight, and scab. Furthermore, careful placement of emitters away from the trunk of trees, shrubs, perennials, vegetables and stalks of cereals will keep the crown of the root system dry and minimize such root problems as crown rot, root rot, collar rot, and armillaria root rot.

(8) Provides better water distribution on slopes, sprinklers often create wasteful run-off when set to water the upper slopes of hills or berms. Drip emitters can apply the water slowly enough to allow all the moisture to soak into the soil. Some emitters, known as pressure-compensating emitters are designed to regulated the water flow so that all emitters in the system put out the same gentle flow, regardless of slope.

(9) Promotes better soil structure, heavy sprinkler irrigation can produce puddles, causing clay particles to stick together, and increase soil compaction. Drip-applied water gradually soaks into the ground and maintains a healthy aerobic soil which retains its loamy structure.

(10) Conserves energy and uses low flow rate.

2.1.3.2 Limitations of drip irrigation

(1) Initial costs are high, a garden hose with a simple oscillating sprinkler will always be cheaper than drip irrigation, but it doesn't offer the same measure of control and water conservation. A well-designed drip system will repay the cost of installation in reduced effort, fewer irrigation chores and greater yields.

(2) Weeding can be difficult, especially with surface drip irrigation and unmulched drip irrigation system will stimulate some weeds around each emitter and care must be taken not to damage the drip system while weeding. A protective and attractive layer of mulch will greatly reduce if not eliminate it.

2.1.4 Performance evaluation of drip irrigation

The performance of drip irrigation systems is heavily influenced by the uniformity of flow through each emitter along a drip line, unlike other systems, the uniformity of drip irrigation is not only a function of the design characteristics but is also significantly affected by installation, maintenance and management practices. Therefore, measuring application uniformity in drip irrigation systems is important component of performance evaluation and assessment of the likely system longevity. Discharge uniformity may be assessed by measuring discharge from a number of emitters using a catch can methodology. Pressure may be measured at the flush point or end of the lateral using a standard pressure gauge or at specific points along the lateral using a needle point pressure gauge inserted directly through the tape or tube. Gul et al (2014) assessed the appropriateness of various uniformity coefficients for drip irrigation systems including the traditional Christiansen (1942) equation as used by a number of workers. Acceptable flow rate 10-20% (Qvar), uniformity coefficient (UC) should be greater than 90%, and coefficient of variation (CV) between 1-20%.

Some of the performance evaluations are:

- **Uniformity coefficient (UC)**

  This can be calculated using equation (2.1) (Christiansen 1942 and Kara et al 2008)

$$UC = 100\ X\ [\ 1 - \left(\frac{\frac{1}{n}\sum_{i=1}^{n}\{q_i - q_z\}}{q_z}\right)] \tag{2.1}$$

Where: q_i = discharge

q_z = mean of discharge (q_i)

- **Distribution efficiency (DU)**

  This is calculated using equation (2.2) (ASTM, 1998):

$$DU = \frac{M_{25}\ X\ 100}{M} \tag{2.2}$$

Where: M = average value of all catch can readings

M_{25} = average of lowest 25% of readings.

- **Coefficient of variation (CV)**

  This is calculated using equation (2.3)

$$CV = \frac{s}{q} X\ 100 \tag{2.3}$$

  Where, s = standard deviation of emitter flow rate

  q = mean of discharge

- **Flow variation (Q_{var})**

  It is calculated using equation (2.4)

$$Q_{var} = \frac{100\ X\ (Q_{max} - Q_{min})}{Q_{max}} \tag{2.4}$$

  Where, Q_{max} = maximum emitter flow rate

  Q_{min} = minimum emitter flow rate

- **Scheduling coefficient based on lowest 25% ($SC_{25\%}$)**

  It is determined using equation (2.5)

$$SC_{25\%} = \frac{1}{DU} \tag{2.5}$$

  Where, DU = Uniformity coefficient

2.1.5 Application efficiency of drip irrigation

It is the ratio of water stored in the root zone of plants to the water applied to the land. It is a measure of how effective the irrigation system is storing water in the crop root zone (Abdulrazzaq and Jahad, 2014). It is obtained by the expression in equation (2.6)

$$ŋa = \frac{wz}{wl} X 100 \quad (2.6)$$

where $ŋa$ = water application efficiency%

wz = Amount of water stored in root zone

wl = Amount of water applied to land

Table 2.1 Potential application efficiencies for irrigation systems

Irrigation methods	Application efficiency
Surface Irrigation (border, furrow, basin)	60%
Sprinkler Irrigation	75%
Drip Irrigation	90%

Source: Irmak et al 2011

2.2 Soil and plant water concepts

2.2.1 Soil water potential

Soil water potential is expressed in energy terms (bars or MPa). The difference in energy between pure water and that of soil water at standard pressure and temperature is called the soil water potential. The soil water potential is expressed as ((Don Scott, 2000) in equation (2.7).

$$\Psi_t = \Psi_g + \Psi_m + \Psi_p + \Psi_o \quad (2.7)$$

Where, Ψ_t = the total soil water potential energy

Ψ_g = the gravitational potential energy

Ψ_m = the matric potential due to capillary pressure

Ψ_p = the pressure potential

Ψ_o = the osmotic potential due to salts

2.2.2 Soil water content

Soil water content or moisture content is the quantity of water contained in a soil material, which can range from 0 (completely dry) to the value of the materials' porosity at saturation. They can be determined in laboratory with soil moisture equipments or in the field with time-domain reflectometry (TDR), hygrometer or a neutron probe. Soil water content is expressed as the mass of water in unit mass of soil (gravimetric) or as volume of water in unit volume of soil (volumetric) (Lars et al 2014).

Soil water content is given on a volumetric or mass (gravimetric) basis. Soil moisture content can be improved by 1 to 10 g for every 1 g increase in soil organic matter (SOM) content (Lars et al 2014).

Gravimetric water content (Θ_g) is measured by weighing the soil when (m_{wet}) and again after drying at 105°C (m_{dry}) as in equation (2.8).

$$\theta_g = (m_{wet} - m_{dry})/m_{dry} \tag{2.8}$$

Where θ_g = gravimetric water content

m_{wet} = mass of wet soil

m_{dry} = mass of dry soil

volumetric water content (Θ_v) is the volume of liquid water per volume of soil, and can be calculated from Θ_g using bulk density (ρ) as in equation (2.9) to (2.11).

$$\Theta_v = volume_{water} / volume_{soil} \quad (2.9)$$

$$= \left(\frac{m_{water}}{\rho_{water}}\right) / \left(\frac{m_{soil}}{\rho_{soil}}\right) \quad (2.10)$$

$$= \Theta_g \; X \; \rho_{soil} / \rho_{water} \quad (2.11)$$

Where, Θ_v = volumetric water content

m_{water} = mass of water

m_{soil} = mass of soil

ρ_{water} = density of water (1.0g/cm^3)

ρ_{soil} = density of soil

2.2.3 Moisture characteristic and concepts of available water

The energy of soil water and soil water content are related by the moisture characteristic (Prunty and Casey, 2002). In saturated soil, all pores are filled with water and the water potential is zero. As suction is increased, progressively smaller pores drain so the soil water content decreases and the water potential becomes more negative. At very high suctions, only the very small pores retain water. In light to medium textured soil, (sands, sandy loams, loams and clay loams), soil structure affect the soil moisture characteristics, while in heavy textured soils, the influence of structure is less distinct.

2.2.3.1 Field capacity

Field capacity is defined as the water content of the soil following drainage of a saturated soil profile underlain by dry soil for about 24-48 hours depending on soil types (Hardy, 2004). The soil water potential at field capacity is variously defined as around -0.1bar to -0.3bar (-0.01to -0.03MPa) depending on soil texture and whether the soils have been saturated.

2.2.3.2 Permanent wilting point

The permanent wilting point is the soil water content at which plants are unable to absorb soil water, and it wilts permanently. The soil water potential at this point is usually considered to be -15bars, although the actual value will depend on the plant type and demand for water.

2.2.3.3 Available water

The available water in a soil is the amount of water that can be utilized by plants for their growth and development. It is commonly taken to be the difference between the water content at field capacity and the permanent wilting point.

2.2.4 Soil water movement and hydraulic conductivity

The hydraulic head determines the direction and rate of water movement, water moves from soil with lower to higher potential. The hydraulic conductivity is a measure of the ability of the soil to conduct water and depends upon the permeability of the soil to water (Don Scott, 2000). Knowledge of the hydraulic conductivity of soil is important to the understanding of soil-water behaviour including the movement of water and solutes within the soil profile and studies of water uptake by plant roots. Hydraulic conductivity depends greatly on soil water content, so it is often determined in both the saturated and unsaturated condition (Lal and Shukla, 2004). Saturated hydraulic conductivity pertains to the conductivity of soil when pores are partially filled.

2.2.5 Management allowable depletion (MAD)

Also known as management allowable deficit is the portion of plant available water that is allowed for plant use prior to irrigation based in plant and management considerations, usually a percent of the available water capacity.

It is defined as a practice whereby a crop is irrigated with an amount of water below the full requirement for optimal plant growth; this is to reduce the amount of water used for irrigation, improve the response of plants to certain degree of water deficit in an acceptable manner, and reduce irrigation amounts or increase the crops water use efficiency (WUE) (Qiang et al (2016). This is the desired soil moisture deficit at the time of irrigation, the portion of available water that is scheduled to be used prior to the next irrigation, the planned soil moisture deficit at the time of irrigation. It is the amount of water that can be withdrawn from the soil between irrigation events without stressing the crop to the point where significant reductions in crop yield or quality are experienced. If the MAD is known, the soil water balance can also show the maximum time allowable between irrigation. Commonly, a crop should be irrigated before reaching the MAD level.

Deficit irrigation is a valuable and sustainable production strategy in dry regions. There is lack of understanding of how plants respond to deficit irrigation, little is known about how deficit irrigation might increase crop production while reducing the amount of irrigation in real world agriculture.

Water deficit irrigation is defined at the following levels; (Qiang 2016)

(1) Severe water deficit- Soil water is less than 50% of the field capacity;

(2) Moderate water deficit- Soil water is remained between 50 to 60% of the field capacity,

(3) Mild water deficit- Soil water is remained between 60 to 70% of the field capacity;

(4) No deficit or full irrigation- Soil water is generally greater than 70% of the field capacity during the key plant growth period; and

(5) Over irrigation- The amount of water irrigated may be greater than what plants would require for optimal growth

2.2.6. Soil water balance

The soil water balance can be variously expressed. For irrigation research as in equation (2.12).

$$ASW_1 = ASW_2 = P + 1 - (ET + Ro + D) \quad (2.12)$$

ASW is available soil water at times 1 and 2. (ASW_1 – ASW_2) is the change in soil water during the interval t_1 to t_2, and P = precipitation, I = I irrigation, ET = evapotranspiration, R_o = surface runoff and D = deep percolation beyond the root zone, all for the interval t_1 to t_2 (Sankara and Yellamanda, 1995). If ASW_1 is the desired state and ASW_2 is the present state, then irrigation required to return the soil water to the desired state, (ASW_1 – ASW_2) can be estimated by assuming R_o and D are zero as in equation (2.13).

$$Irrigation\, requirment = ET - (I + T) \quad (2.13)$$

In budgeting approaches in irrigation scheduling, ET is estimated from potential evaporation combined with the use of a crop coefficient (Hartz), 1999). Sankara and Yellamanda (1995) suggested a simplified water balance equation, used by Burt (1999) to calculate the components of the water balance when water was applied to a bare soil surface as in equation (2.14).

$$E = I - D \quad (2.14)$$

Where E = Evaporation, I = Irrigation and D = Drainage.

2.2.7 Monitoring soil and plant water in irrigation scheduling

Successfully operating and managing an irrigation system requires a proactive monitoring approach to managing soil water. There are three approaches to monitoring and scheduling irrigation, as stated by Goldhamer and Snyder (1989).

(a) Soil plant methods that estimates soil water status by its appearance , feel or more objectively, by water content or suction.

(b) Plant-based methods which includes visible symptoms such as wilting, that reflect leaf turgor and thus indirectly leaf water potential, and non contact thermometry with an infrared thermometer (a water stressed plant transpires less and is cooled less by evaporation).

(c) The water budget approach, which estimates crop water use from weather data and, from this, irrigation requirement.

Measurements of soil water can be used to indicate when to irrigate, thus avoiding over and under irrigation. Soil water sensors measure either soil water potential (SWP) or volumetric soil water content (VSWC). Devices for measuring soil water potential include, tensiometer, gypsum blocks, and granular matrix sensor (Shock et al 2005). A variety of FDR (frequency domain reflectore) (Stirzaker et al., 2005), TDR (time domain reflector) (Charlesworth, 2005) and capacitance probes (Fares and Alva, 2000) are available for measuring volumetric soil water content.

2.3 Tensiometer

Tensiometers measure only soil water potential. They do not provide direct information on the amount of water held in the soil (Whalley et al., 1994). The use of tensiometers for irrigation scheduling has been widely reported for over thirty years (Hartz 2000). There has been much research on the appropriate depth of placement and water potential guidelines. Recommendation vary with soil type and crop. The main limitation with tensiometer is that they operate only in water potential up to -75kpa. Further drying leads to breaks in teh water column thus requiring a high degree of of maintenance (Giddings, 2000). Also farmers will often want to deplete soil water beyond the range of the tensiometer, meaning that some interpretation needs to be made.

2.3.1 Granular matrix sensor/gypsum block

The granular matrix sensor is similar to gypsum block, although apparently more durable. It operates on the principle that resistivity of the block depends on its moisture content, which in turn depends on soil water potential. Granular matrix sensors operate in the range 0-0.2 MPa, and therefore have a wider range of application than the tensiometer.

2.3.2 Wetting front detector, capacitance probe/frequency domain reflector.

The wetting front detector, which originated from Australia, is a soil misture monitoring device which can be used to detect wetting fronts. Strirzaker et al., (2005) suggested that the 'Fullstop' wetting front detector might be the simplest one and it comprised of a specially shaped funnel, a filter and afloat mechanism. The funnel of the detector is buried in the soil within the root zone of the crop. If sufficient water or rain falls on the soil to move to the funnel, it passes through a filter.

2.3.3 Time domain reflector

A TDR is an instrument which emits a pulse charge of electromagnetic energy, using sensors buried in the soil. The pulse signal reaches the end of the sensor and is reflected back to the TDR control unit. The time taken for the signal to return is related to the water content of the soil surrounding the probe (Charlesworth, 2005). The use of multi-wire in the TDR provide rapid determination of soil profile water content and offers the capability of mmonitoring the dynamics of the soil water volume around a point source to differentiate soil water conditions at different vertical and horizontal soil volumes (Souza and Matsura, 2003).

2.3.4 Neutron probe

The neutron scattering method (neutron probe) measures volumetric water content of soil indirectly using high energy neutrons emmited from the probe. The neutron probe method is suitable for coarse or medium textured soils but not suitable for measurements near the soil surface and in shallow soils without special calibration.

2.4 Evapotranspiration

According to Brown (2014) the word evapotranspiration is from the combination of the prefix evapo, (from soil evaporation) and the word transpiration, both of which represents evaporative processes. Evapotranspiration is the loss of water from a vegetated surface through combined processes of soil evaporation and plant transpiration.

World Metrological Organization (2008) defined evapotranspiration as the amount of water evaporated in form of water from the soil and plant when the ground is at its natural moisture content. Allen et al gave values for converting Evapotranspiration as shown in Table 2.1.

Table 2.2: Conversion Factor for Evapotranspiration.

	depth	volume per unit area		energy per unit area *
	mm day^{-1}	m^3 ha^{-1} day^{-1}	l s^{-1} ha^{-1}	MJ m^{-2} day^{-1}
1 mm day^{-1}	1	10	0.116	2.45
1 m^3 ha^{-1} day^{-1}	0.1	1	0.012	0.245
1 l s^{-1} ha^{-1}	8.640	86.40	1	21.17
1 MJ m^{-2} day^{-1}	0.408	4.082	0.047	1

Source: Allen et al 2009

2.4.1 Actual evapotranspiration

Actual evapotranspiration was defined by World Metrological Organization (2008) as the quantity of water from the soil and plant evaporated in the form of water vapour when the ground is at its natural moisture content.

2.4.2 Potential evapotranspiration

Suat et al. (2014) defined potential evapotranspiration as the amount of water transpired by a short green crop completely shading the ground, of uniform height with adequate water in the soil profile, in a given time. In potential evapotranspiration short crop can refer to many types of horticultural and agronomic crops that fit into the definition of short green crop. These authors reported that evapotranspiration concept was first introduced in the late 1940 and early 50’s by Howard Penman.

Eagleman (1996) wrote that potential evapotranspiration rate has been used almost exclusively as an estimate of the water required by crops and in defining the aridity of a climate.

2.4.3 Reference evapotranspiration

Suresh (2008) refer to reference evapotranspiration as "evapotranspiration from reference surface without shortage of water". The reference surface is a hypothetical grass reference crop with specific characteristics. This was introduced to study the evaporative demand of the atmosphere, independent of crop type, crop development, and management practices. The soil factor do not affect evapotranspiration as water is abundantly available in the reference surface. Suresh (2008) said that it is only climatic parameters that affect reference evapotranspiration. It does not consider crop characteristics and soil factors. FAO Penman-Monteith method is the most accurate method of determining reference evapotranspiration (Suresh, 2008).

2.4.4 Factors affecting evapotranspiration

World Metrological Organization (2008) reported that "factors affecting the rate of evaporation from anybody or surface can be broadly divided into two groups, meteorological factors and surface factors, either of which can be rate limiting". The meteorological factors is further subdivided into energy and aerodynamic variables. The solar and terrestrial radiation supplies the energy required to change water from liquid to vapour phase. Aerodynamic variables, such as wind speed at the surface and vapour pressure difference between the surface and the lower atmosphere, control the rate of transfer of the evaporated water vapour.

The meteorological factors affecting evaporation to include:

a) Solar radiation: evaporation requires energy input to change the state of the water molecules from liquid to gaseous state, the process is most active under the direct radiation of sun, therefore solar radiation greatly affects the rate of evapotranspiration.

b) Wind: As vaporization takes place the boundary layer between the earth and the air becomes saturated and it must be continually replaced by drier air for evaporation to continue. The removal of this moist air is dependent on wind speed.

c) Relative humidity: At lower humidity the air can absorb more water, but as the humidity increases its ability to absorb water decreases. And for evaporation to be sustained, drier air with less humidity must replace the high humid air.

d) Temperature: As stated in (a) energy input is necessary for evaporation to proceed. In terms of temperature, when the ambient temperature is high, evaporation will proceed more rapidly than when it is low because the capacity of air to absorb water vapour increases as its temperature rises. He also commented that air temperature has a double effect on how much evaporation takes place.

Suresh (2008) discussed the factors affecting evapotranspiration under three subheadings

1. Weather parameters: Evapotranspiration is largely affected by weather parameters; temperature, humidity, solar radiation, wind speed and so on. The fraction of solar radiation that reaches the soil surface is the main factor that determines evapotranspiration and it decreases as crop develops.

2. Crop factors: Crop factors also determines to a large extent the evapotranspiration rate and the include type of crop, stage of growth, e.t.c.

2.4.5 Crop coefficient

Crop coefficient are properties of plant factors used in predicting evapotranspiration (ET). The basic crop coefficient is simply the ratio observed from the crop studied over that observed for the calibrated reference crop under the same condition. It can be calculated from equation (2.15) to (2.16).

$$ET_c = ET_o \times K_c \tag{2.15}$$

Therefore $k_c = \frac{ET_c}{ET_o}$ (2.16)

Important point to note in Suresh's view is that he elaborated on the two types of crop coefficients.

2.4.6 Water balance approaches in irrigation scheduling

The soil water balance represents the integrated amount of water in the soil at a particular time. The water balance method is an indirect way of monitoring water status, using simplifications of the soil water balance equation. It is used to estimate crop water use (Goldhamer and Snyder, 1989) from climatic data (Allen et al 1998).climatic parameters including solar radiation, temperature, relative humidity and wind speed. The combination of soil evaporation (E) and transpiration (T) make up the total water use, vwhich is commonly referred to as evapotranspiration (ET). estimation of evapotranspiration generally uses four factors: reference evapotranspiration (ET_r) based on a specific type of crop, a crop factor (K_{cb}) that describes both the dynamic and seasonal developmental change in the crop evapotranspiration in relation to ET_r, a soil factor (K_{cs}) which describes the effect of low soil water content on transpiration and has close relationship with crop growth parameters such as rooting depth and the soil factor (K_{so}), which describes the evapotranspiration amount from either rainfall or irrigation. The crop water use is represented by equation (2.17) (Allen et al 1998):

$$ET_c = ET_r \left[(K_{cb} K_{cs}) + K_{so}\right] \quad (2.17)$$

The water balance approach was developed in irrigation to estimate ET from large areas. Its application is difficult under drip irrigation because of the multidimensional water application pattern (Lazarovitch et al., 2007).

2.4.7 Measurement of evaporation

Evaporation can be measured in two ways, either directly in the field or indirectly in the laboratory, these methods are;

Lysimeters, Pan Evaporation, Blaney-Criddle Equation, Hargreaves Equation, Thornthwaite Equation, Penman's Equation, FAO penman Monteith's method, ET_o Calculator.

2.4.8 Water use efficiency

Generally, plant growth is directly related to transpiration (T), although under field conditions, changes in soil moisture result from both T and soil evaporation(E) (Hillel, 2004). E and T are commonly summed to give evapotranspiration (ET), which can be measured as a change in soil water. Both farmers and scientists are concerned with water use efficiency. In irrigated crops, efficiency of water use can be affected by the method, amount and timing of irrigation. Water use efficiency has been defined in various ways and it is important to understand the differences. Loomis (1983) defined it as the ratio of dry matter produced (Y) per unit of water transpired by a crop (T), expressed as kg/mm or kg/ha/mm, in equation (2.18), Hiajun et al (2017):

$$WUE = Y/T \tag{2.18}$$

This approach given the biomas production relative to the water actually used by the plant, and should more correctly be termed the 'transpiration efficiency' (TE). The TE of different crops may vary with differences in photosynthetic mechanism (C_3, C_4, and CAM) and vapour pressure deficit (van Keulen 1975) in equation (2.19).

$$WUE = Y_e/ET \tag{2.19}$$

The term Y_e/ET given the agronomic yield of the system relative to total water use, and is a more correct use of the term 'water use efficiency' or agronomic water use efficiency. Soil surface modifications such as tillage and retaining surface residue may influence WUE by reducing soil evaporation (E) and increasing crop transpiration. He noted that factors such as poor soil structure, profile salinity, and irrigation management that restrict the expansion and efficiency of the plant root system will all reduce water use efficiency.

Overall agronomic efficiency of water use (Fag) in irrigated systems is defined by FAO (2012) using an adaptation of the soil water balance as in equation (2.20)

$$Fag = P/U \tag{2.20}$$

Where P is crop production (total dry matter or the marketable yield) and U is the volume of water applied. The components of U are expressed by equation (2.21):

$$U = R + D + E_p + E_c + T_w + T_c \tag{2.21}$$

Where R is the volume of water lost by runoff from the field,

D is the volume drained below the root zone (deep percolation)

E_p is the volume lost by evaporation during the conveyance and application to the field.

E_c is the volume evaporated from the soil surface

T_w is the volume transpired by weeds

T_c is the volume transpired by the crops

In all agricultural systems,, low water use efficiency can occur when soil evaporation is high in relation to crop transpiration. Early growth rate is slow (eg, crop establishment stage), water application does not correspond to crop demand, and also shallow roots are unable to utilize deep water in the profile. This was demonstrated by Patel and Rajput (2007) during the early growth phase of potato.

2.4.9 Crop water requirement

Estimating crop water requirement is important for irrigation planning. It is defined as quantity of water, regardless of its source, required by a crop or diversified pattern of crops in a given period of time for its normal growth under field conditions at a place (Ojha and Michael, 2005). It includes the losses due to evapotranspiration, or consumptive use plus the losses during the application of irrigation water (unavoidable losses) and the quantity of water required for special operations such as land preparation, transplanting, leaching, etc. It is given as (Ojha and Michael, 2005) in equation (2.22):

$$CWR = IR + ER + S \tag{2.22}$$

Where,

IR is the irrigation water

ER is the effective rainfall

S is the soil profile contributions

2.5 Irrigation

2.5.1 Net irrigation

The depth of water application is the quantity of water, which should be applied during irrigation in order to replenish the water used by the crop during evapotranspiration (Megersa and Abdulahi, 2015). The computation of the net irriration requires the following inputs (Diakhate, 2014):

- The available soil moisture (FC-PWP)
- The allowable soil moisture depletion (MAD)
- The effective root zone depth of the crop (RZD)

Soil survey and tests are done to determine the field capacity (FC) and permanent wilting point (PWP) the soil (Mbah, 2012, Silva et al 2015). Shown below in table 2.4 is the maximum effective root zone of some crops , while table 2.5 shows duration within various growth stages of maize

Table 2.3 Effective root zone depths of some common crops

SHALLOW ROOTED (60cm)	MODERATELY ROOTED (90cm)	DEEP ROOTED (100cm)	VERY DEEP ROOTED (180cm)
Rice	Wheat	Maize	Sugarcane
Potato	Tobacco	Cotton	Citrus
Caulifi ower	Castor	Sorghum	Coffee
Cabbage	Groundnut	Pearl millet	Apple
Lettuce	Muskmelon	Soybean	Grapevine
Onion	Carrot	Sugar beet	Safflower
	Pea	Tomato	Lucerene
	Bean		
	Chilli		

Source: Michael (1981)

The maximum net depth to be applied per irrigation can be calculated, using the following equation (Valipour, 2012a) in equation (2.23):

$$d_{net} = (FC - WP) X\ RZP\ X\ MAD \tag{2.23}$$

Where:

d_{net} = readily available moisture or net depth of water application per irrigation for selected crop (mm)

FC = soil moisture at field capacity (mm/m)

PWP = soil moisture at the permanent wilting point (mm/m)

RZD = the depth of soil that the roots exploit effectively (m)

MAD = the allowable portion of available moisture permitted for depletion by the crop before the next irrigation.

2.5.2 Irrigation frequency

This refers to number of days between irrigations during periods without rainfall, it depends on the consumptive use rate of a crop and on the amount available moisture in the crop root zone. (Michael 1999).

It is essential to maintain readily available water in the soil if crops are to make satisfactory growth given optimum yield (Adejumobi et al 2015). The peak daily water use is the peak daily water requirement of the crop determined by subtracting the rainfall (if any(from the peak daily crop requirements (Wang et al., 2011; Wang et al., 2013). Irrigation frequency is the time interval it takes the crop to deplete the soil moisture at a given soil moisture depletion level (Lv et al., 2010, Gao et al., 2010, Wang et al., 2012).

Irrigation frequency is calculated using (Michael, 1999) in equation (2.24):

$$IF = \frac{FC - mc}{Pm} \tag{2.24}$$

Where,

IF = Irrigation frequency (days)

FC = Field capacity of the soil in the effective root zone

mc= moisture content of the same zone at the time of starting of irrigation

Pm = Peak period moisture use rate of crop

2.5.3 Irrigation period

This is the number of days that can be allowed for applying one irrigation to a given design area during the peak consumptive use period of the crop being irrigated, it must be designed that the irrigation period is not greater than the irrigation frequency (Michael, 1999). Irrigation period is given by (Michael, 1999) in equation (2.25):

$$Pi = \frac{N}{Pm} \tag{2.25}$$

Pi = Irrigation Period

N = Net amount of moisture in soil between start of irrigation and lower limit of moisture depletion

Pm = Peak period moisture use rate of crop.

2.5.4 Gross irrigation

This is the total amount of water applied in a field through out irrigation. It equals the net depth of irrigation divided by farm irrigation efficiency (Scagel et al, 2011). The farm irrigation efficiency includes possible losses of water from pipe leaks (Wang et al., 2012a) and is presented in equation (2.26):

$$GIR = \frac{dn}{AE} \tag{2.26}$$

Where

GIR = Gross Irrigation Requirement(cm)

dn = Net Irrigation

AE = Application Efficiency

2.5.5 Irrigation scheduling to improve water use efficiency

Irrigation scheduling means applying water at intervals based on the needs of the crop with the primary objective of managing soil water within defined limits. It is the process by which an irrigator determines the timing, amount and quality of water to be applied to the crop (Bierman, 2005). Vasquez et al (2005) illustrated the difficulty in trying to precisely apply irrigation water with drip irrigation. They compared scheduling using crop evapotranspiration (ET_c) with volumetric soil water content measured by TDR, maize in a silty clay loam. The surface drip had drainage during crop establishment when water was applied at a higher rate than crop evapotranspiration. Sensors must be placed in the active root zone in proximity to the emitter. Sensor placement in drip irrigation varies, but is mostly located midway between emitters (Howell and Meron, 2007).

2.6.1 Lateral spacing and installation

A wider lateral spacing is practiced in heavy textured soil. Lateral spacing is generally one drip line per row (Lamm and Camp, 2007).

2.6.2 Emitter/drip hole spacing

Emitters are plastic devices which precisely deliver small amount of water. Hla and Scherer (2003) described two types of emiters, point source emitters discharge water from individual or multiple outlets, line source emitters have perforations, holes, porous walls, or emitters extruded into the plastic lateral lines (Ayers et al., 2007). Soil characteristics and plant spacing determine emitter spacing. Similarly, an emitter spacing of 0.3m was suitable for corn production for deep silt loam soils under subsurface drip irrigation (Lamm and Aiken, 2005). In a semi-arid environment, 0.45m spacing was used in clay loam soils for drip irrigated corn (Howell et al., 1995). In general, emitter spacing should normally be less than the drip spacing and closely related to crop spacing (Lamm and Camp, 2007).

2.7 Maize production

Maize *(Zea Mays L)* is a monocotylydene belonging to the family *Graminaceae* and trybe *Maydaeae(*FAO 2012). It originated in America from the domestication of a wild grass known as teosante (Zea Mexicana), which later spread to the rest of the world. United states is the largest producer of maize followed by China, Brazil, Russia and Europe (FAO 2012). Africa is a minor producer of maize accounting for 7% of global maize production (FARA, 2009) while Nigeria is the largest producer of maize in Africa followed by South Africa (IITA, 2009)

Table 2.4 Maize yield in Nigeria

DATE	VALUE (HG/HA)	VALUE(KG/HA)	CHANGE
2017	15933	1593.3	-8.93%
2016	17495	1749.5	12.15%
2015	15599	1559.9	-1.58%
2014	15850	1585	8.44%
2013	14616	1461.6	-3.32%
2012	15118	1511.8	-7.09%
2011	16271	1627.1	-12.06%
2010	18502	1850.2	-15.75%
2009	21961	2196.1	12.21%
2008	19571	1957.1	14.79%
2007	17049	1704.9	-6.23%
2006	18182	1818.2	9.54%
2005	15598	1559.8	

Source: knoema.com

2.8 Soil properties

Soil physic seeks to define, measure, and predict the physical properties and behaviour of the soil, both in its natural state and under the influence of human activity. Among soil physical properties, one distinguishes: horizonation, soil colour, texture, bulk density, porosity, soil structure, soil consistence, moisture content, water retention, temperature, infiltration, saturated and unsaturated hydraulic conductivity, penetration resistance.

2.8.1 Soil texture

Soil texture is the relative proportions of sand, silt and clay and also includes particles larger than sand in a soil. These proportions describe the classes of soil texture with a textural triangle. It has a large influence on water holding capacity , water conducting ability, soil structure (Tueche et al., 2007), chemical soil properties and the relative stabilisation of soil organic matter (Bot and Benites, 2005). Moreover, the proportions of sand, silt and clay can significantly correlate diversely with crop yield (Tueche et al., 2013).

2.8.2 Bulk density

Bulk density is an indicator of the amount of pore space available within individual soil layers or horizons, as it is inversely proportional to pore space. A high bulk density above 1.5 (Adekiya and Ojeniyi, 2002; Adekiya et al., 2009) indicates either compaction of the soil or high sand content. The cone penetrometer is useful in determining soil strength and various level of soil compaction. Measurements can be done *in situ* with the static hand penetrometer Eijkelkamp type. Soil compaction can be induced by natural processes (as rain drops impact) and by field traffic of humans, animals and heavy machinery. Excessive soil compaction can impede root growth and therefore limits the amount of soil explored by roots thus reducing the plant's ability to take up nutrients and water.

2.8.3 Soil structure

Soil structure is the way individual particles of sand, silt, and clay are assembled into larger units called aggregates (FAO, 2011). It is caused by the adhesion of those particles by various binding agents which influence soil structure development: amount and type of clay, as well as the exchangeable ions on the clay amount and type of organic matter, (Six et al., 2006); presence of iron and aluminium oxides binding between organic and inorganic compounds (aluminium oxides, cations, clays), e.g. polyvalent cations such as Ca2+, Mg2+ and Al3+;plants roots, bacteria and fungi exude sticky polysaccharidesthat bind soil into small aggregates. The addition of the raw organic matter that bacteria and fungi feed upon favours the formation of desirable soil structure. The destruction of soil structure during land preparation or soil faunal activity decomposing SOM or both, may improve the availability of nutrients to crops. However, aggregation builds intra-aggregate and interaggregate pore space which control water, gases, solutes and pollutants movements in the soil. Thus, soil structure can affect aeration, soil compaction, water relations, soil temperature, resistance to erosion and plant root growth.

2.9 Role of soil hydraulic properties

Knowledge of soil hydraulic properties assists in the design of drip irrigation systems (Mehta and Wang, 2004). Non uniformities in hydraulic properties and infiltration rates are considered to be the major reasons for inefficiencies in drip irrigation and may cause non-uniformities in soil water content and could potentially affect plant growth. Soil hydraulic conductivity is a limiting factor for water uptake by plants under drip irrigation, particularly in sandy soils (Li et al., 2002).

2.9.1 Soil wetting pattern

A basic need for better drip irrigation systems is information about the moisture distribution patter, shape and volume of soil wetted emitter. The volume of wetted soil represents the amount of water stored in the root zone. Its depth should coincide with rooting depth while its width should be related to the spacing between emitters. One possibility for controlling the wetted volume of a soil is to regulate the emitter discharge rate according to the soil hydraulic properties. The wetting front is an important factor in drip infiltration, indicating the boundaries of the wetted soil volume (Battam et al 2003). A simple technique known as the pit method was developed by Battam et al. (2003) for design management of drip systems.

Soil texture is an unreliable predictor of wetting and for adopting different spacing of emitters (Thorburn et al 2003). Under given climatic conditions, effect of soil type on the depth-width-discharge combination is influenced by water holding capacity and hydraulic conductivity of the soil (Thorburn et al, 2003). The wetting pattern with drip irrigation can be affected not only by irrigation management, but also design aspects such as emitter spacing and drip line depth.

2.10 Tillage

Tillage is the agricultural preparation of soil by mechanical agitation of various types such as digging, stirring and overturning.

Manual tillage as commonly practiced in the humid tropics of SSA has a strong impact on productivity in this labour constrained environment. Mechanical tillage has the advantage of cultivating larger area with lower labour demand. But within the humid-tropics, tse-tse fly infestation and the abundance of tree and shrub stumps had limited the development of animal based systems, furthermore, mechanization schemes based on the use of tractors have met with limited success because of high capital costs relative to the capital resources and scale of operation of farmers, as well as the lack of know-how in equipment use and maintenance (personal observation). Nevertheless, farmers in the humid savanna area are increasingly adopting mechanical tillage, here, entrepreneurs may own a tractor and better-off farmers hire tractors by the day. However, the ownership and use of tractors, in the Eastern Nigeria for instance, is rare. This is because in the Eastern Nigeria areas where field sizes are small, forest regrowth and tree and shrub stumps render their movement difficult. Thus, adoption of mechanical tillage tends to be slower in forested areas.

2.10.1 Conventional tillage

This is the sequence of soil tillage such as ploughing and harrowing, to produce a fine seed bed and also the removal of most of the plant residue from the previous crop. This is the traditional way of planting and in which soil is prepared for planting by completely inverting it with a plough (USDA 2014), subsequent working of the soil with other implements is usually preffered to smooth the soil surface.

2.10.2 Conservative tillage

Conservation agriculture has been developed in conventional farming to minimize and prevent soil erosion, reduce labour and energy inputs and preserve fertility (Alteri et al 2011)

It is a tillage system that creates a suitable soil environment for growing a crop and that conserves soil, water and energy resources mainly through the reduction in the intensity of tillage, and retention of plant residues (OECD, 2001). Conservation tillage leaves at least 30% of crop residue on the soil surface, this slows water movement, which reduces the amount of soil erosion. It also benefits farmers by reducing fuel consumption and soil compaction, by reducing the number of times the farmer travels over the field, the farmer realises significant saving in fuel and labour. However, it delays warming of the soil due to the reduction of dark earth exposure to the warmth of sun.

Food and agricultural organisation FAO defined it as a range of practices based on three main principles:

- Minimum soil disturbance obtained
- A permanent soil cover living or mulch cover crops
- Diversified crop rotation

2.10.3 No tillage

This is a way of growing crop from year to year without disturbing the soil through tillage. It is an agricultural technique, which increases the amount of water that infiltrates into the soil, the soil retention of organic matter and its cycling of nutrients. No tillage involves sowing of crops into soil that has not been tilled since the previous harvest

2.10.4 Tillage research in Nigeria

A wide range of tillage methods are used in different regions of humid tropical Africa. In regions of Alfisol such as in Nigeria, grain crops are planted on ridges, heaps and manually cleared soils. Reduced tillage is gaining ground especially in areas susceptible to water erosion. Studies conducted in the humid tropics of Nigeria dealt with mechanised and herbicide-dased zero tillage (Lal, 1976; Olaoye, 2002) and manual clearing (Ojeniyi and Adekayode, 1999, Ojeniyi et al, 2000). Most of the studies found out that the crops benefited from tillage (Ojeniyi, 1989, 1991) although Olaoye (2002) who worked in the derived savanna zone of Nigeria found that zero tillage soil had least least bulk density and highest yield compared with ploughed soils. Tillage systems are sequences of operations that manipulate soil in order to prepare good seed bed for crop production. The ways in which these operations are implanted affect physical and chemical properties of the soil which in turn affect plant growth.

In a study of the effect of tillage system of soil properties and yield of Oba 98 variety using three year field trials in Zaria Nigeria by Namakka et al., (2014), tillage practices enhanced soil nutrients with higher cation exchange capacity, highest cations and anions concentrations due to organic matter accumulation in the soil, improved soil structure that resulted to better grain yield of maize. The study suggested that conservative tillage enhances good soil structure and nutrients production. Obalum et al, (2011) in a study to monitor the short term effects of tillage mulch practices under sorghum and soybean in Nsukka, Nigeria subjected a sandy loam soil to no till, conventional tillage, bare fallow and mulch cover. The study suggested that cropping conventional tillage with mulch cover soil to soybean could be a promising agronomic combination for enhancing the soil organic carbon and fertility status of the soil. Aiyelari et al., (2002) studied the effects of tillage practices on growth and yield of cassava and some soil properties in Ibadan, Southwestern Nigeria. The tillage practices were heaping, no-till + herbicide, ridging and no till-slash and burn, results revealed that tillage practices had no significant effect on sprouting percentage in 1994 but in 1995, heaping treatment was significantly ($P<0.05$) higher than others. Tillage had no marked effect on cassava height in both years while number of leaves only differed significantly ($P<0.05$) 8 months after planting with heaping treatment higher than others. There is need for further investigation into the effect of reduced tillage without residue, minimum disturbance of the soil through conservative tillage and proper tilling through conventional tillage.

2.11 Penetration resistance (PR)

The agriculture industry benefits from this in the identification of high compaction areas, plough plans, and clay zones to help determine appropriate irrigation, fertilization and cultivation practices. This is achieved by the use of penetrometer. The penetration resistance can be calculated from the pentrometer using (Herrick et al, 2002) in equation (2.27)

$$\text{Soil resistance} = \frac{Penetrometer\ \ reading\ (N)}{base\ area\ of\ penetrometer\ \ cone\ (cm^3)} \tag{2.27}$$

2.12 Least limiting water range (LLWR)

Water is primary factor in limiting crop production. Water deficiency is not only due to rain and its poor distribution but also due to poor structural quality of soil. Many soil physical properties have potential to limit crop production. Plant growth is affected by soil hydro-physical characteristic such as soil water content, aeration and penetration resistance (PR). A method called non limiting water range (NLWR) has been first developed by Letey (1985) to account for each of these limiting soil physical conditions. This concept was later improved and renamed as the least limiting water range (LLWR) by Silva *et al* (1994).The limits and definitions of both NLWR and LLWR are the same and it is just a change in term from “non-limiting” to “least limiting”

Tillage is the most effective way to modify soil surface characteristics due to its effect on pore space. The least limiting water range (LLWR) is defined as the range of soil water content in which there are minimal limitations to plant growth, considering water availability, air-filled porosity, and soil mechanical resistance (Sato et al, 2016). The LLWR expresses the effects of different management systems on the improvement or degradation of soil physical quality. Thus, it is difficult to define critical limits beyond which crop growth and development is impaired (Renato et al, 2009). Integration of dynamic soil physical properties using the LLWR approach may allow a better understanding of soil–crop relationship in tillage and cropping systems, particularly in regions with limited precipitation and low SOM (Filho *et al*, 2013). In agricultural areas, soil management can lead to change in its structure, mainly due to compaction and subsequently, soil *ρb* can reach values outside the limits in which conditions are ideal for plant growth. Soil management decisions often aimed at improving or maintaining the soil in a productive condition. Several indicators have been used to denote changes in the soil by various management practices, but changes in *ρb* is the most commonly reported factor.

Crop response to soil compaction depends on the interaction among different crops, soil type, water content and compaction degree. The water content between FC and PWP is generally considered optimal for agricultural crop growth. According to the LLWR concept, this optimal range can be narrowed by high PR on the dry side and by poor aeration on the wet side. As such, the LLWR of a soil can be directly linked to physiological limitations of plant growth (Kay *et al*,2006). If the soil water content falls outside the LLWR in the growing season, plant growth is adversely affected. Every LLWR value greater than zero signifies that there exists a soil water content where root and plant growth are least limited by soil physical constraints. The probability of soil falling outside this range of least limiting conditions throughout a growing season decreases with increasing LLWR. The difference of the actual water content to either the upper or lower specification limit of the LLWR is a better indicator for plant growth than the value of the LLWR itself (Silva and Kay 2004). The LLWR, an indicator of soil structural quality is dynamic in nature and varies inversely with *ρb* changes; its effects can be further modified by variation in soil texture (Choudhary *et al,* 2014). The LLWR can be used to evaluate improvement or degradation of soil physical properties. A wider LLWR, at a specific *ρb*, generally will be less restrictive to plant growth. However, as long as the water content of a soil remains within the LLWR, no productivity restrictions are anticipated. The LLWR will vary as soil properties, including texture or organic matter change. Such variations can be expected for different soil types as well as within the profile depth of a specific soil. The LLWR is, thus, a sensible indicator of soil physical quality and may be used to distinguish soil management differences (Tormena *et al,* 2007, Asgarzadeh *et a,l* 2010, Olibone *et al,* 2010 and Kadzien *et al,* 2011). Due to the high sensitivity of the LLWR to soil physical properties such as soil *ρb* and soil structure, the LLWR is a valuable indicator of soil functioning (Silva and Kay 1996, Mckenzie and Mcbratney 2001, Lapen *et al,* 2004, Sato 2016). Monitoring temporal variation of the soil water content and evaluating how often this variation occurs within or outside LLWR are useful tools to make inferences regarding conditions in which plants are more or less subject to physical stress in terms of water availability, aeration, and resistance to root penetration (Sato et al, 2016). To estimate the LLWR in soil, soil water content values Θ_v, will be calculated at the following points: 0.10cm^3 air filled porosity (10% aeration), field capacity (-0.01 MPa matric potential), wilting point (-1.5MPa matric potential), and the soil strength restriction limit (2MPa), considered to seriously restrict root growth(Zou et al, 2000).

Calculation of LLWR LLWR (Karitika 2016): The upper limit is soil water content at 10% aeration porosity on volumetric base (θap) or soil water content at field capacity (θfc) which ever is lower. Lower limit of LLWR= Lower limit is soil water content either at wilting point (θwp) or corresponding to soil PR 2 MPa (θ2MPa) whichever is higher. Magnitude of LLWR = Soil water content between upper and lower limit of LLWR.

2.13 Review of related literatures on effect of soil treatment on crop yield

- Asenso et al (2018) evaluated the effects of soil biochemical properties on maize grain in Latosolic red soil of Southern China. Various tillage treatments were applied, highest grain yield 0f 7.34ton ha^{-} was obtained in subsoilling by using a subsoiler, while the lowest grain yield was obtained in minimum tillage
- Guan *et al* (2015) in a study on the effect of different tillage methods on soil physical properties and crop yield shows that plow-tillage (PT) and rotary-tillage decreased the soil ρb in the 0– 20 cm soil depth and the PR in the 0–30 cm soil depth. PT had greater root mass density (RMD), RLD and root surface density (RSD) than those under NT across the 0–110 cm soil profile at the tilling stage and in the 0–40 cm soil profile at the flowering stage, respectively. Soil strength and ρb are two major soil physical factors known to affect crop root development.
- Anjum et al, (2019) in a study to determine the influence of different tillage practices on crop yield in a randomised complete bock design (RCBD) with four replications observed that maize sown under deep tillage gave maximum yield (7.2tha^{-1}), number of grains cob^{-1}(528), 100-grain weight (265g), while lowest grain yield (3.08tha^{-1}), number of grains per cob(319), 1000 grain weight (204g) were obtained in zero tillage.
- Mueen-ud-din et al, (2015) in their study to evaluate the effect of various tillage practices and farm yard manure on the yield of wheat observed that all the yield and yield parameters were significantly affected by the various tillage practices and farm yard

manure, it was observed that the application of FYM was more appropriate with four passes of cultivator for better grain yield.

- Aikins et al (2012) Studied the effect of four tillage methods on maize performance, the experiment was arranged in a randomised complete block design with four treatments(disc ploughing only, disc ploughing followed by disc harrowing, disc harrowing only and no tillage). Ploughing and harrowing recorded the highest 100 grain weight (186g) while no tillage recorded the least 100 grain weight (149g).
- Cook and Trlica (2016) evaluated the effects of four tillage (moilboard plough, chisel tillage, alternate tillage, and no till) and five fertiliser (no fertilisation, N- omly, N+NPK starter, NPK+NPK starter, and NPK broadcast) treatments on crop yield. Corn yield was affected by fertiliser ($P<0.001$), Tillage ($P<0.001$) and their interaction ($P<0.001$).
- Aikins and Afuakwa (2010) observed that number of pods plant^{-1}, number of seeds pod^{-1} and 1000 seed-weight are generally influenced by the tillage treatments. According to them, tillage carried by plowing and followed by disc harrowing provided the highest number of pods plant^{-1}, the greatest number of seeds pod-1 and the highest 1000 seed-weight. While no tillage treatment produced the lowest number of pods plant-1, number of seeds pod-1 and 1000 seed-weight. Such results were attributed to soil loosening by tillage treatments.
- Alam et al, (2014) studied the effect of four tillage practices (zero tillage, minimum tillage, conventional tillage and deep tillage) on crop yield. This was done in a randomised complete block design with four replications. The highest grain yield (4.50t/ha) was found in deep tillage, followed by conventional tillage (4.00t/ha). The lowest grain yield (3.00t/ha) was obtained in no tillage.

- Yang et al, (2017) determined the effects of farming practices on crop yield. The farming practices include two tillage patterns(conventional and reduced tillage), two cropping patterns (continuous and rotation) and two mulching patterns (film and straw). Over the four years studied, the average maize yield which ranged from 6.5-12.3Mg/ha respectively varied from year to year.
- Barut and Akpotat (2005) compared different tillage systems in terms of their effects on physical properties of soil, task time fuel consumption and crop yield. The seedbeds were prepared in four different tillage practices, including minimum tillage with subtre, minimum tillage non subtle, conventional tillage with subtle, conventional tillage non subtle. Highest grain yield of 8719kg ha^{-} was obtained in conventional tillage without subtle while the lowest grain yield of 7288kg ha^{-} was obtained in minimum tillage with subtle.

2.14 Review of literature on effect of tillage practices on least limiting water range

- Fereshte et al, (2017) evaluated soil physical properties using least limiting water range in a dry farm land. Least limiting water range was determined for four tillage practices (conventional tillage, reduced tillage, no tillage and fallow no tillage). Mean least limiting water range (0.07-0.08cm^3/cm^3) was lower in compacted soils than the soils under conventional tillage, no tillage, fallow no tillage and reduced tillage. The values of LLWR were 0.12cm^3/cm^3 for no tillage and conventional tillage. LLWR for tilled plots (0.12cm^3/cm^3) became greater than compacted soils by 1.3 times. Analysis of the lower and upper limits of LLWR further indicated that penetration resistance was the only limiting factor for soil water content, but aeration was not a limiting factor. The LLWR was more dependent on soil water content at permanent wilting point and penetration resistance.

- Kahlon and Karitika (2017) studied the effect of tillage practices on least limiting water range in Northwest India. The treatments included four tillage modes (conventional tillage, no tillage without residue, no tillage with residue and deep tillage) as well as three irrigation regimes based on the irrigation water and pan evaporation i.e. 1.2, 0.9, and 0.6. the experiment was conducted in a split plot design with three replications. The mean least limiting water range was found to be highest in deep tillage ($0.26cm^3/cm^3$) and lowest in no tillage without residue ($0.15cm^3/cm^3$). The field capacity was a limiting factor for the upper range beyond soil bulk density of $1.41mg/m^3$ and after that 10% air filled porosity played a major role. For the lower range, the permanent wilting point was critical beyond soil bulk density $1.50mg/cm^3$ and thereafter penetration resistance at 2Mpa becomes a limiting factor.
- Aggarwal et al, (2004) quantified the upper as well as the lower limit of LLWR of a sandy loam soil under bed and conventional tillage during wheat growth. Soi penetration data and soil moisture content at 4-6 days interval during dry cycle after each irrigation along with bulk density done only once during the dry cycle. The observations were used to develop multiple regression equations which could be used to predict penetration resistance as function of bulk density, soil moisture content and depth. The result demonstrated that throughout the growth, it was moisture content that determined the upper range of LLWR, while the lower range was represented initially by moisture content at permanent wilting point but was later represented by moisture content at 2MPa penetration resistance. It was observed that moisture content at 10% aeration decreased

with increase in bulk density, where as moisture content at field capacity and wiltinp point decreased slightly with increase in bulk density. In contrast, moisture content at 2MPa penetration resistance increased appreciably with increase in bulk density.

- Reichert et al., (2004) determined the effects of soil management on penetration resistance (PR), bulk density, moisture and root distribution, and to relate bean yield with the amount of days that soil moisture was outside the least limiting water range, on a sandy loam Hapludalf. Soil management systems were continuous no tillage for 12 years, chisel tillage of previous no tillage and conventional tillage of previous no tillage. Soil bulk density of 5cm depth was $1.72 mg/m^3$ for no tillage, $1.65 mg/m^3$ for chisel tillage and $1.52 mg/m^3$ for conventional tillage. The least limiting water range obtained in the study were $0.155 m^3/m^3$ for chisel tillage, $0.110 m^3/m^3$ for conventional tillage and $0.107 m^3/m^3$ for no tillage.
- Meng et al, (2018) studied the effect of long term conservation tillage on least limiting water range. Three tillage practices were used in this study, including no tillage, rotary tillage, and mouldboard plough with maize residue. Compared with rotary tillage and mouldboard plough with maize residue, the bulk density was significantly greater in both soil layers ($P<0.05$). No obvious differences in soil bulk density between rotary tillage and mouldboard plough with maize residue treatments were observed. For 5-10cm layer, rotary tillage treatment yielded the greatest LLWR($0.20 cm^3/cm^3$). There was no significant difference in LLWR between no tillage and rotary tillage. For 15-20cm layer, the values of LLWR under rotary tillage and mouldboard plough with maize residue treatments were significantly greater than that under no tillage treatment.

- Sato et al, (2016) investigated the soil physical quality in an area cultivated oil palm by monitoring the temporal variation of the soil water content and relating it to the critical limits of the least limiting water range (LLWR). Increasing bulk density led to a LLWR reduction. Considering LLWR calculated from the mean values of bulk density, it was noted a wide variation during the evaluated period with maximum LLWR of $0.33 m^3/m^3$ and a minimum of $0.13 m^3/m^3$.
- Fabricio et al, (2015) determined the least limiting water range of a highly clayey typic dystrophic red latosol and correlated it with the soil physical attributes. It was observed that in no till farming, limitation of plant development can occur as the soil dries out, mainly due to the higher resistance to mechanical penetration. Besides this, it was found that $LLWR_{0\text{-}0.10m}$ and $LLWR_{0.10\text{-}0.20m}$ values were correlated in greater numbers with macronutrients and micronutrients analyzed.
- Kahlon *et al* (2013) reported that tillage method and mulch rate had significant effect on ρb, which decreased from 1.46-1.31, 1.45-1.36, 1.50-1.47 Mg m-3 under NT, ridge tillage and plough tillage (PT) respectively, with increase in mulch rate from 0-16 Mg ha-1.
- Gathala *et al* (2011) reported that the differences in PR among tillage treatments (NT and CT) were more drastic beneath 30 cm soil depth.
- Choudhury *et al* (2014) reported that application of NT with residue resulted in 46.5 % higher WSA in surface as compared to CT. They also suggested that NT promotes macro aggregation as compared to CT. The decline in the size of macro aggregates in CT could be due to the disruption of macro aggregates, which may have exposed, previously protected SOM against oxidation.

2.15 Summary of literature review/ knowledge gap

Several literatures reviewed pointed at the effect of combination of the soil treatments (irrigation, NPK application and tillage) on crop yield, soil moisture content and soil temperature. Most of the works focused more on crop yield rather than soil moisture content and soil temperature. In some studies, the maximum crop yield were obtained in conventional and conservative tillage, depending on the soil type, while the least crop yields were obtained mainly in no tillage plots.

The least limiting water range were determined from, moisture content at field capacity, permanent wilting point, 10% aeration and penetration resistance at 2MPa in the researches reviewed.

So many works have been done on the effect of soil treatment on crop yield, soil moisture content and soil temperature but the research of interaction of the variables on the responses and determination of the least limiting water range at different soil depths and tillage methods in South eastern Nigeria is lacking in literature. The optimisation of the process variables (irrigation deficit, NPK application rate and tillage) and responses (crop yield, soil moisture content and soil temperature) using the Response Surface Methodology is also lacking in literature, hence the knowledge gap for this research.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

Field experiment was conducted at the Department of Agricultural and Bioresources Engineering Experimental Site/ Farm Workshop, Nnamdi Azikiwe University, Awka. The site lies between latitudes 6°15’11.8N to 6°15’5.3E and longitudes 7°7’118N to 7°7’183N and altitude of 142m. during the dry season, previous studies carried out in the area shows that the soil in the area is sandy loam. Figure 3.1 shows the map of Anambra state and location of Nnamdi Azikiwe University, while figure 3.2 shows the Research Site. It is a typical of savanna covered with grass. The geologic formation of Nnamdi Azikiwe University, Awka is Imo shale (Odoh et al 2012). The Anambra River and its tributaries are the major Rivers that drain the area. There are two major climatic seasons, dry season (November to March) and rainy season (April to October) with reduced rain (August break) in August. Dry season temperature ranges from 20°C to 38°C which increases evapotranspiration, while rainy season temperature ranges from 16 to 28°C,with lower evapotranspiration. The average annual rainfall varies from 1,500mm to 1,600mm, while average yearly windspeed is 1.73kmph with average yearly relative humidity of 77% . The whole research project site measures a total of 5,227.08 square meters. The experiment was conducted from 27th November 2017 to 22th February 2018.

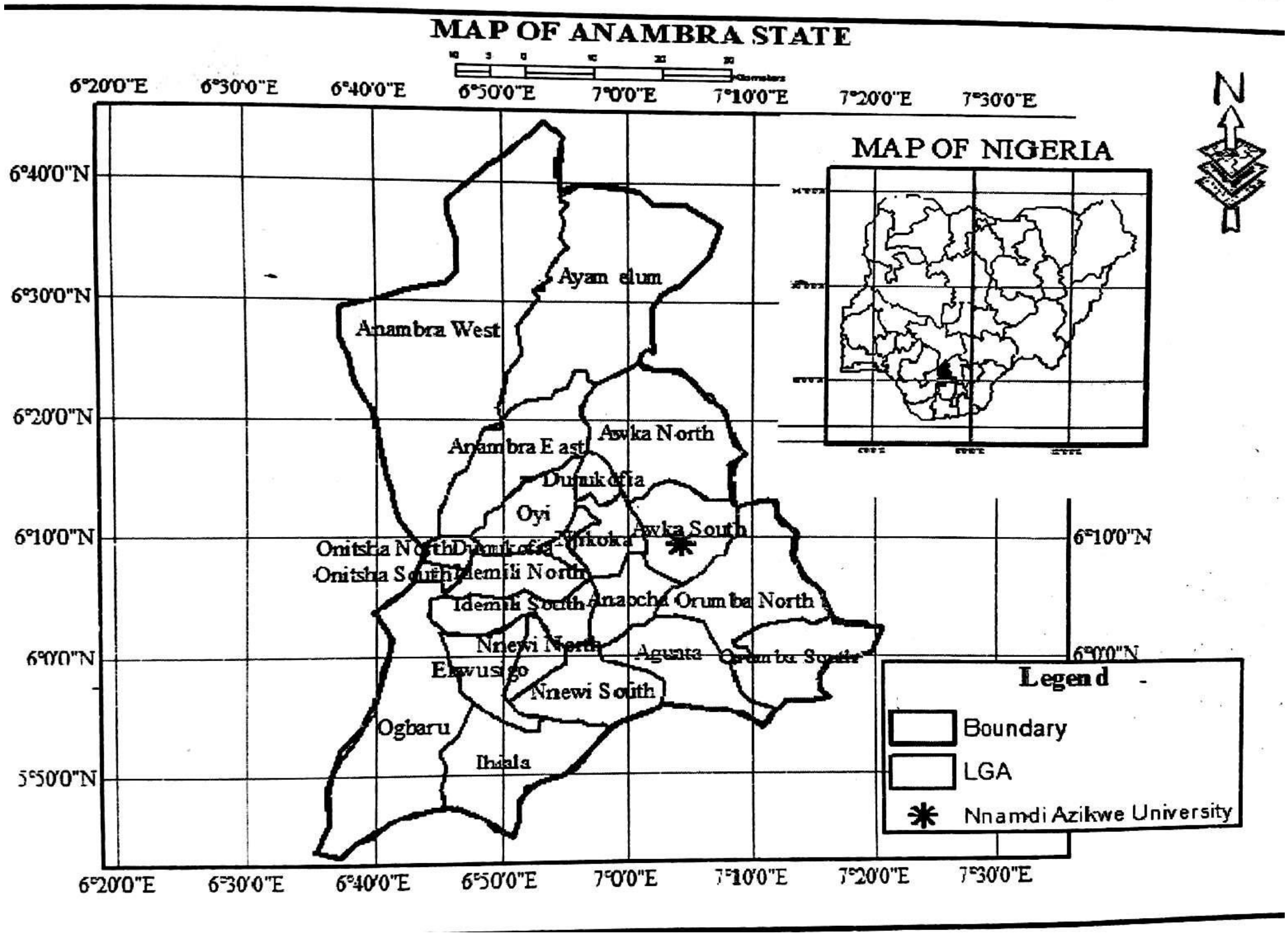


Fig.3.1: Map of Awka South showing Nnamdi Azikiwe University

3.1.1 Materials and equipment.

The materials used for the experiment were as follows:

- 25mm PVC pipe for the main line
- 12.5mm PVC for the submain
- 19mm PVC for the laterals
- 19mm end cap
- 25mm by 12.5 bend

- 12.5mm by 19mm inch bend
- 25mm ball gauge
- 12.5mm ball gauge
- 25mm by 12.5mm Tee
- 12.5mm by 19mm Tee
- 2mm drill machine

The equipments include:

- Design expert 11 software
- Pressure gauge
- Moisture meter
- Storage tank
- Block stand
- Evaporation pan
- Double ring infiltrometer
- Measuring tape
- Levelling instrument
- Digital calliper
- Measuring cylinder
- Tractor
- Collection cans
- Pressure plate apparatus
- Soil penetrometer

3.1.2 Field preparation

The field is a level ground and field preparation was done by dividing the plot into three major plots/sections A,B and C. Conventional tillage was done in the plot A by thoroughly tilling with plough and harrow, conservative tillage was applied in plot B by ploughing with one tractor pass. Plot C received no tillage. Each major plot has a dimension of 27m X 27m. The plots were levelled to obtain a level ground.

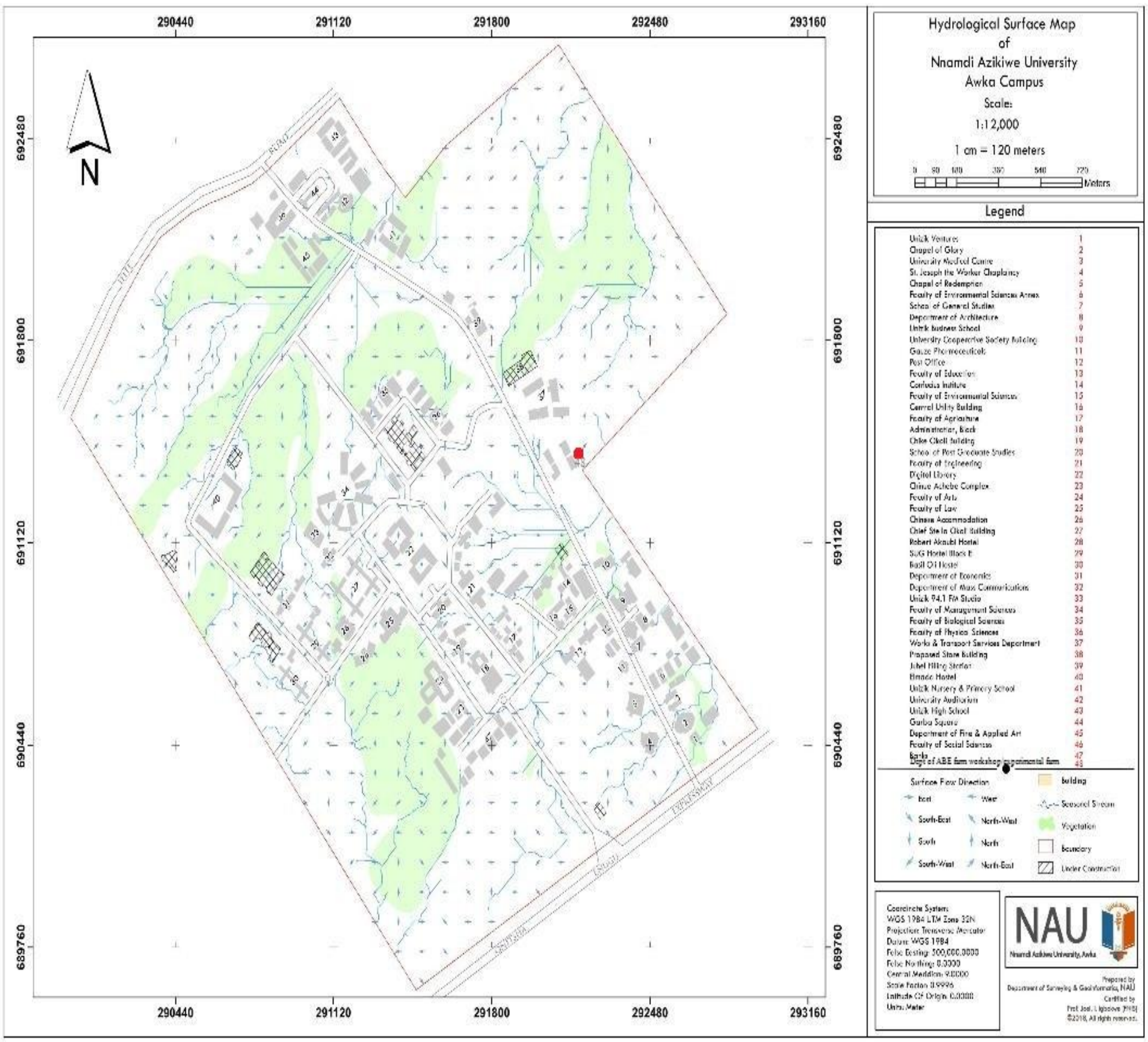


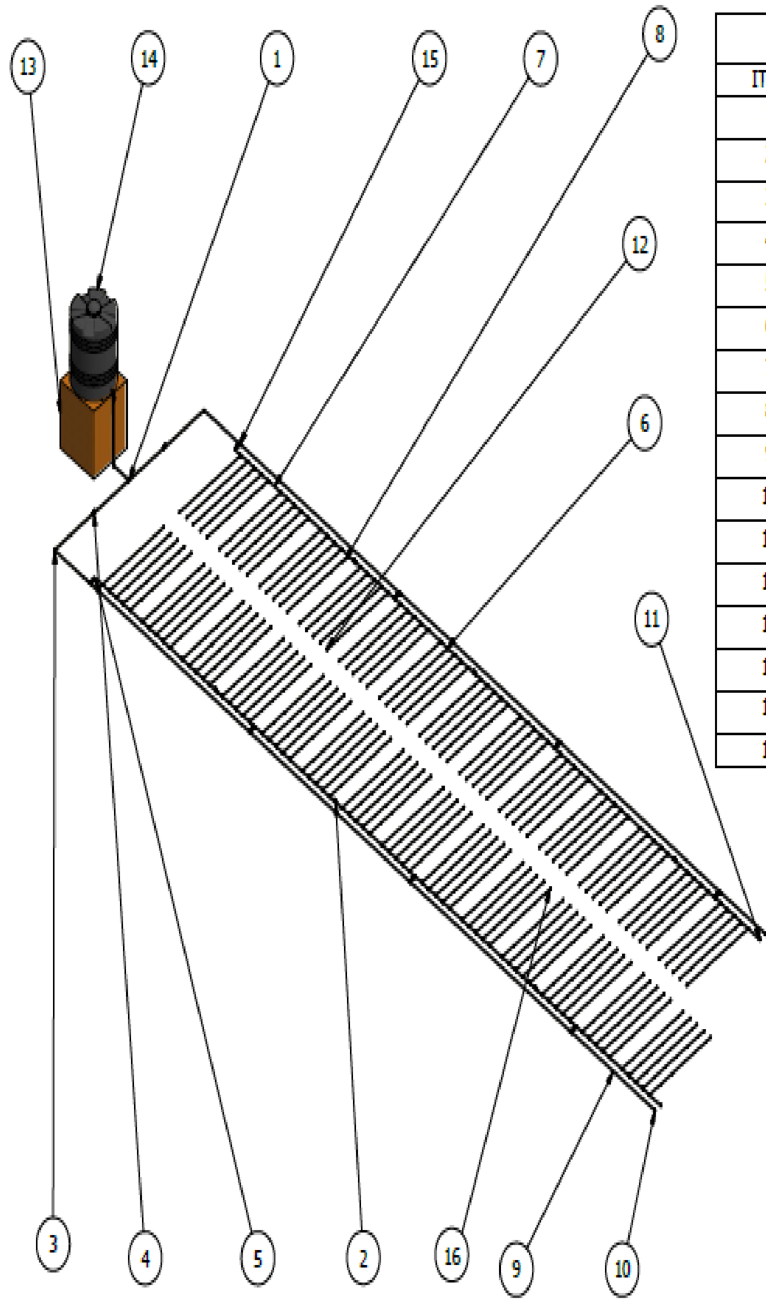
Fig.3.2 Map of Nnamdi Azikiwe University showing the research site (represented with red dot)
Source: Department of Surveying and Geoinformatics, NAU. Downloaded from http://www.google.com/search=map+of+nnamdi+azikiwe+university

3.1.3 Field layout.

The experiment was laid out using central composite design (CCD). The choice of CCD was preferred because it takes categoric and numeric factors into consideration. The design has 2 numeric factors; irrigation deficit and NPK application and one categoric factor; tillage. The experimental field consists of 3 plots with 9 sub plots in each plot. The experimental design was performed as follows:

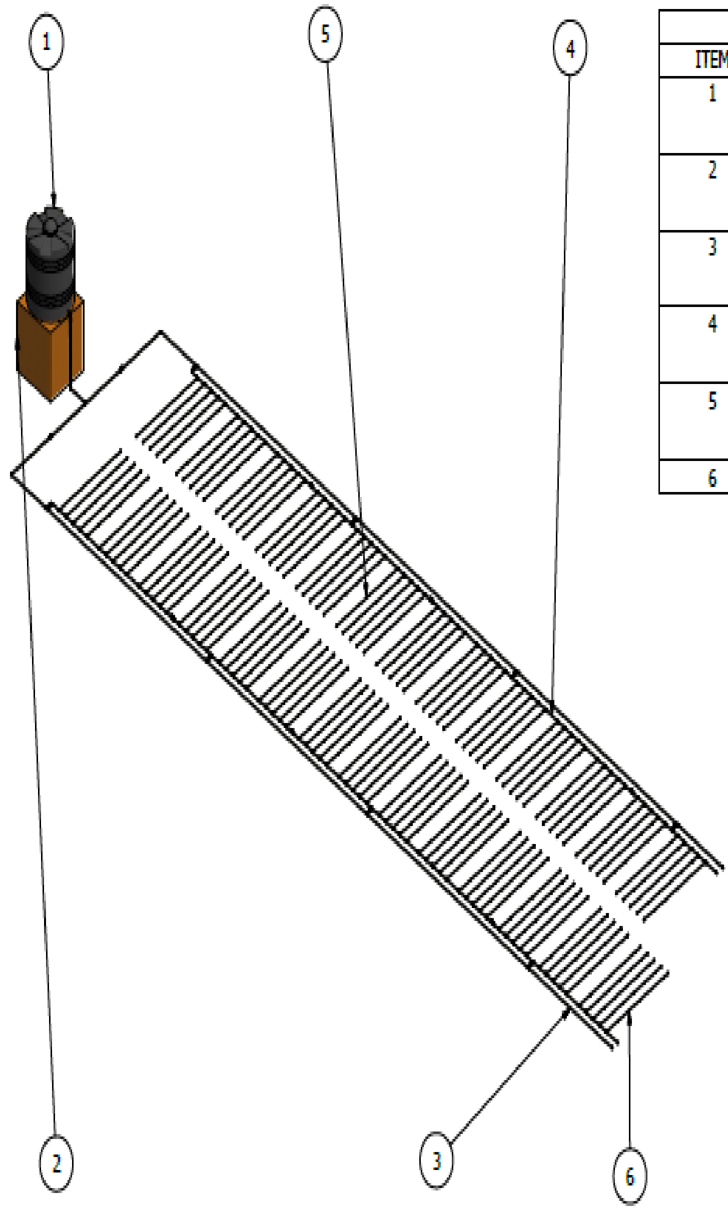
Tillage (conventional tillage, conservative tillage and zero tillage), in conventional tillage, the area was tilled thoroughly with plough and harrow, conservative tillage was done with plough, one tractor pass, while no tillage was obtained by not tilling; three irrigation deficit levels (50% MAD, 30 MAD and 10% MAD) and three levels of NPK fertiliser rates (450kg/ha, 550 kg/ha and 650 kg/ha).

The experimental plot was divided into 27 sub-plots with each sub-plot measuring 3m X 3m. 25mm PVC pipes were used as the main line, 19mm PVC pipes served as the submain while 12.5mm PVC pipes were used as the lateral. Laterals were laid at 0.5m spacing while holes were perforated in the laterals at 0.45m spacing to serve as emitter, with these, crop spacing was 0.5m X 0.45m.



PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	T-Joint PVC pipe	1" T
2	14	Valve	3/4" Valve
3	3	Bend PVC Pipe	1" Bend
4	3	Valve	1" Valve
5	2	Bend PVC Pipe	3/4" Bend
6	141	T-Joint PVC pipe	3/4" X 1/2" T
7	2	PVC pipe	3/4" PVC pipe
8	135	PVC pipe	1/2" PVC pipe
9	2	PVC pipe	1" PVC pipe
10	2	End cap	1" End cap
11	2	End cap	3/4" End cap
12	135	End cap	1/2" End cap
13	1	Tank stand	Block
14	1	Tank	PVC tank
15	2	T-Joint PVC pipe	1" X 3/4" T
16	675	Emitter	

Fig 3.3 Isometric view of the drip irrigation system



PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	Tank	PVC Tank
2	1	Tank stand	Block
3	2	Main line	
4	2	Submain	
5	135	Laterals	
6	675	Emitter	

Fig 3.4 View of the drip irrigation system

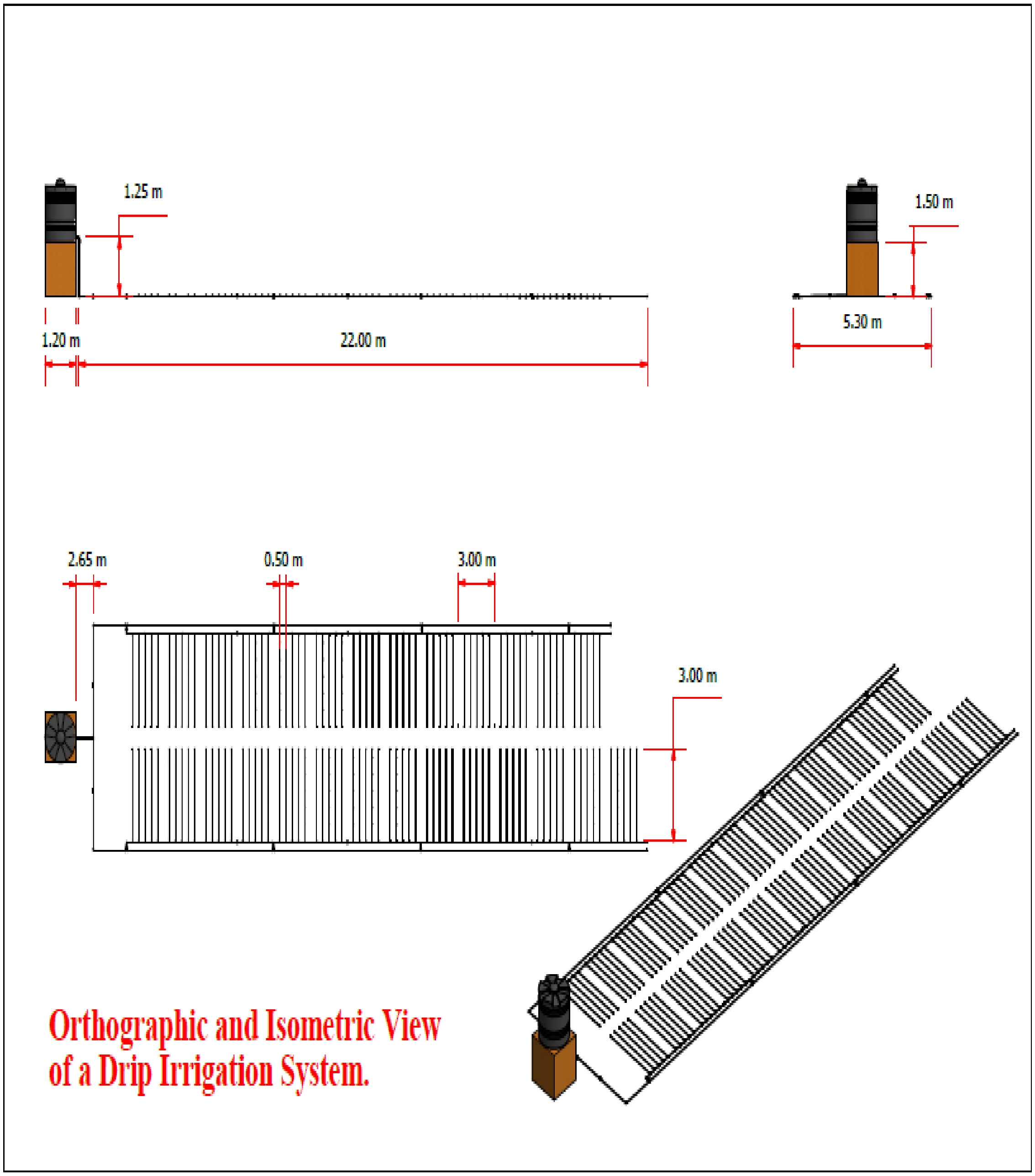


Fig 3.5 Orthographic and isometric view of the drip irrigation system

3.2 The experimental setup

3.2.1 Installation

25mm PVC pipes were connected to the tank to serve as the main line, tiny holed net was inserted in the PVC pipes for filtering the irrigation water. 19mm PVC pipes were further connected to the mainline and they served as the submain which was connected to the laterals. The connections were done using elbows to connect the main line to the submain, tee connectors were used to connect the submain to the laterals, bends were used to connect main lines to mainlines and submains to submain at the edge of the plot, end caps were used to cover the ends of the pipes to prevent water from flowing out, while valves were also connected for controlling the flow of water. The test crop (maize) was planted at a planting space of 0.5m x 0.45m spacing.

3.3 The test crop.

The crop for the experiment was zea mays hybrid OBA SUPER 13, which was collected from the Anambra State Agricultural Development Programme (ADP).

Table 3.1 Duration and period within the various growth stages

Growth stages	Duration(days)	Period
Initial stage	14	November 27 to December 11
Crop development stage	24	December 12 to January 4
Mild stage	27	January 5 to February 1
Late stage	20	February 2 to February 22

3.4 Drip irrigation system

The plot was divided into twenty seven sub plots of area 3m x 3m each, 25mm PVC pipes were used at the edges of the plot to serve as main line, it was connected to an over head tank, 25mm PVC were connected to 12.5mm PVCs using 25mm by 12.5mm tee, 25mm ball gauge was installed to control water entering to the submain. 19mm PVC pipes served as the submain line, it served as the extension of the main line, 12.5mm by 19mm tee was also used to connect the submain to the laterals, 12.5mm pvc pipes served as the laterals, 12.5mm ball gauge was also installed in the submain to control water flowing from the submain to the lateral, the laterals supplied water to the emitters. 2mm diameter holes were made in the laterals to serve as the emitters. The mains, submains and laterals were covered at the end using 25mm,12.5mm and 19mm end caps respectively.

3.5 Weather parameters

The mean temperature, monthly rainfall, relative humidity, sunshine duration were collected from Nigerian Meterorological Agency (NIMET).

3.6 Tillage

The farm land was divided into three major plots (A, B and C) after land clearing. Conventional tillage was applied to block A by thorough tilling using plough and harrow mounted to the tractor, this involves several tractor passes in the block

Block B received conservative tillage, this implies minimum disturbance of the soil, it was done using plough mounted to the tractor with only one tractor pass.

No tillage was applied to block C.

3.7 Soil sampling

Soil Samples were collected at the depths of 0-25cm, 25-75cm, 75-100cm, from blocks A,B, and C and were used to determine different soil physical and chemical parameters.

3.7.1 Particle size distribution

Standard test method for particle-size analysis of soils (ASTM D 422) was used for particle size distribution.

Soil samples were collected from the depths and blocks as specified above using a manual auger. The samples were oven dried and sieved with a set of sieves. The sieves were arranged in ascending order varying from larger to smaller sizes from top to bottom with the collector placed at the bottom. The sand was poured in the topmost sieve and was shaken with a mechanical shaker for 10 minutes. The individual grain size was then used to grade the soil. The weight retained and weight passing through each sieve was noted. The weights passing through each sieve were calculated from dry soil. The cumulative percentage passing was calculated using equation 3.1:

$$\%passing = \frac{weight\ pasing\ \ each\ sieve}{total\ \ weight}\ X\ 100 \qquad (3.1)$$

3.7.2 Bulk density (BD)

The BS 1377:Part 2: 1990 Standard Method was used to determined the bulk density after the soil samples were collected at different depths from different major plots as in section 3.7. The bulk densities of different soils were calculated after oven drying, using the equation (3.2):

$$\text{Bulk density} = \frac{\text{weight of dry soil (g)}}{\text{Total Soil Volume } (\text{cm}^3)} \tag{3.2}$$

3.7.3 Particle density (PD)

The particle density was determined using the formula in equation (3.3):

$$\text{Particle density} = \frac{\text{weight of dry soil (g)}}{\text{volume of sand particle } (\text{cm}^3)} \tag{3.3}$$

3.7.4 Porosity

Porosity was determined using the formula in equation (3.4):

$$\text{Porosity \%} = \left(1 - \frac{BD}{PD}\right) X\ 100 \tag{3.4}$$

Where BD = bulk density (gcm^{-3})

PD = particle density (gcm^{-3}).

3.8 Soil temperature

Daily soil temperature was determined at different soil depths (0-25cm, 25-50cm, 50-75cm, 75-100cm) at different blocks during the growing period, this was done using soil thermometer.

3.9 Moisture content (MC)

Daily moisture content was also determined throughout the growing period at different depths (0-25cm, 25-50cm, 50-75cm and 75-100cm) at different plots using soil moisture meter, the moisture meter was calibrated using gravimetric method of moisture content determination using equation (3.5):

$$Moisture\ content\ \% = \frac{weight\ of\ moisture\ (g)}{weight\ of\ dry\ soil\ (g)}\ X\ 100 \tag{3.5}$$

3.10 Soil water retention studies

Soil samples were collected from each block (block A,B and C) at different depths (0-25, 25-50. 50-75, 75-100cm), the saturated soil samples were placed in a pressure plate apparatus to equilibrate the soils to selected water potentials by the method described by Zou et al(2000). After equilibrium at each matric potential (ψm), the samples were weighed immediately to calculate volumetric water content (θv) at this ψm. The process was done at 7ψm levels: -0.01, -0.03, -0.1, -0.2, -0.5, and -1.5 Mpa. The time for equilibrium was 1 day for -0.01Mpa and 4 weeks for -1.5Mpa

3.10.1 Field capacity (FC)

The field capacity was determined at a pressure of -0.01Mpa using the pressure plate apparatus.

3.10.2 Permanent wilting point (PWP)

Permanent wilting point of the soils were also determined at -1.5Mpa using the pressure plate apparatus.

3.10.3 Available water (AW)

Available water is referred to as the zone between the percentage wilting point and field capacity. It is the difference between the field capacity and the permanent wilting point. It was determined using equation (3.6):

$$AW = FC - PWP \tag{3.6}$$

AW = Available water

FC = Field Capacity

PWP = Permanent Wilting Point

Available water per meter depth of soil in cm/m is expressed as equation (3.7)

$$AWPMD = AW \times BD \tag{3.7}$$

Where AWPMD = Available water per meter depth of soil in cm/m,

AW = Available Water,

BD = Bulk Density.

Available water in cm is given in equation (3.8)

$$AWCM = AWPMD \times d \tag{3.8}$$

AWCM = Available water in cm

AWPMD = Available water per meter depth of soil

d = depth of root zone

3.11 Infiltration

The double ring infiltrometer method was used to determine the water infiltration. The infiltrometer with inner ring 30cm and outer ring 60cm was carefully driven into the soil to a depth of 15cm, water was poured into the inner ring until the depth was approximately 13cm, at the same time, water was poured into the outer ring to prevent water from going out from the inner ring. After 15 minutes, the drop in water level was recorded. Water was poured back into the ring to the initial position and records were made until a constant infiltration rate was observed. Readings were taken at 15 minutes at the beginning of the test and was later extended to 30 minutes.

3.12 Calibration of flow

To obtain a uniform flow in the drip system, the three different PVC pipes (main submain and lateral) were calibrated to determine

- Quantity of water from the mains
- Quantity of water from the submains
- Quantity of water from the laterals
- Quantity of water from the emitter holes

The valve of the tank was opened and water was collected from the mains pipe for 30 minutes, the collected water was measured and this gave the mains flow rate. The same was done for submain and the laterals. Also collector cans were used to collect water from the drip holes by placing them under each drip hole of 2mm diameter each. The collected water over 30 minutes was measured using a measuring cylinder to check uniformity of water flow from each drip hole.

3.13 Soil chemical properties

Soil samples was collected from the blocks at different depths as in 3.5 above was used to determine various soil chemical properties in the lab, these properties are; Soil pH, Soil Electronic Conductivity, Soil Organic Carbon Content, Soil Nitrogen Content, Soil Phosphorus Content and Soil Potassium Content.

3.13.1 Soil pH

This was determined in the laboratory using Laboratory pH meter Hana model H1991300 (ALPHA; 1998).

3.13.2 Soil electronic conductivity (EC)

Soil electronic conductivity was measured according to APHA 2510 B guidelines Model DDS-307 (APHA, 1998).

3.13.3 Soil organic carbon content (OC)

This is the amount of carbon found in the soil and was based on the Walkely-Black chromic method.

3.13.4 Soil nitrogen (N)

Nitrogen is one of the elements required for life and it simulates above ground growth, available nitrogen in the soil was be measured in the lab using Kjeldahl method.

3.13.5 Soil phosphorus (P)

Determination of soil available phosphorus was done in the lab using standard method 4500-P B.5 and 4500-PE (ALPHA; 1998).

3.13.6 Soil potassium (K)

Available potassium in the soil was determined using atomic absorption spectrophotometer according to the method of APHA 1995 (American Public Health Association).

3.14 Crop water requirement

3.14.1 Evapotranspiration

This was determined daily using the Hargreaves equation (Hargreaves and Samani 1985), equation (3.10)

$$ET_o = a + b.(0.408).0.0023.\left(\frac{T_{max} + T_{min}}{2} + 17.8\right).\sqrt{T_{max} - T_{min}}\,.R_a \quad (3.10)$$

ET_o = Reference evapotranspiration

Tmax(°C) is the maximum daily air temperature

Tmin(°C) is the minimum daily air temperature

Ra ($MJm^{-2}d^{-1}$) is the extra terrestrial solar radiation converted to equivalent evaporation in mm day^{-1} with a factor of 0.408.

The parameters a($mm\ d^{-1}$) and b are calibrated coefficients, determined on a monthly basis by regression analysis or visual fitting. An adjusted version of Hargreaves equation is with a=0, b = 1

3.14.2 Consumptive use (CU)

Consumptive use (CU) is computed as the product of crop factor and potential evapotranspiration (Mbah, 2012). This is expressed mathematically in equation (3.11):

$$CU = KET_p \tag{3.11}$$

Where: K = crop factor; ET_P = Potential evapotranspiration

The equation will be used to determine monthly consumptive use for the growing months.

3.15 Net irrigation requirement

The net irrigation requirement is the depth of irrigation water, exclusive of precipitation, carry-over soil moisture or groundwater contribution in soil that is required consumptively for crop production (Mbah, 2012). The maximum net depth to be applied per irrigation can be calculated using (Michael 1981) in equation (3.12):

$$d = \sum_{i=1}^{n} \frac{(M_{fci} - M_{bi})}{100} . A_i . D_i \tag{3.12}$$

Where:

d = net depth of water application per irrigation for selected crop (cm)

M_{fci} = field capacity moisture content in the i_{th} layer of the soil (%)

M_{bi} = moisture content before irrigation in the ith layer of the soil (%)

A_i = bulk density of the soil in the ith layer

D_i = depth of the ith layer of soil within the root zone (cm)

n = number of soil layers in the root zone D.

3.16 Gross irrigation requirement

This is the net irrigation of the crop plus losses in water application and any other possible losses and will be calculated using equation (3.13).

$$GIR = \frac{dn}{AE} \tag{3.13}$$

Where

GIR = Gross Irrigation Requirement(cm)

dn = Net Irrigation

AE = Application Efficiency

3.17 Irrigation frequency (IF)

This refers to the number of days between irrigations during periods without rainfall (Michael 1999). It was determined using the equation (3.14) (Michael 1999);

$$IF = \frac{AWC.R_z.MAD}{ET_c} \tag{3.14}$$

Where,

IF = Irrigation frequency (days)

AWC =Available water holding capacity(inch/ft)

R_z = Root zone depth (ft)

MAD = management allowable depletion

ET_c = crop water use rate

This was done for different stages of crop growth considering different depths of soil.

3.18 Irrigation run time

This is the time allowed for one irrigation application and it was determined using equation (3.15)

$$\boldsymbol{Rt = \frac{d^{gross}}{Pr}} \quad (3.15)$$

R_t = Irrigation run time

d^{gross} = gross irrigation in cm

Pr = Application rate in cm/hr

3.19 Basic hydraulics of drip irrigation

3.19.1 Head loss on main line

The head loss on mainline was determined by William and Hazen Equation in equation (3.16)

$$\Delta H = \frac{Q^{1.852}}{D^{4.872}}) L \quad (3.16)$$

Where ΔH = energy drop by friction (m)

Q = total discharge in the pipe (lit/sec)

3.19.2 Total energy drop for lateral

This was determined by introducing an F-value as a reduction coefficient or determined by the integration using Michael and Ojha (1981) in equation (3.17)

$$\Delta H = 5.35 \left(\frac{Q^{1.852}}{D^{4.872}}\right) L \tag{3.17}$$

3.20 Performance criteria for system flow

3.20.1 Flow variation (Q_{var})

Emitter flow variation Q_{var} was calculated using equation (3.18):

$$Q_{var} = \frac{100 X (Q_{max} - Q_{min})}{Q_{max}} \tag{3.18}$$

Where: Q_{var} = Emitter flow variation

Q_{max} = maximum emitter (drip hole) flow rate

Q_{min} = minimum emitter (drip hole) flow rate

Example: for emitters at the zero tillage subplot

3.20.2 Uniformity coefficient

Uniformity coefficient (UC) was calculated using Christiansen (1942) equation in equation (3.19):

$$UC = 100\ X\ [1 - \left(\frac{\frac{1}{n}\sum_{i=1}^{n}\{q_i - q_{ii}\}}{q_{ii}}\right)] \tag{3.19}$$

Where, q = discharge

q_{ii} = mean of discharge (q)

n = number of drip holes evaluated

3.20.3 Coefficient of variation (CV)

This was calculated using equation (3.20)

$$CV = \frac{s}{q} \tag{3.20}$$

Where, s = standard deviation of emitter flow rate

q = mean of discharge

3.20.4 Scheduling coefficient based on lowest 25% ($SC_{25\%}$)

This was determined using equation (3.21)

$$SC_{25\%} = \frac{1}{DU} \tag{3.21}$$

Where, DU = Uniformity coefficient

3.21 Air-filled porosity

It is was determined by the following equation (3.22) by Zou et al 2000;

$$\varepsilon_a = 1 - \left(\frac{\rho_b}{\rho_s}\right) - \theta_v \tag{3.22}$$

Where θ_v = volumetric water content (cm^3/cm^3)

ρ_b = soil bulk density (g/cm^3)

ρ_s = particle density (g/cm^3)

3.22 Penetration resistance

This was determined using equation (3.23):

$$\text{Soil resistance} = \frac{Penetrometer \quad reading\ (N)}{base\ area\ of\ penetrometer \quad cone\ (cm^2)} \tag{3.23}$$

3.23 Least limiting water range

Upper limit: The upper limit is soil water content at 10% aeration porosity(volumetric basis) or soil water content at field capacity (volumetric basis), which ever is lower

Lower limit: The lower limit is soil water content at wilting point (volumetric basis) or soil moisture content at penetration resistance of 2MPa (volumetric basis) which ever is higher.

Magnitude of LLWR: This is the water between the upper and lower limits of LLWR

3.24 Leaf area

The length and breadth of the broadest leaves of the selected tagged plants was measured using a ruler. The leaf area was then determined using the linear regression analysis equation (3.24):

$$Leaf\ Area = k\ (LXW) \tag{3.24}$$

where, k = 0.75 which is constant for all cereals, L = Leaf length W = Leaf width.

3.25 Cobs plant per cob (Cob^{-1})

Five plants were selected randomly from each plot and the number of maize ears in each plant was counted. Ears that have less than 5% of the kernels of normal ears were not counted

3.26 Grain per cob (Cob^{-1})

Three ears were selected from each subplot at random and number of kernels in each ear was counted.

3.27 1000- grain weight

This is a measure of the grain size and it is the weight in grams of 1000 seeds. Maize ears were selected at random from each subplot and one thousand grains counted from each subplot and weighed.

3.28 Cob weight

Cobs were selected at random from each subplot and weighed, the weights were recorded and average taken

3.29 Cob thickness

Cobs were selected at random from each subplot and the thickness of recorded, average for each subplot were recorded.

3.30 Grain yield

Maize yield was determined using corn yield estimator. The following were inserted in the calculator to give the grain yield; harvestable cobs (ears) in $1/1000^{th}$ acre, average number of grain (kernels) rows per ear and average number of grain (kernels) per row.

$1/1000^{th}$ acre was determined by measuring out the row meter (m), divide 6273 by the row width, this gave $1/1000^{th}$ acre.

3.31. Experimental design and optimization parameters

Response Surface Methodology (RSM) was used to investigate the influence of irrigation deficit, NPK fertilizer application and Tillage on soil temperature, soil moisture content and crop yield. The central composite design and their values are shown in Table 3.2. For this research, the factors irrigation deficit(%), NPK Application rate (Kg/Ha) and Tillage were represented with A, B and C respectively.

3.32 Statistical analysis:

The experimental data obtained from central Composite design were analyzed by Response Surface Methodology (RSM). An empirical model, following a second order polynomial which includes interaction terms was used to calculate the predicted response. Least limiting water range and bulk density were also analysed using EXCEL SOLVER.

Table 3.2 Independent variables and levels used for response surface design

Independent variables	**Symbols**	**Ranges and levels**		
		-1	**0**	**+1**
Irrigation Deficit(%)	A	10	30	50
NPK Aplication rate (KG/HA)	B	400	500	600
Tillage	C	1	2	3

The data was analyzed using Design Expert Program Software version 11.0.2.0 and the Coefficients, Analysis of Variance (ANOVA), Regression Analysis and plotting of 3D surface were also evaluated.

The values, -1, 0 and +1 are coded values representing the lower, medium and upper ranges respectively in the design expert, response surface methodology.

Table 3.3 Experimental Design Matrix.

		Factor 1	Factor 2	Factor 3	Response1	Response 2	Response 3
Std	Run	A:Irrigation Deficit	B:NPK Application Rate	C:Tillage	Crop Yield	Soil moisture content	Soil temperature
		%	KG/HA		KG/HA	%	®C
22	1	50	600	3			
17	2	30	600	2			
10	3	10	400	2			
18	4	30	500	2			
23	5	10	500	3			
24	6	50	500	3			
7	7	30	400	1			
21	8	10	600	3			
14	9	10	500	2			
25	10	30	400	3			
8	11	30	600	1			
2	12	50	400	1			
12	13	10	600	2			
20	14	50	400	3			
4	15	50	600	1			
11	16	50	400	2			
19	17	10	400	3			
3	18	10	600	1			
27	19	30	500	3			
13	20	50	600	2			
16	21	30	400	2			
5	22	10	500	1			
1	23	10	400	1			
15	24	50	500	2			
26	25	30	600	3			
6	26	50	500	1			
9	27	30	500	1			

3.33 Evaluation of the optimised process

The accuracy of the optimised process was determined by examination of coefficient of determination (R^2), coefficient of performance (CP^1_A), the root mean square error (RMSE), and the index of agreement (d).

- The R^2 value is an indicator between the observed and the optimised values and it is given by (Fernanadez et al, 2006) in equation (3.25):

$$R^2 = \frac{((\sum_{i=1}^{n} Ob_i - Ob_{av})(Op_i - Op_{av}))^2}{\sum_{i=1}^{n}(Ob_i - Ob_{av})^2 \sum_{i=1}^{n}(Op_i - Ob_{av})^2} \quad (3.25)$$

Where R^2 = Coefficient of Determination

Ob_i = the i^{th} observed parameter

Ob_{av} = the mean of the observed parameter

Op_i = the i^{th} optimised parameter

n = total number of events

The value of 1 for the coefficient of determination means that the dispersion of the optimisation is equal to the observed.

- The coefficient of performance approaches zero as observed and optimised get closer. The equation to calculate CP^1_A are shown in equation (3.26) and (3.27)

$$CP_A = \sum_{i=1}^{N}[Op(i) - Ob(i)]^2 \quad (3.26)$$

Where CP_A = coefficient of performance for the error series

Op(i) = the i^{th} optimised parameter

Ob(i) = the i^{th} observed parameter

N = total number of events

$$CP_A^1 = \frac{CP_A}{\sum_{i=1}^{N}[Ob(i) - Ob(avg]^2} \quad (3.27)$$

Where CP^1_A = coefficient of performance

CP_A = coefficient of performance for the error series

Ob(i) = the i^{th} observed parameter

Ob(av) = the mean of the observed parameter

N = total number of events

- RMSE is an indicative of the error associated with estimated streamflow with a better agreement close to 0.0 and is shown in equation (3.28) (El-Sadek et al, 2003):

$$RMSE = \frac{\sqrt{\sum_{i=1}^{n}(Ob(i) - Op(i)^2/n}}{Obav} \quad (3.28)$$

- The index of agreement (d) is a standardised measure of the degree of model prediction error and varies between 0 and 1 (Yaun et al., 2008) a value of 1 indicates a perfect agreement between observed and optimised, and 0 indicates no agreement at all (Willmont 1984). The index of agreement equation is shown in equation 3.29.

$$d = 1 - [\frac{\sum_{i=1}^{n}(Ob(i) - (Op(i)^2}{\sum_{i=1}^{n}(\{Op(i) - Op(av) + \{Ob(i) - ob(av)\})^2}] \quad (3.29)$$

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Soil Sampling Results

4.1.1 Grain size analysis

The results of grain size analysis of the soil samples A,B and C are presented in Appendix O

The sieve sizes for the grain size analysis ranged from 0.300mm to 4.75mm, these sieves were arranged with the largest sieve at the top and the smallest below, followed by the tray at the bottom. From results, no soil particle was retained in the largest sieve for the three soil samples, that is why the weights of the sieve and samples remained the same as the weight of the sieve, the highest soil samples were retained at sieve size 0.600mm for the three soil samples with 54.6g, 45.6g and 54.9g for samples A, B, and C respectively while the least soil samples were retained in sieve size 0.300mm for the three soil samples with 0.7g, 1.5g and 0.9g for samples A, B and C respectively, and the finest soil samples collected at the tray were 1.66g, 2.4g and 1.36g for samples A, B, and C respectively.

The quantities D_{60}, D_{30} and D_{10} indicate that 60%, 30% and 10% of the particles (in weights) respectively are smaller than or passed the sieve diameter.

The results of determined effective size, uniformity coefficient and coefficient of degradation from the Semi-Logarithmic Graph in Fig 4.1 are presented in Appendix J

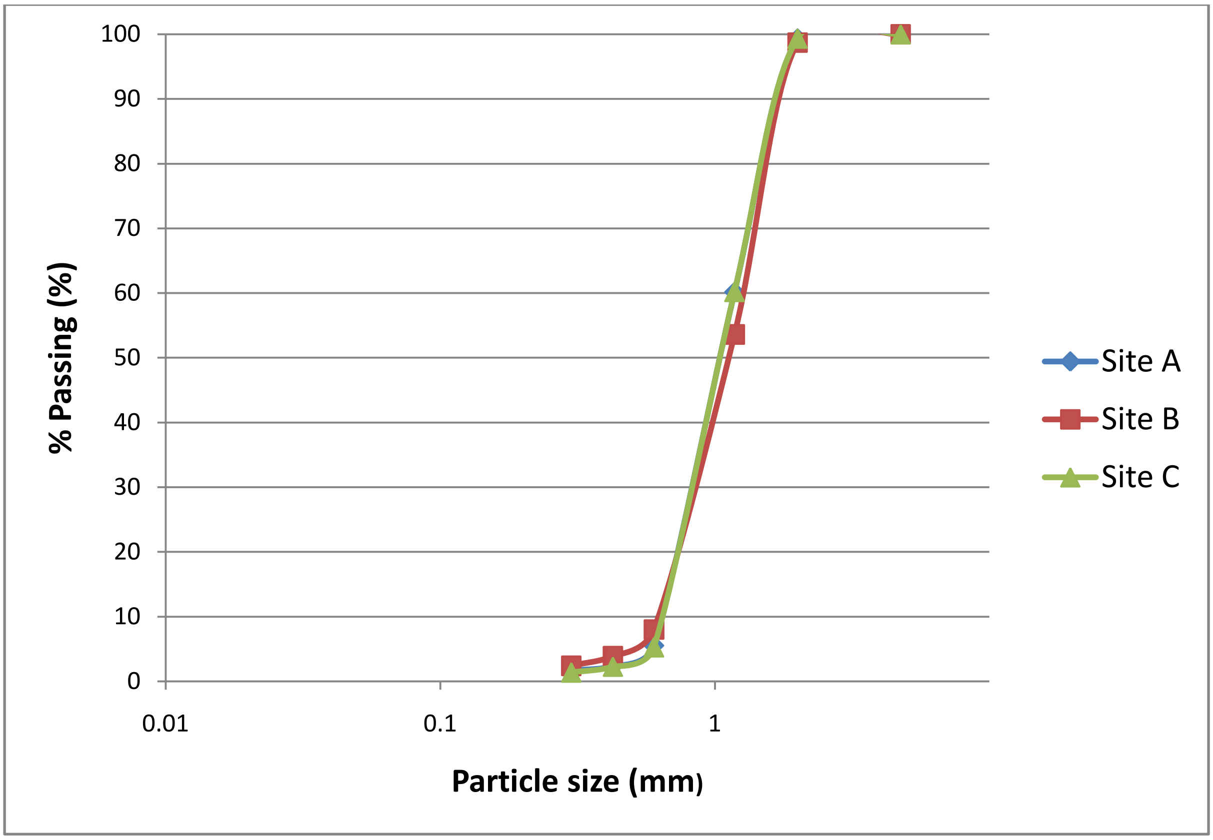


Fig 4.1: Grain size distribution curve for samples A, B, C

4.1.2 Bulk Density

Bulk density was calculated using equation 3.2, the result of bulk density is shown in Appendix C

From the result of bulk density in Appendix C and the plot in Fig 4.2, normal range of bulk density above 1.0g/cm^3 was obtained, unlike that obtained by Zou et al (2000) which obtained low bulk densities, 0.7 and 0.85g/cm^3 for low and high bulk densites respectively. For conventional tillage, the lowest value of bulk density was at 75-100cm depth (1.431g/cm^3) while the highest value was obtained at 0-25cm depth (1.47g/cm^3). The same trend was followed in conservative tillage which was lowest at 75-100cm depth (1.53g/cm^3) and highest at 0-25cm depth (1.55g/cm^3). No tillage was also lowest at 75-100cm depth (1.53g/cm^3) and highest at 0-25cm depth (1.59g/cm^3). Decrease in soil bulk density with intensive tillage was also reported in Karlon and Chawla (2017), Jie et al (2013) and Kurdish et al (2006). Oduma et al (2018) in a study in South Eastern Nigeria also recorded a bulk density of 1.62g/cm^3 for no tillage, 1.49g/cm^3 for conservative tillage and 1.33g/cm^3 for conventional tillage. There are high values of bulk density for no tillage. This is because there was no disturbance of the soil particles by the tillage implement, followed by conservative tillage and there are lowest values at conventional tillage due to complete disturbance of the soil. For no tillage, the bulk density decreased as the soil depth increased. The same trend was observed in conventional tillage with decrease in bulk density as the soil depth increases. Bulk density remained the same from 0-25 to 25-50cm depth at conservative tillage but started decreasing as the soil depth increased. Decrease in bulk density with decrease in soil depth was as a result of the poor soil structure wish was as a result of very low values of least limiting water range.

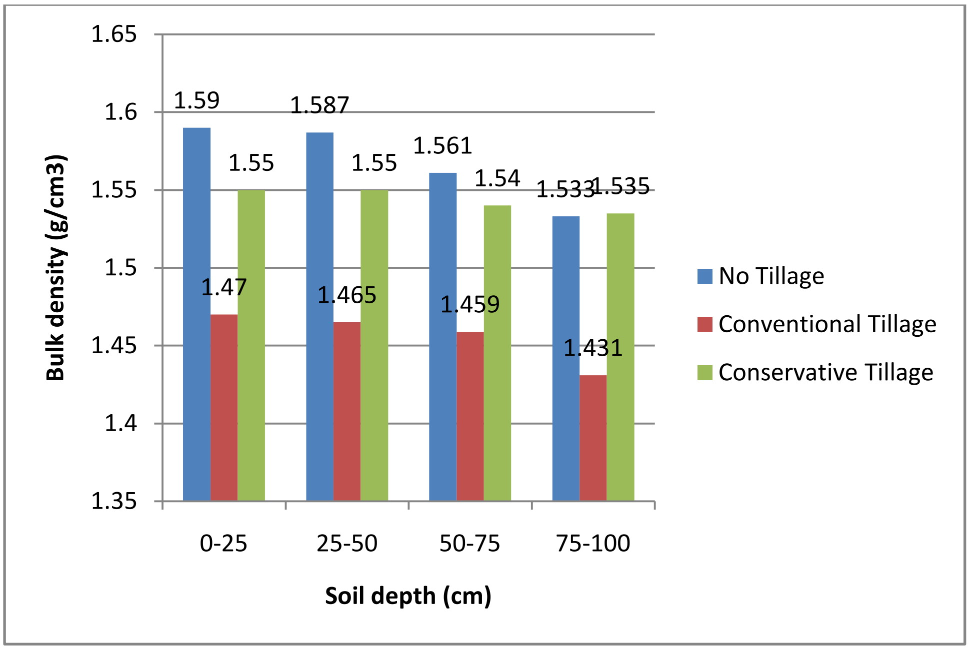


Fig 4.2 Effect of soil depth on bulk density

4.1.3 Particle density

The particle density was calculated using equation (3.3), and the result of particle density analysis is presented in Appendix C

From the particle density result in Appendix C and the Fig 4.3, particle density decreased as soil depth increased for the three tillage treatments, this is in agreement with Alam and Salahin (2013) where particle density decreased from 2.58g/cm^3 to 2.55g/cm^3 as the soil depth increased. At 0-25cm soil depth, particle density of 2.63g/cm^3 was obtained for no tillage and conventional tillage, a lower particle density of 2.58g/cm^3 was obtained for conservative tillage at the same depth. For 25-50cm depth, 2.59g/cm^3, 2.58g/cm^3 and 2.54g/cm^3 were obtained for no tillage, conventional tillage and conservative tillage respectively, at 50-75cm depth, the particle density for no tillage was lower (2.54g/cm^3) than conventional tillage (2.55g/cm^3), while 2.49g/cm^3 was obtained at conservative tillage, at 75-100cm soil depth, particle densities of 2.57g/cm^3, 2.48g/cm^3 and 2.45g/cm^3 were obtained for no tillage, conventional tillage and conservative tillage respectively. The decrease in particle density with decrease in soil depth was because of the decrease in bulk densities with decrease in soil depth.

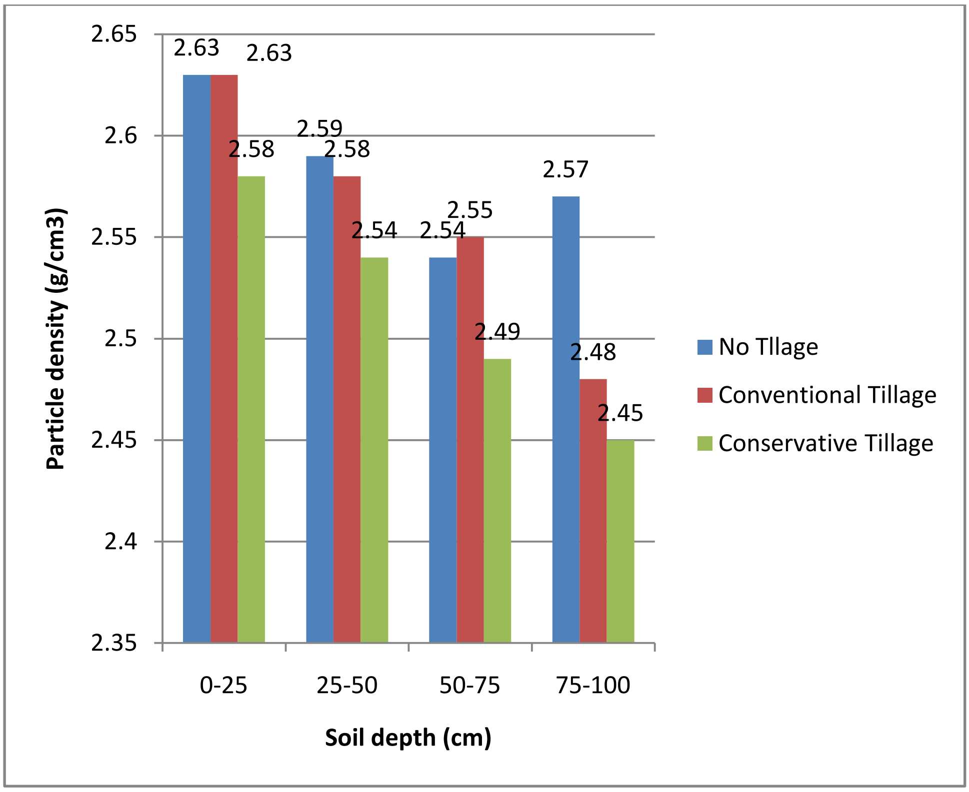


Fig 4.3 Effect of soil depth on particle density

4.1.4 Porosity

Porosity was calculated using equation (3.4) and the results are in appendix C

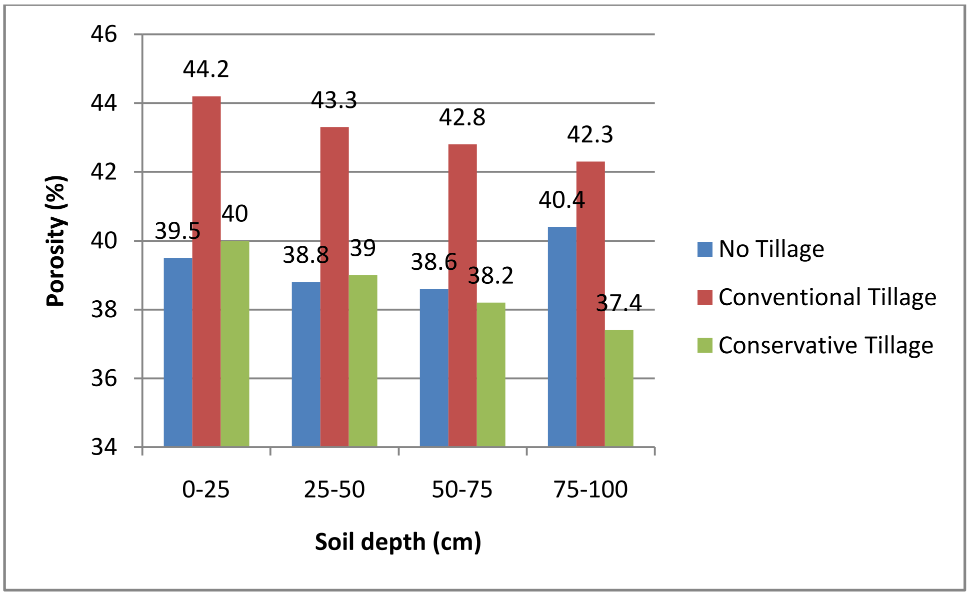


Fig 4.4 Effect of soil depth on porosity

From Fig 4.4, porosity for conventional tillage decreased with increase in soil depth form 44.2% for 0-25cm soil depth to 42.3% for 75-100 cm soil depth, the same trend was observed in conservative tillage with 40% porosity at 0-25cm soil depth and 37.4% at 75-100cm soil depth. There was slight difference in no tillage as the porosity decreased from 39.% at 0-25cm soil depth to 38.2% at 50-75cm soil depth and a sharp increase to 40.4% at 75-100cm soil depth, this is in agreement with with Oduma et al (2018) in a study in a sandy loam soil in South Eastern Nigeria, where they obtained lowest porosity of 50.8% in no tillage and highest porosity of 58.22% in conventional tillage, Omar et al (2015) also recorded a value of 40.% at 0-15cm and 40.7% for 15-30cm soil depth for no tillage, 42.2% and 43.2% for 0-15cm soil depth and 15-30cm soil depth respectively for conservative tillage, and 41.3% and 42.2% for 0-15cm soil depth and 15-30cm soil depth respectively for conventional tillage. From the result, it is clear that soil porosity increases with increase in depth, this is because increase in bulk density decreases porosity

4.2 Penetration Resistance

The result of penetration resistance was calculated using equation 3.23. The results of penetration resistance for all the tillage methods at different soil depths are shown in Table 4.1

Table 4.1 Penetration resistance

Tillage method	Soil depth (cm)	Penetration resistance (MPa)	Penetration resistance (MN/m^2)
No tillage	0-25	2.76	2.76
No tillage	25-50	3.16	3.16
No tillage	50-75	3.65	3.65
No tillage	75-100	4.1	4.1
Conservative tillage	0-25	2.57	2.57
Conservative tillage	25-50	2.93	2.93
Conservative tillage	50-75	3.31	3.31
Conservative tillage	75-100	3.73	3.73
Conventional tillage	0-25	2.15	2.15
Conventional tillage	25-50	2.47	2.47
Conventional tillage	50-75	2.95	2.95
Conventional tillage	75-100	3.41	3.41

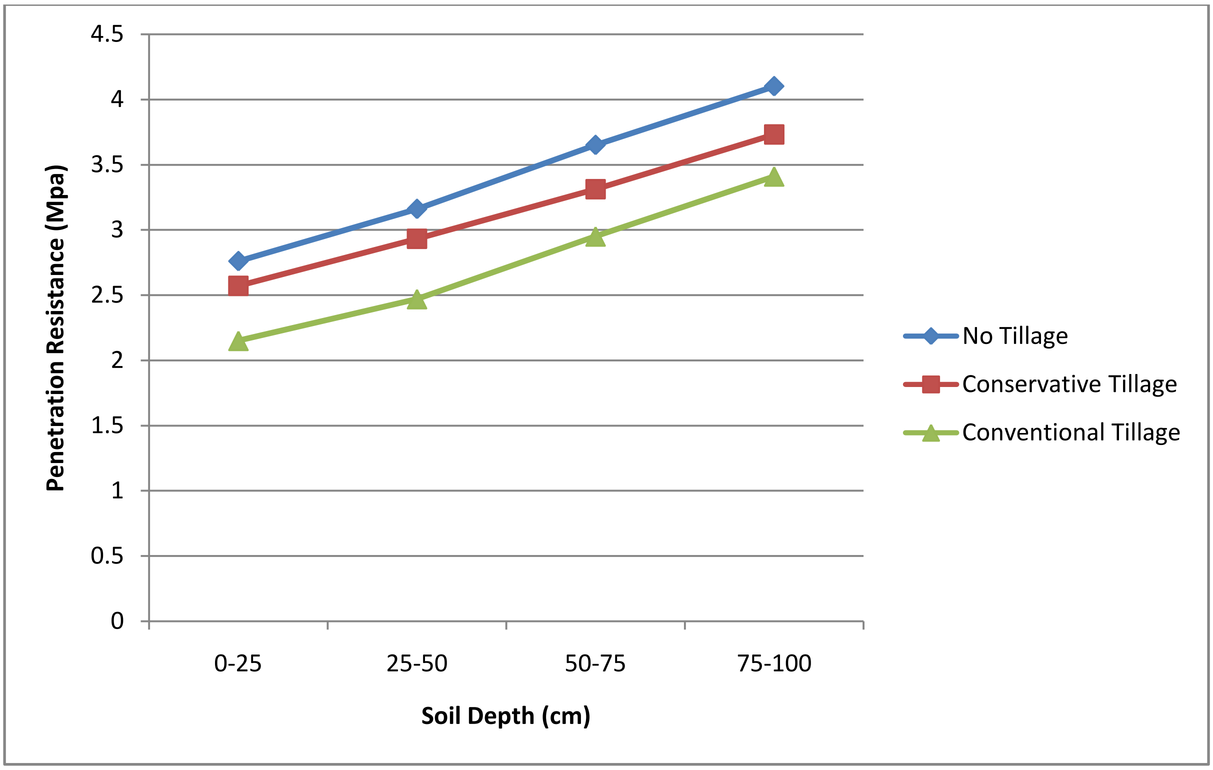


Fig 4.5 Effect of tillage practices on penetration resistance

From Fig 4.5, for no tillage, conservative tillage and conventional tillage, minimum penetration resistance was obtained at 0-25cm depth for each of the tillage practices, the least penetration resistance was at conventional tillage at 2.15MPa. Highest penetration resistance occurred at no tillage (75-100cm) with a resistance of 4.1MPa. The highest penetration resistance was observed at no tillage with an average penetration resistance of 3.4MPa, followed by conservative tillage with an average of 2.9MPa, while the least was conventional tillage, with an average of 2.7MPa, this is because there was more disturbance of the soil in conventional tillage, followed by conservative tillage and no tillage. This result was in agreement with that of Zhao et al., (2014) where they observed higher penetration resistance in conservative tillage than in conventional tillage, the penetration was lower with increase of tillage. Pervaiz et al., (2009) similarly observed maximum penetration resistance in conservative (633KPa) tillage and minimum in conventional tillage (539Kpa). Conventional tillage caused physical manipulation of sub surface soil and increased soil porosity leading to decrease in penetration resistance. Lampurlanes et al., (2003) found larger penetration resistance in No tillage than other tillage methods.

4.3 Soil temperature

The soil temperature was determined using the soil thermometer and the results of the average soil temperature during the growing period are shown in Appendix G

The soil temperature throughout the growing period was determined and the average for all the sub plots were obtained. The maximum temperature obtained was 28°C in sublots 1, 7,11, 12, and 15, these subplots were no tillage subplots hence having high temperature because of less penetration of moisture while the minimum was 23°C in subplots 4, 9,13, and 24. These subplots received conservative tillage allowing penetration of moisture without allowing much moisture to be lost.

4.4 Soil moisture content

The soil moisture content of the samples were determined using the soil moisture metre and the average soil moisture contents for the growing period are shown in appendix H. The average soil moisture from the subplots throughout the growing period ranged from 9.11% to 14.96. The variations in soil moisture content could be because of soil temperature and different tillage methods applied

4.5 Soil moisture content at different matric potentials

Soil samples were collected at different depths at different tillage methods and was placed in the pressure plate apparatus and moisture content was determined at seven matric potentials (-0.01MPa, -0.03MPa, -0.07MPa, -0.1MPa, -0.2MPa, -0.5MPa and -1.5MPa). Permanent wilting point was determined at -1.5MPa while field capacity was determined at -0.01MPa. The result of moisture content at different matric potentials is presented in Appendix K.

The relationship between soil matric potential and volumetric water content for the three tillage practices at different soil depths over the range between field capacity and wilting point as shown in Figs 4.6, 4.7, and 4.8 shows that soil water content increased with decrease in soil matric potential, that is, soil moisture decreased as matric potential moved from field capacity to wilting point. This is in agreement with Zou et al., (2000) where volumetric moisture content increased from permanent wilting point of 0.09, 0.11, 0.12, 0.18, 0.21, 0.23, 0.26 0.30, 0.32, 0.22, 0.26, 0.30 to field capacity of 0.28, 0.31, 0.33, 0.39, 0.43, 0.47, 0.42, 0.48, 0.51, 0.36, 0.43, 0.44 respectively, this is because field capacity means more moisture content, while permanent wilting point means very little moisture content.

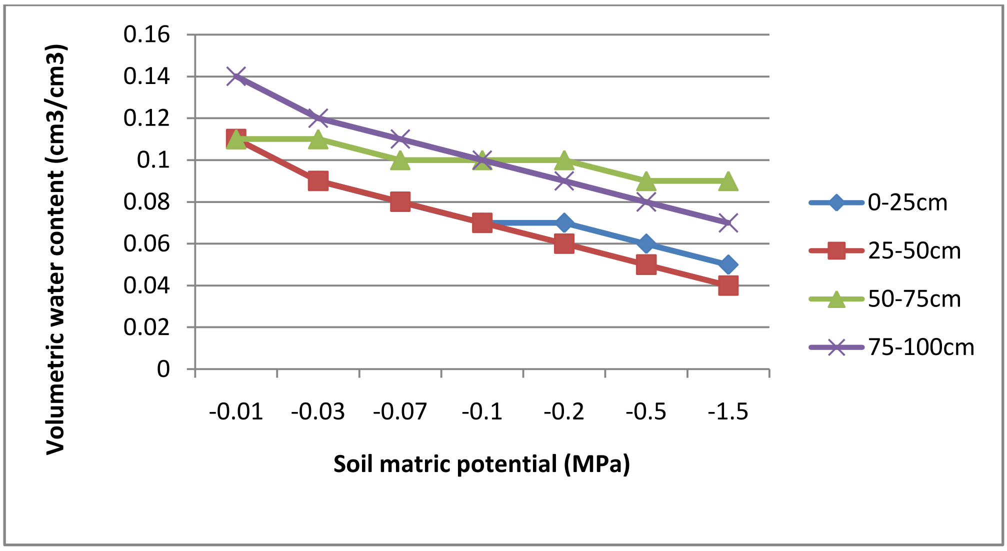


Fig 4.6 Relationship between soil matric potential(ψm) and volumetric water content for conservative tillage

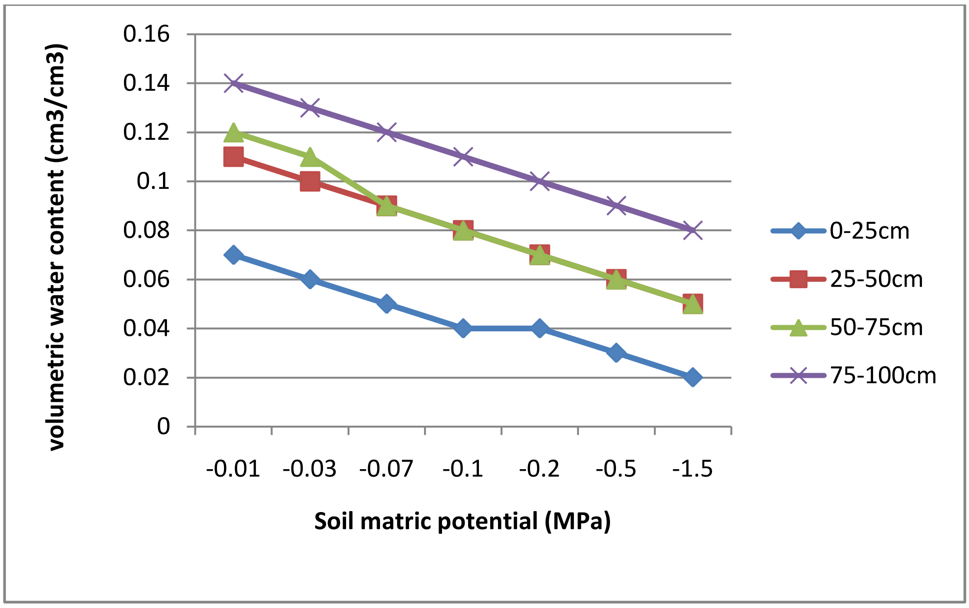


Fig 4.7 Relationship between soil matric potential(ψm) and volumetric water content for no tillage

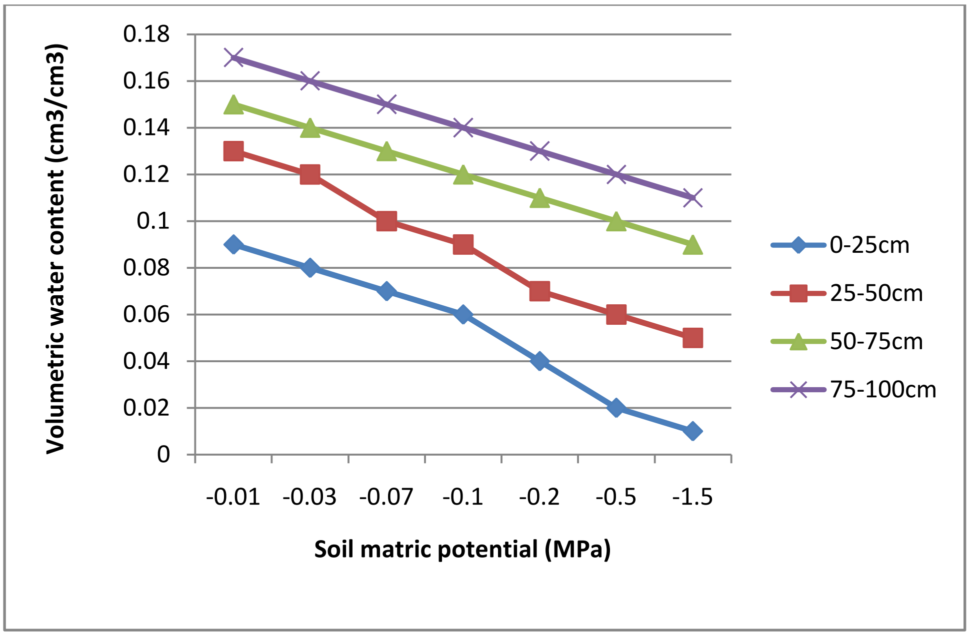


Fig 4.8 Relationship between soil matric potential(ψm) and volumetric water content for conventional tillage

4.6 Field capacity

The field capacity was determined at -0.01MPa and shown in Appendix K. From the result, the field capacity was minimum at no tillage ($0.07cm^3/cm^3$, $0.11cm^3/cm^3$, $0.12cm^3/cm^3$, and $0.14cm^3/cm^3$) for soil depths 0-25cm, 25-50cm, 50-75cm and 75-100cm for conservative tillage ($0.11cm^3/cm^3$, $0.11cm^3/cm^3$, $0.11cm^3/cm^3$, $0.14cm^3/cm^3$) and conventional tillage ($0.09cm^3/cm^3$, $0.13cm^3/cm^3$, $0.15cm^3/cm^3$, $0.17cm^3/cm^3$). At 0-25cm soil depth, there was a bigger value of field capacity in conservative tillage than conventional tillage, this could be because of runoff which occurred in the top soil in conventional tillage as there was maximum disturbance of soil. This is not in agreement with the observation reported by Alam et al., (2014). This is because the soil type is clay loam where highest FC was observed in no tillage ($0.14cm^3/cm^3$), followed by conservative tillage ($0.08cm^3/cm^3$). Also from the results, increase in soil depth increased field capacity which is in agreement with Alam and Salahin (2013) where field capacity increased from $0.24cm^3/cm^3$ to $0.3cm^3/cm^3$.

4.7 Permanent wilting point (PWP)

The permanent wilting points were determined at -1.5MPa as shown in the Appendix K.
From the result, permanent wilting point increased with increase in soil depth in conventional tillage and no tillage with PWP of $0.01cm^3/cm^3$, $0.05cm^3/cm^3$, $0.09cm^3/cm^3$ and $0.11cm^3/cm^3$ at 0-25cm, 25-50cm, 50-75cm and 75-100cm soil depths respectively for conventional tillage and PWP of $0.02cm^3/cm^3$, $0.05cm^3cm^3$, $0.05cm^3/cm^3$ and $0.08cm^3/cm^3$ at 0-25cm, 25-20cm, 50-75cm and 75-100cm soil depths respectively for no tillage. This is in agreement with Alam and Salahin (2013) which recorded an increase in permanent wilting point with increase in soil depth of $0.10cm^3/cm^3$ to $0.15cm^3/cm^3$. There was variation in permanent wilting point for conservative tillage which could be as a result of the bulk density of the soil.

4.8 Least limiting water range (LLWR)

4.8.1 Least limiting water range for conventional tillage

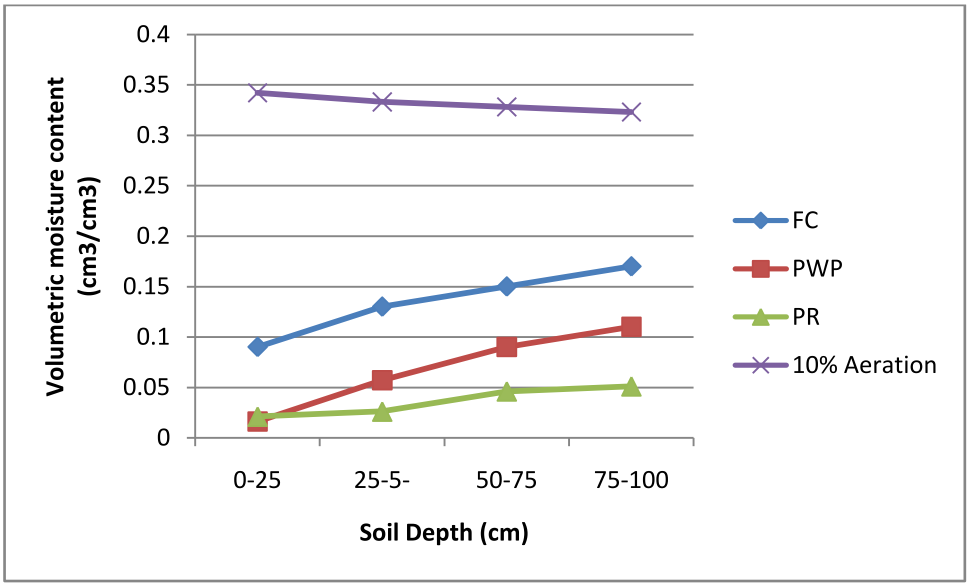


Fig 4.9 Critical points for determination of least limiting water range (LLWR) for root growth for conventional tillage

The upper limit of LLWR is soil water content at 10% aeration porosity or soil water content at field capacity whichever is lower, while the lower limit of LLWR is soil water content at wilting point or penetration resistance at 2MPa which ever is higher (Katritika 2016). As presented in Fig 4.9, water content for the higher limit of LLWR was determined by the field capacity rather than the air filled porosity, while the lower limits of LLWR was determined by wilting point rather than soil strength. The LLWR is the difference between the upper limit and the lower limit. The highest LLWR was 0.074cm^3/cm^3 and this was at 0-25cm soil depth, followed by 0.073cm^3/cm^3 at 25-50cm soil depth, LLWR remained constant with a value of 0.06cm^3/cm^3 at 50-75cm and 75-100cm soil depths. Decrease in LLWR resulted in decrease in bulk density which is contrary to Calonego and Rosolem (2011), who reported increase in LLWR with sudden variations in bulk density. The fact of considering LLWR as a good indicator of crop productivity was found to be correct with a correlation coefficient of 0.9 in Table 4.2 and significance $p<0.05$ in Table 4.3. This is in agreement with Kahlon and Karitika (2017) which also recorded a high correlation coefficient of 0.85 in maize. The least limiting water range has the upper range at field capacity instead of 10% aeration and lower range at permanent wilting point instead of 2MPa penetration resistance because of the poor structure of the soil.

4.8.2 Least limiting water range for conservative tillage

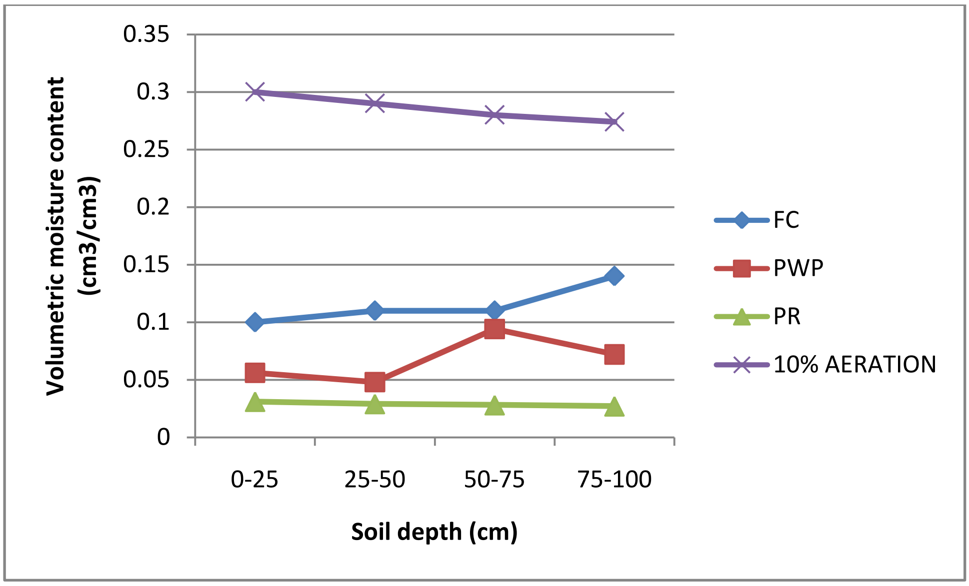


Fig 4.10 Critical points for determination of least limiting water range (LLWR) for root growth for conservative tillage

As presented in Fig 4.10, water content for the higher limit of LLWR was determined by the field capacity rather than the air filled porosity, while the lower limits of LLWR was determined by wilting point rather than soil strength. The highest LLWR was $0.068cm^3/cm^3$ and this was at 50-75cm soil depth, followed by $0.062cm^3/cm^3$ at 25-50cm soil depth, $0.051cm^3/cm^3$ at 75-100cm depth and the least was $0.044cm^3/cm^3$ at 0-25cm soil depth. Increase in LLWR with sudden decrease resulted in decrease in bulk density which is in agreement with Calonego and Rosolem (2011), which reported increase in LLWR with sudden decrease with an increase in bulk density. The fact of considering LLWR as a good indicator of crop productivity was found to be correct with a correlation coefficient of 0.9 in Table 4.2 and significance p≤0.05 in Table 4.3. This is in agreement with Kahlon and Karitika (2017) which also recorded a high correlation coefficient of 0.85 in maize. The least limiting water range has the upper range at field capacity instead of 10% aeration and lower range at permanent wilting point instead of 2MPa penetration resistance because of the poor structure of the soil.

4.8.3 Least limiting water range for no tillage

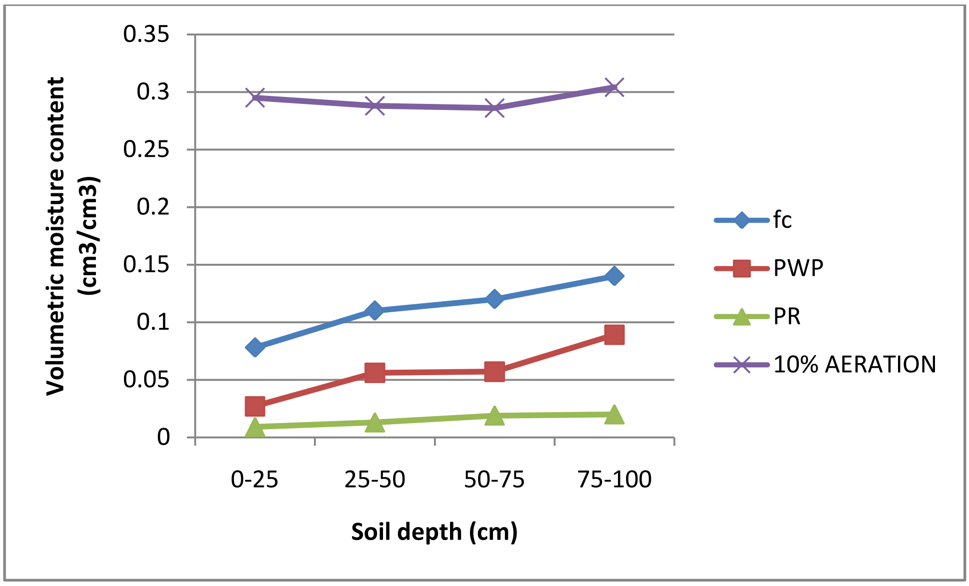


Fig 4.11 Critical points for determination of least limiting water range (LLWR) for root growth for no tillage

As presented in Fig 4.11, water content for the higher limit of LLWR was determined by the field capacity rather than the air filled porosity, while the lower limits of LLWR was determined by wilting point rather than soil strength. The highest LLWR was $0.06cm^3/cm^3$ and this was at 50-75cm soil depth, LLWR was constant at $0.05cm^3/cm^3$ for 0-25cm, 25-50cm and 75-100cm the soil depths. Increase in LLWR with sudden decrease resulted in decrease in bulk density which is in agreement with Calonego and Rosolem (2011), which reported increase in LLWR with sudden decrease with an increase in bulk density. The fact of considering LLWR as a good indicator of crop productivity was found to be correct with a correlation coefficient of 0.9 in Table 4.2 and significance $p<0.05$ in Table 4.3. This is in agreement with Kahlon and Karitika (2017) which also recorded a high correlation coefficient of 0.85 in maize.

The least limiting water range was found to be lowest in no tillage with a mean of $0.052cm^3/cm^3$, followed by conservative tillage with a mean of $0.06cm^3/cm^3$ and conventional tillage with a mean of $0.07cm^3/cm^3$. This is in agreement with Kahlon and Katrina (2017) which recorded lowest mean limiting water range of $0.15m^3/m^3$ at no tillage and highest mean LLWR of $0.26m^3/m^3$ at deep tillage. The least limiting water range has the upper range at field capacity instead of 10% aeration and lower range at permanent wilting point instead of 2MPa penetration resistance because of the poor structure of the soil.

4.9 Statistical Analysis of Bulk Density and Least Limiting Water Range

This was done for bulk density at different tillage methods and soil depths and is presented in Table 4.2-4.3.

Table 4.2 R^2, Multiple R, standard error and observation table for bulk density and least limiting water range

	Multiple R	**R Square**	**Standard Error**	**Observation**
No Tillage	0.996	0.992	0.005739	3
Conventional	0.996	0.992	0.007	3
Conservative	0.993	0.987	0.0083	3

For the three tillage methods, R^2 values greater than 90% was obtained for analysing bulk density and LLWR and this is in agreement with Kahlon (2017) which obtain an R^2 of 85% correlation coefficient.

Table 4.3 ANOVA for bulk density and least limiting water range

	Df			SS			MS			F			P -Value @ 0.05		
Tillage	**NT**	**CST**	**CVT**	**NT**	**CST**	**CVT**	**NT**	**CST**	**CVT**	**NT**	**CST**	**CVT**	**NT**	**CST**	**CVT**
Regression	1	1	1	0.0085	0.010	0.0124	0.0085	0.010	0.0124	259.1	155.7	253.25	0.03 Sig.	0.05 Sig.	0.03 Significant
Residual	2	2	2	6.59E-05	0.00014	9.82E-05	3.29E-05	7.02E-05	0.0001						
Total	3	3	3	0.0086	0.0121	0.013									

4.10 Irrigation requirement

4.10.1 Irrigation Frequency

Irrigation frequency was determined using equation 3.14 and the result for all the tillage methods and different irrigation deficit levels are presented in Appendix H. The soil depths are the stages in soil growth as in Table 3.1 where, 0-25cm represents the initial stage, 25-50cm represents the crop development stage, 50-75cm represents the mild stage and 75-100cm represents the late stage.

4.10.1.1 Irrigation Frequency for Conventional Tillage

At 10% MAD, irrigation frequency was 3 days, 4 days, 1 day and 4 days for 0-25cm, 25-50cm, 50-75cm and 75-100 cm respectively.

At 30% MAD, irrigation frequency was 4days, 4days, 3days and 4days for 0-25cm, 25-50cm, 50-75cm and 75-100cm soil depths respectively.

At 50% MAD, irrigation frequency was 4days, 10days, 6days and 5days for 0-25cm, 25-50cm, 50-75cm and 75-100cm respectively.

Irrigation frequency is higher in 50% MAD because a lot of water was allowed to deplete from field capacity hence more days before irrigation.

4.10.1.2 Irrigation Frequency for Conservative Tillage

At 10% MAD, irrigation frequency was 3 days, 3 days, 4 day and 3 days for 0-25cm, 25-50cm, 50-75cm and 75-100 cm respectively.

At 30% MAD, irrigation frequency was 4days, 4days, 5days and 3days for 0-25cm, 25-50cm, 50-75cm and 75-100cm soil depths respectively.

At 50% MAD, irrigation frequency was 6days, 7days, 10days and 5days for 0-25cm, 25-50cm, 50-75cm and 75-100cm respectively.

4.10.1.3 Irrigation Frequency for No Tillage

At 10% MAD, irrigation frequency was 5 days, 4 days, 4 day and 3 days for 0-25cm, 25-50cm, 50-75cm and 75-100 cm respectively.

At 30% MAD, irrigation frequency was 5days, 5days, 5days and 4days for 0-25cm, 25-50cm, 50-75cm and 75-100cm soil depths respectively

At 50% MAD, irrigation frequency was 5days, 6days, 4days and 4days for 0-25cm, 25-50cm, 50-75cm and 75-100cm respectively.

Irrigation frequency is higher in 50% MAD for conventional tillage, conservative tillage and no tillage because a lot of water was allowed to deplete from field capacity hence more days before irrigation. The mean number of days is less in no tillage because runoff is more likely to occur in tilled soil than undisturbed soil.

4.11 Evapotranspiration

The Daily Evapotranspiration for the growing period was obtained climatic data and calculated using Hargreaves equation, (equation 3.10). The calculated daily evapotranspiration is presented in Appendix B. The maximum evapotranspiration is

7.3mm/day and this was obtained in the 38th day of the growing period. This is because the average temperature calculated from the minimum and maximum temperature is high in this period. The least evapotranspiration is 1mm/day at 83rd day because the average temperature from the minimum and maximum temperature of the period is low.

4.12 Consumptive Use (CU)

The calculated consumptive use from equation 3.11 is presented in Appendix B

The highest consumptive use was 6.3mm/day obtained in 38th day and 0.86mm/day at 83rd day. These correspond to the days of highest and lowest evapotraspiration because consumptive use increases as evapotranspiration increases

4.13 Available Water

The available water was calculated using equations (3.6), (3.7) and (3.8) and presented in Table 4.4.

Table 4.4 Available water for the three tillage methods.

Tillage	**Depth(cm)**	**Available water**
NT	0-25	3.17cm
	25-50	6.06cm
	50-75	7.9cm
	75-100	9.24cm
CST	0-25	1.9cm
	25-50	5.05cm
	50-75	2.34cm
	75-100	11.41cm
CVT	0-25	1.9cm
	25-50	4.3cm
	50-75	7cm
	75-100	7.7cm

From Table 4.4, available water increased with increase in soil depth for the three tillage methods. For no tillage, the least available water was 3.17cm at 0-25cm soil depth while the highest was 9.24 at 75-100cm soil depth. For conservative tillage, the least available water was 1.9cm for 0-25cm soil depth and highest at 75-100cm soil depth with a value of 11.41cm, while for conventional tillage, it was 1.9cm for 0-25cm soil depth and 7.7cm for 75-100cm soil depth. There was more available water as soil depth increased because of higher evapotranspiration at the soil surface.

4.14 Basic hydraulics of drip irrigation

The results of energy drop by friction for the mainline and total energy drop for the lateral are presented in Appendix M

4.15 Emitter flow rate

Emitter flow rate is the rate of discharge from the emitters of the drip irrigation facility

There was variation in flow rate for different emitters in Table 4.5, emitters closer to the source had higher flow rates and this was controlled by adjusting the valves for suitable flow rates. Three different flow rates were obtained for the different MAD as shown in Table 4.5 below,

Table 4.5 Average emitter flow rate

Emitter flow rates @10%MAD (gpm)	**Emitter flow rates @ 30%MAD (gpm)**	**Emitter flow rates @ 50%MAD (gpm)**
0.007	0.007	0.007
0.0063	0.0061	0.0060
0.0056	0.0055	0.0053

4.16 Net irrigation water requirement (NIWR)

This is the actual amount of water necessary for cop growth, it was determined using equation (3.12) and shown in Appendix D

For the three tillage treatments, net irrigation increased with increase in management allowable depletion, this is because more water is removed at higher management allowable depletion. The average net irrigation for conservative tillage at 0-25cm, 25-50cm, 50-75cm and 75-100cm soil depth were found to be 0.59cm, 1.26cm, 2.1cm and 2.3cm respectively. For conventional tillage at 0-25cm, 25-50cm 50-75cm and 75-100cm soil depth, the average net irrigation obtained was 0.59cm, 1.5cm, 0.70cm and 2.3cm respectively, while for no tillage at 0-25cm, 25-50cm, 50=75cm and 75100cm soil depths an average net irrigation of 0.97cm, 1.8cm, 2.3cm and 2.7cm respectively were obtained. From the results, net irrigation increased with increase in soil depth for all the tillage methods.

4.17 Gross irrigation water requirement (GIWR)

This is the quantity of water to be applied in realty, taking into consideration water losses

This was calculated from equation 3.13, the calculations and results are shown in Appendix E

There was increase in gross irrigation with increase in soil depth, this is because of the net irrigation which increased with increase in soil depth. For conservative tillage at 0-25cm, 25-50cm, 50-75cm and 75-100cm soil depths, there were average gross irrigations of 0.67cm, 1.56cm, 2.33cm and 2.61cm respectively. For conventional tillage at 0-25cm, 25-50cm, 50-75cm and 75-100cm soil depths, average gross irrigations recorded are 0.67cm, 1.69cm, 0.97cm and 2.6cm respectively while for no tillage at 0-25cm, 25-50cm, 50-75cm and 75-100cm, gross irrigations of 1.07cm, 2.00cm, 2.64cm and 3.04cm respectively was obtained.

The difference in the gross irrigation and net irrigation is water not contributing to target.

4.18 Catch can test

This was done to determine the quantity of water collected after 30 minutes of irrigation application, the irrigation application rate was determined from this process

Table 4.6 Result of the Catch Can Test

Container number	Average water depths observed (cm)	Time (mins)	Cummulative water depths observed (cm)
1	0.41	5.0	0.41
2	0.83	10.0	1.24
3	1.3	15.0	2.54
4	1.7	20.0	4.24
5	2.09	25.0	6.33
6	2.5	30.0	8.83

The result of the application rate is presented in Appendix L

4.19 Irrigation run time

This is the time allowed for irrigation water to run. The irrigation run time was calculated using equation (3.9) and tabulated in Appendix F

For conservative tillage, average irrigation run time of 0.23hr, 0.4hr, 0.8hr, and 0.86hr were obtained for 0-25cm, 25-50cm, 50-75cm and 75-100cm soil depths respectively. For conventional tillage average irrigation runtime of 0.22hr, 0.6hr, 0.33hr and 0.86hr were obtained for 0-25cm, 25-50cm, 50-75cm and 75-100cm respectively, while for no tillage, average irrigation run time of 0.35hr, 0.6hr, 0.9hr and 1hr were obtained for 0-25cm, 25-50cm, 50-75cm and 75-100cm soil depths respectively. More irrigation run times were obtained in no tillage, this is because it will take time for the soil to absorb water because of the absence of tillage.

4.20 Flow variation

This is the statistical measure of how flow changes from time and space. This was determined using equation (3.15) and presented in Table 4.7.

Table 4.7 Result of flow variation

Flow variation @10%MAD (%)	Flow variation @ 30%MAD (%)	Flow variation @ 50%MAD (%)
20%	19.5%	19%

There was flow variations of 15.56% in 10% MAD, 16.7% at 30% MAD and 18.9% in 50% MAD. A flow variation of 10-20% is acceptable Christensen (1942), the flow variations in Table 4.7 are within acceptable range.

4.21 Uniformity coefficient

This was also calculated using equation 3.19 and shown in Table 4.8

Table 4.8 Result of Uniformity Coefficient

Uniformity coefficient @10%MAD (%)	Uniformity coefficient @ 30%MAD (%)	Uniformity coefficient @ 50%MAD (%)
96	99	99

There was uniformity coefficient of 96% for 10% MAD, 99% for 30% MAD and, 99% for 50% MAD. Uniformity coefficient up to 90% is acceptable, (Christensen 1942). The uniformity coefficients in Table 4.8 are within the acceptable range.

4.22 Coefficient of variation (CV)

This was calculated using the equation (3.20), and shown in Table 4.9.

Table 4.9 Result of Coefficient of variation

Coefficient of variation @10%MAD (%)	Coefficient of variation @ 30%MAD (%)	Coefficient of variation @ 50%MAD (%)
15.56%	16.7%	18.9%

There was coefficient of variation of 15.56% for 10% MAD, 16.7% for 30% MAD and 18.9% for 50% MAD, these fall within acceptable range of coefficient of variation as coefficient of variations between 1-20% are acceptable, Christensen (1942)

4.24 Scheduling coefficient based on lowest 25% ($SC_{25\%}$)

This helps to define how much critical dry area shall be left in irrigated area and irrigation duration being necessary for its application to eliminate this area. This was determined using equation 3.21 and tabulated in Table 4.10.

Table 4.10 Result of Scheduling coefficient

Schedulling coefficient @10%MAD	Flow variation @ 30%MAD	Flow variation @ 50%MAD
1.18	1.093	1.10

Schedulling coefficient of 1.18, 1.093 and 1.10 were obtained for 10% MAD, 30% MAD and 50% MAD respectively and this falls within the acceptable range as schedulling coefficient varies from 1.1 to 1.4 with an efficient irrigation coefficient less than 1.3 (Zoldoske 2003)

4.24 Soil parameters

4.24.1 Soil pH

From the pH result presented in Fig. 4.12, pH decreased with increase in soil depth for conservative tillage with values of 7.07, 7.05, 7.01 and 6.98 for, 0-25cm, 25-50cm, 50-75cm and 75-100cm soil depths respectively, the same trend was also observed in no tillage with values of 7.07, 7.05, 7.01 and 6.98 for 0-25cm, 25-50cm, 50-75cm and 75-100cm soil depths respectively. The decrease in pH with increase in soil depth for conservative and no tillage was as a result of minimum disturbance of the soil in the two methods, which did not allow much movement of water down the soil layer. A different trend was observed in conventional tillage pH remained constant with value of 6.79 at 0-25cm, 25-50cm, and 50-75cm soil depths, there was a slight decrease of 6.78 at 75-100cm soil depth, this is because there was movement of water in the soil layer. The mean pH was 7.02, 6.787, and 6.51 for conservative tillage, conventional tillage and no tillage respectively, this is in agreement with the observation by Kahlon and Singh 2014 where conventional tillage and no tillage were applied in a sandy loam soil, the mean highest pH of 7.43 was observed in conventional tillage while a lower mean pH of 7.34 was observed in no tillage.

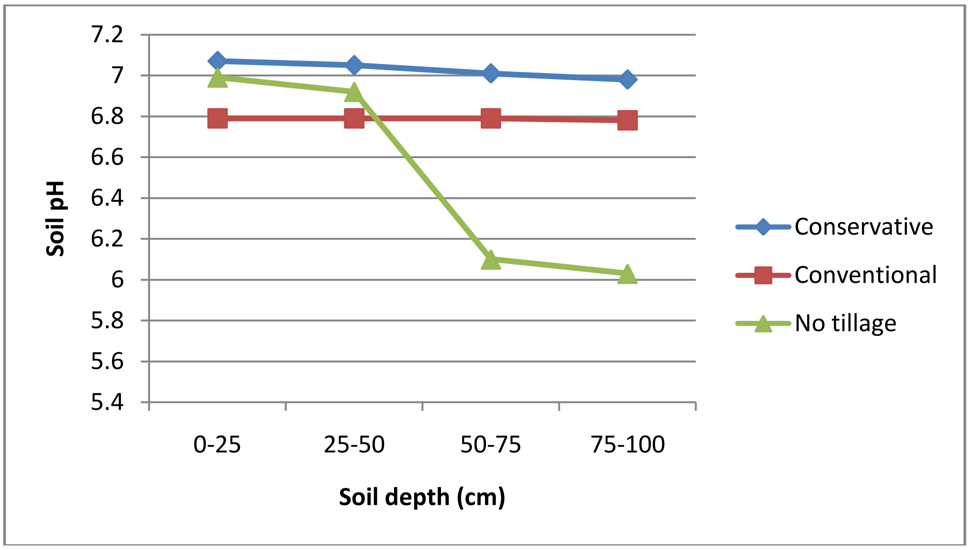


Fig 4.12 Graph of Soil pH

4.24.2 Soil electrical conductivity (EC)

From the result of soil electrical conductivity presented in Fig. 4.13, increase in soil depth decreased soil electrical conductivity for the three tillage methods. For conventional tillage, electrical conductivity decreased from 53.9µs/cm to 50.6µs/cm, for conservative tillage, it decreased from 54.4µs/cm to 51.9µs/cm, while for no tillage, there was a decrease from 55.6µs/cm to 53.7µs/cm. The decrease in electrical conductivity with increase in depth is as a result of decrease in soil temperature. A mean average electrical conductivity of 52.1µs/cm, 52.9µs/cm and 54.4µs/cm were obtained for conservative tillage, conventional tillage and no tillage respectively, in contrast, Kahlon and Singh (2014) and Patni et al (1998) reported decrease in soil electrical conductivity under no tillage, which might be due to more downward movement of salts along with infiltration into deeper layers.

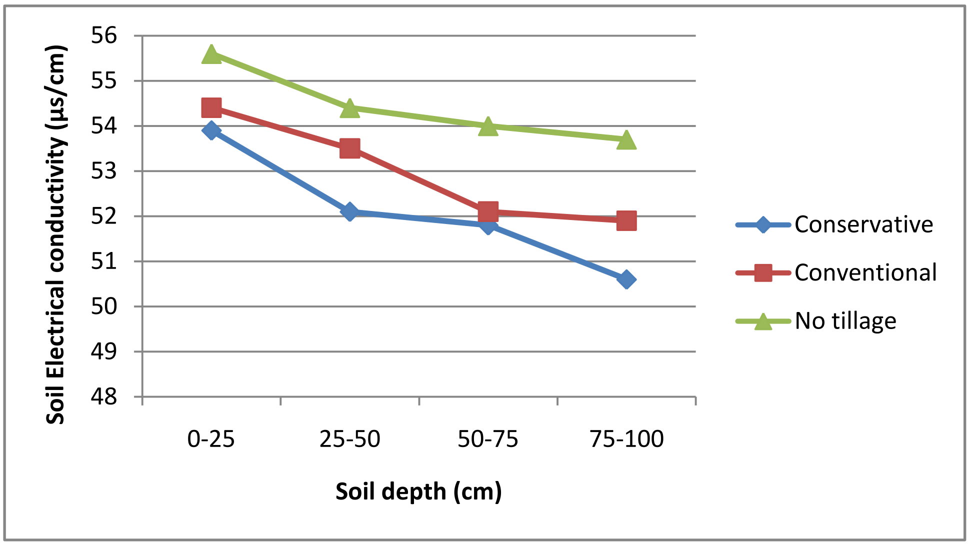


Fig 4.13 Graph of soil electrical conductivity

4.24.3 Soil potassium

From the results presented in Table 4.13 and Fig 4.14, increase in soil depth decreased soil potassium for the three tillage methods. The mean soil potassium for the tillage treatments are 7.6ppm, 7.79ppm, and 7.9ppm for conservative tillage, conventional tillage and no tillage respectively. The mean highest tillage was in no tillage, followed by conventional tillage, and the least mean potassium was in conservative tillage. This is in agreement with the findings by Saiful et al., (2015) in which the highest mean potassium was in no tillage, followed by conventional tillage. Accumulation of soil potassium occurred in upper part of no tillage with a value of 9.376ppm. There was more accumulation of potassium in conventional tillage than conservative tillage, this could be as a result of compaction by farm machineries during tillage practice which did not allow much infiltration.

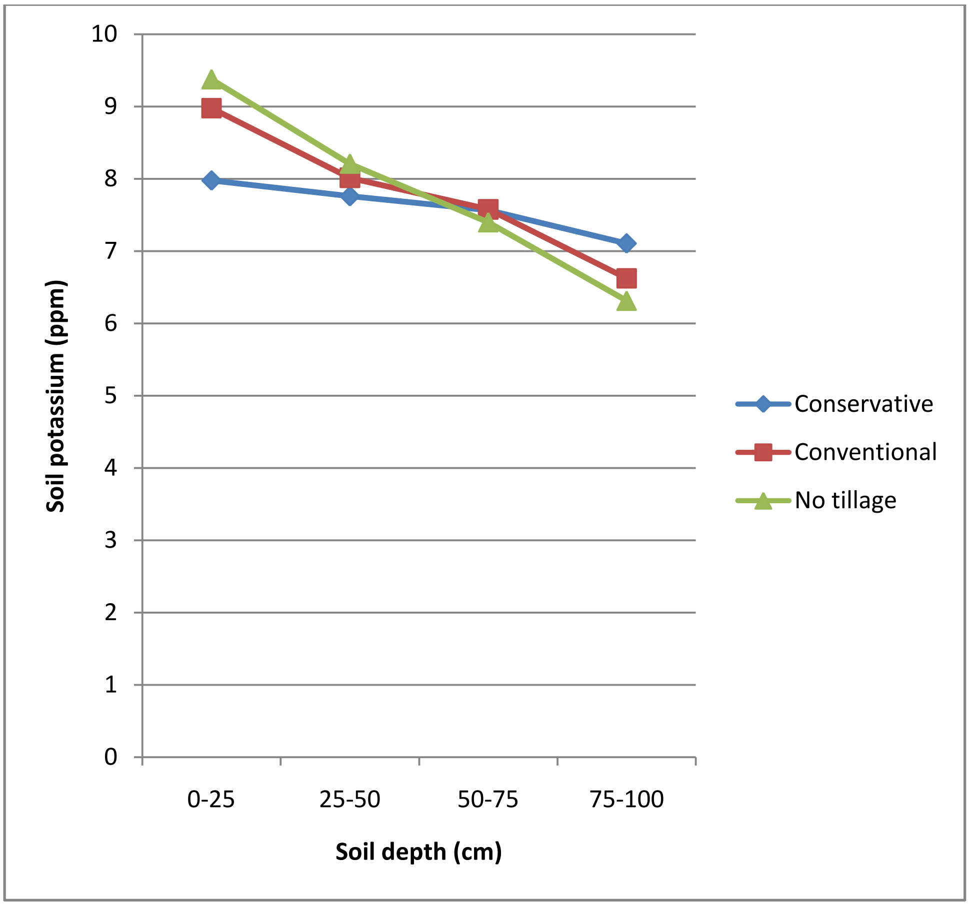


Fig 4.14 Graph of soil potassium

4.24.4 Soil Organic carbon content (OC)

From the result of soil organic carbon content in Table 4.14 and Fig 4.15, soil organic carbon content reduces with increase in soil depth for the three tillage methods with an average soil organic content of 6.8g/kg, 6.4g/kg and 6.9g/kg for conservative tillage, conventional tillage and no tillage respectively. This is in agreement with the report by Kahlon and Singh (2014) which reported a the highest average soil organic carbon content in no tillage with a value of 3.01g/kg and the lowest average soil organic content of 2.58g/kg in conventional tillage with a value of 2.58g/kg. also reported highest mean soil organic carbon content in no tillage. The highest mean soil organic carbon content is in no tillage because no tillage reduces soil disturbance, improves soil maintenance and benefits soil quality. Zentner et al.,(2004) reported 14-17% higher soil organic carbon in surface soil under no tillage than conventional tillage practices.

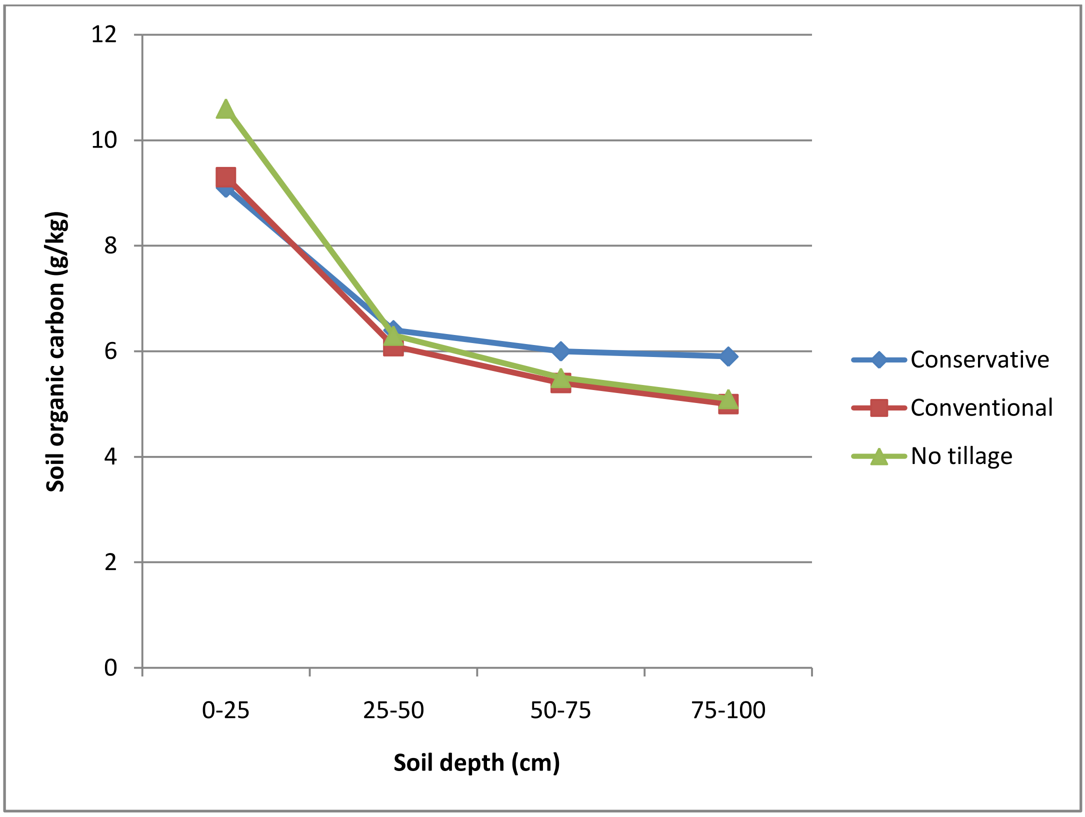


Fig. 4.15 Graph of soil organic carbon

4.24.5 Soil nitrogen (N)

From the result of soil nitrogen presented in Table 4.15 and Fig. 4.16, increase in soil depth decreased soil nitrogen for conventional tillage, with values of 1.5g/kg, 1.3g/kg, 1.2g/kg and 1.0g/kg for 0-25cm, 25-50cm, 50-75cm and 75-100cm soil depths respectively similar trend was not observed for no tillage (1.9g/kg, 1.9g/kg, 1.5g/kg and 1.4g/kg for 0-25cm, 25-50cm, 50-75cm and 75-100cm respectively) and conservative tillage (1.6g/kg, 1.6g/kg, 1.5g/kg and 1.3g/kg for 0-25cm, 25-50cm, 50-75cm and 75-100cm respectively). This shows that there was more organic matter accumulation with decrease in soil depths for the three tillage methods. The average soil nitrogen for conservative tillage was 1.5g/kg and 1.3g/kg for conventional tillage while an average soil nitrogen of 1.7g/kg was obtained for no tillage. Arshad et al 1990 and Moussa-Machraoui et al (2010) also reported more average soil nitrogen in no tillage due to high organic matter accumulation

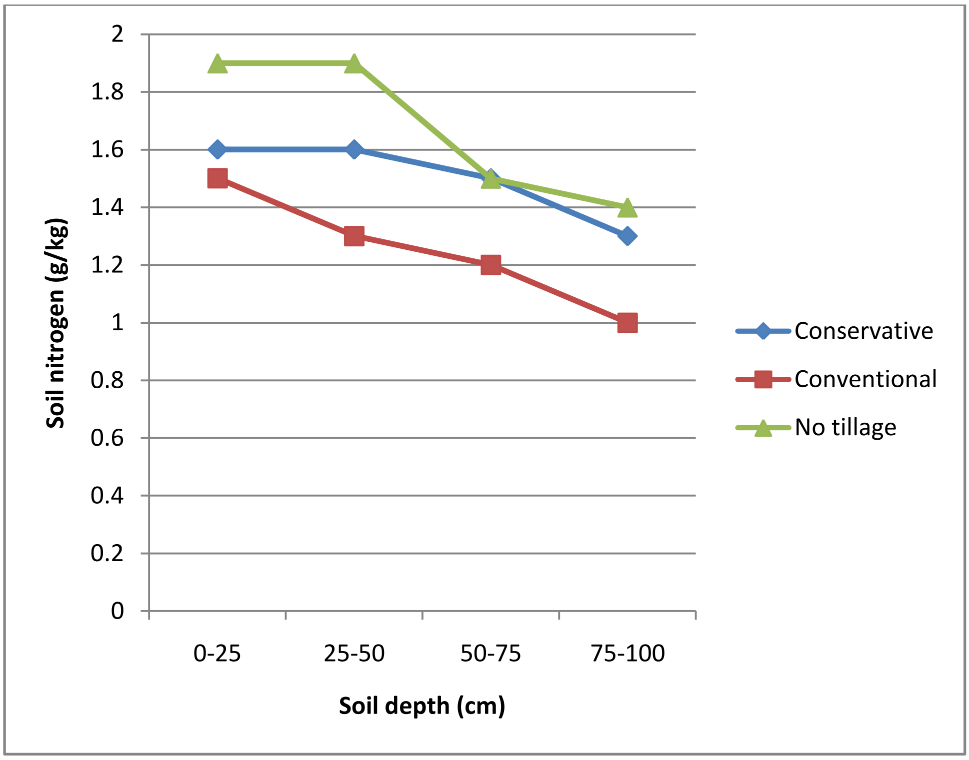


Fig 4.16 Graph of soil nitrogen (g/kg)

4.24.6 Soil phosphorus (P)

From the result of soil phosphorous in Table 4.16 and Fig 4.17, increase in soil depth resulted in increase in soil phosphorus for conservative tillage, with values of 2.83mg/kg, 4.69mg/kg, 6.154mg/kg and 7.79mg/kg for 0-25cm, 25-50cm, 50-75cm and 75-100cm soil depths respectively, similar trend was also observed in conventional tillage with values of 3.095mg/kg, 3.594mg/kg, 6.045mg/kg and 6.514mg/kg for 0-25cm, 25-50cm, 50-75cm and 75-100cm soil depths respectively while different trend was observed in no tillage where values of 5.065mg/kg, 4.956mg/kg, 4.649mg/kg and 4.411mg/kg for 0-25cm, 25-50cm, 50-

75cm and 75-100cm soil depths respectively. There was more accumulation of phosphorous in the upper soil layer in no tillage because of compaction which allows only little amount of mineral down the soil layer unlike in conventional tillage and conservative tillage with less accumulation of phosphorous in the upper soil layer because of disturbance from agricultural implements. Neugschwandtner et al., (2014) observed accumulation of phosphorus in the upper soil layer and depletion in deepest sampled soil layer over time

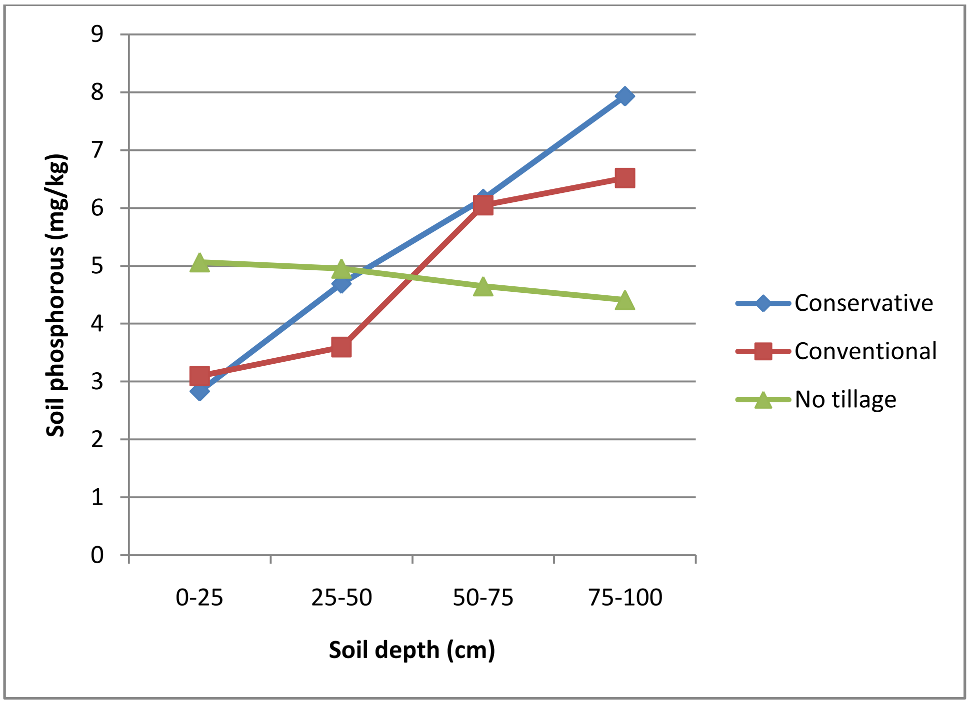


Fig 4.17 Graph of soil phosphorous

4.25 Infiltration

Table 4.11 Infiltration Data for Test Site (conventional tillage)

Time interval	Elapsed time ΔT (total)min	Cylinder readings		Infiltration $I = \frac{\Delta V}{A_r}$ (mm)	Infiltration rate (mm/hr)	Cumulative infiltration (mm)
		Elev. V (CM$^{3)}$	ΔV (CM$^{3)}$			
1. START	15	1000	470	6.65	26.60	26.60
END	(15)	530				
2. START	15	1000	435	6.13	24.5	51.10
END	(30)	565				
3. START	15	1000	410	5.80	23.48	74.58
END	(45)	590				
4. START	15	1000	780	11.03	22.06	96.64
END	(60)	220				
5. START	30	1000	420	5.94	11.58	108.52
END	(90)	580				
6. START	30	1000	390	5.5	11.00	119.52
END	(120)	610				
7. START	30	1000	390	5.5	11.00	130.52
END	(150)	610				

From the infiltration result of conventional tillage in Table 4.11, at 15, 30, 45, 60, 90 120 and 150 minutes, infiltration rates of 26.60mm/hr, 24.5mm/hr, 23.48mm/hr, 22.06mm/hr,11.58mm/hr 11.00mm/hr and 11.00mm/hr were observed respectively. The basic infiltration rate was observed at 120mins and thereafter to be 11mm/hr for the location. Martin et al., (2004) reported a faster infiltration rate in conventional tillage than conservative tillage.

Table 4.12 Infiltration Data for Test Site (conservative tillage)

Time interval	Elapsed time ΔT (total)min	Cylinder readings		Infiltration $I = \frac{\Delta V}{A_r}$ (mm)	Infiltration rate (mm/hr)	Cumulative infiltration (mm)
		Elev. V (CM^{3})	ΔV (CM^{3})			
1. START	15	1000	160	2.27	9.06	9.06
END	(15)	840				
2. START	15	1000	155	2.19	8.77	17.83
END	(30)	845				
3. START	15	1000	145	2.05	8.20	26.03
END	(45)	855				
4. START	15	1000	130	1.84	7.36	33.39
END	(60)	870				
5. START	30	1000	220	3.12	6.24	39.63
END	(90)	780				
6. START	30	1000	200	2.83	5.66	45.29
END	(120)	800				
7. START	30	1000	200	2.83	5.66	50.95
END	(150)	800				

From the infiltration result of conservative tillage in table 4.12, at 15, 30, 45, 60, 90 120 and 150 minutes, infiltration rates of 9.06mm/hr, 8.77mm/hr, 8.20mm/hr, 7.36mm/hr, 6.24mm/hr 5.66mm/hr and 5.66mm/hr were observed respectively. The basic infiltration rate was observed at 120mins and thereafter to be 5.66mm/hr for the location. Martin et al., 2004 reported a slower infiltration rate in conservative tillage compared to conventional tillage.

Table 4.13 Infiltration Data for Test Site (No tillage)

Time interval	Elapsed time ΔT (total)min	Cylinder readings		Infiltration $I = \frac{\Delta V}{A_r}$ (mm)	Infiltration rate (mm/hr)	Cumulative infiltration (mm)
		Elev. V ($CM^{3)}$	ΔV ($CM^{3)}$			
1. START	15	1000	110	1.56	6.22	6.22
END	(15)	890				
2. START	15	1000	95	1.35	5.40	11.62
END	(30)	905				
3. START	15	1000	60	0.88	3.50	15.12
END	(45)	740				
4. START	15	1000	45	0.63	2.50	17.62
END	(60)	955				
5. START	30	1000	70	1.00	2.00	19.62
END	(90)	930				
6. START	30	1000	60	0.85	1.70	21.32
END	(120)	940				
7. START	30	1000	60	0.85	1.69	23.01
END	(150)	940				

From the infiltration result of no tillage in table 4.13, at 15, 30, 45, 60, 90 120 and 150 minutes, infiltration rates of 6.22mm/hr, 5.40mm/hr, 3.50mm/hr, 2.50mm/hr,2.00mm/hr 1.70mm/hr and 1.69mm/hr were observed respectively. The basic infiltration rate was observed at 150mins and thereafter to be 1.69mm/hr for the location. Martin et al., 2004 reported a faster infiltration rate in conventional tillage than conservative tillage. Khairul et al (2014) reported slower rate of infiltration in no tillage, although infiltration rate may increase frequent cultivation is carried on over the years.

From the infiltration results in the three tillage methods. Basic infiltration rates of 120mins was observed for conventional and conservative tillage, while 150mins was observed for no tillage, the delay in no tillage was as a result of compaction which didn’t allow faster infiltration of water.

4.26 Crop data

4.26.1 Leaf area The length and breadth of the broadest leaves of the selected tagged plants was measured using a ruler. The leaf area was then determined using the linear regression analysis equation by KVET et al (1971):

$$Leaf\ Area = k\ (LXW) \qquad 4.2$$

where, k = 0.75 which is constant for all cereals, L = Leaf length W = Leaf width.

The values for leaf area index at different treatments are presented in Table 4.24

Table 4.14 Average Leaf Area

	Conventional tillage	Conservative tillage	No tillage
10% MAD/600Kg/Ha NPK	Length = 89 Width = 13.3 Leaf Area = 887cm^2	Length = 110cm Width = 15cm Leaf Area = 1237.5	Length = 79cm Width = 13 Leaf Area = 770.25
10% MAD/500Kg/Ha NPK	Length = 84.1cm Width = 13cm Leaf Area = 819cm^2	Length = 95cm Width = 14.1cm Leaf Area = 753.4cm^2	Length = 69cm Width = 12.3cm Leaf Area = 636.6cm^2
10% MAD/400Kg/Ha NPK	Length = 80cm Width = 12.3cm Leaf Area = 738cm^2	Length = 91 cm Width = 13.4cm Leaf Area = 887.cm^2	Length = 65cm Width = 12.3cm Leaf Area = 600cm^2

	Conventional tillage	Conservative tillage	No tillage
30% MAD/600Kg/Ha NPK	Length = 84 Width = 11.4 Leaf Area = 718.2cm^2	Length = 90cm Width = 14.1cm Leaf Area = 951cm^2	Length = 73cm Width = 11 Leaf Area = 602cm^2
30% MAD/500Kg/Ha NPK	Length = 81 Width = 11.1 Leaf Area = 674cm^2	Length = 85.1 Width = 13.4 Leaf Area = 855	Length = 67.3 Width = 10.3 Leaf Area = 693.1
30% MAD/400Kg/Ha NPK	Length = 75 Width = 10.4 Leaf Area =585	Length = 82 Width = 13 Leaf Area = 799	Length = 64.1 Width = 9.1 Leaf Area = 437.4

	Conventional tillage	Conservative tillage	No tillage
50% MAD/600Kg/Ha NPK	Length = 80 Width = 10.4 Leaf Area = 718.2cm^2	Length = 81cm Width = 12.1cm Leaf Area = 735cm^2	Length = 65cm Width = 10 Leaf Area = 602cm^2
50% MAD/500Kg/Ha NPK	Length = 77.1 Width = 10.1 Leaf Area = 584cm^2	Length = 79.1 Width = 11.4 Leaf Area =	Length = 63.3 Width = 9.3 Leaf Area = 441cm^2

		676.3cm^2	
50% MAD/400Kg/Ha NPK	Length = 73 Width = 9.4 Leaf Area = 515cm^2	Length = 75 Width = 10.1 Leaf Area = 568.1cm^2	Length = 59.1 Width = 9 Leaf Area = 399cm^2

From the result of the leaf area index presented in Table 4.14, the average leaf area index obtained were 693.41cm^2, 829.1cm^2, and 575.7cm^2 for conventional tillage, conservative tillage and no tillage respectively. The highest leaf area index highest obtained at Conservative tillage/ 10% MAD/600Kg/Ha NPK with a value of 1237.5cm^2, while the lowest Leaf area index was obtained at No tillage/50%MAD/400Kg/ha NPK.

On the average, the highest leaf area index of 829.1cm^2 was obtained at conservative, while the lowest leaf area index of 575.7cm^2 was obtained at no tillage. This is because conservative tillage is the best practice which reduces runoff, and erosion and retains soil nutrients, while no tillage doesn't allow proper transport of the nutrients

This is not in agreement with the observation by Gandura et al., (2017) where they recorded average leaf are index of 1230.66cm^2, 1002.00cm^2, and 751.06cm^2 for conventional tillage, conservative tillage and no tillage respectively, they observe the highest leaf area index at conventional tillage, while the lowest was at no tillage.

4.26.2 Grain cob^{-1}

This is the number of grains contained in a corn cob and the values for different treatments are presented in Table 4.15

Table 4.15 Grain Cob^{-1}

	Conventional tillage(g)	Conservative tillage(g)	No tillage(g)
10% MAD/600Kg NPK	504	594g	467g
10% MAD/500Kg NPK	503	591g	467g
10% MAD/400Kg NPK	501	577g	461g

	Conventional	Conservative	No tillage(g)

	tillage(g)	tillage(g)	
30% MAD/600Kg NPK	495	509	433
30% MAD/500Kg NPK	416	495	401
30% MAD/400Kg NPK	396	439	371

	Conventional tillage(g)	Conservative tillage(g)	No tillage(g)
50% MAD/600Kg NPK	453	471	409
50% MAD/500Kg NPK	433	450	391
50% MAD/400Kg NPK	390	410	351

From the result of grain cob$^-$ in Table 4.15, highest grain cob$^-$ of 594 was obtained in conservative tillage at 10% MAD and 600Kg/Ha NPK, while the lowest was obtained at No tillage, 50%MAD and 400Kg/Ha NPK application. The average grain per cob obtained were 454.5, 515.1, and 416.7 for conventional tillage, conservative tillage and no tillage respectively. This is not in agreement with Anjum et al., (2019) were highest number of grain cob$^-$ of 528 was obtained in conventional tillage, while the lowest number of grain cob$^-$ of 319 was obtained on no tillage. The difference in result could be as a result of soil type, infiltration rate and permeability.

4.26.3 1000- grain weight (wet)

This is the weight of 1000 grains in grams for the different treatment methods and the values are presented in Table 4.16

Table 4.16 Result for 1000-grain weight (wet)

	Conventional tillage(g)	Conservative tillage(g)	No tillage(g)
10% MAD/600Kg/Ha NPK	324	342	245
10% MAD/500Kg/Ha NPK	280	288	190
10% MAD/400Kg/Ha NPK	263.1	271	151.1

	Conventional tillage(g)	Conservative tillage(g)	No tillage(g)
30% MAD/600Kg/Ha NPK	316	316	231
30% MAD/500Kg/Ha NPK	296	299	219
30% MAD/400Kg/Ha NPK	275	279	197

	Conventional tillage(g)	Conservative tillage(g)	No tillage(g)
50% MAD/600Kg/Ha NPK	301	295	219
50% MAD/500Kg/Ha NPK	290	291	196
50% MAD/400Kg/Ha NPK	279	279	190

From the result of 1000 grain weight in Table 4.16, the same trend observed in grain cob^{-} was observed in 1000 grain weight. The highest 1000 grain weight was observed in conservative tillage/10%MAD/600Kg/Ha, while the lowest was in no tillage/50%MAD/400Kg/Ha. The highest value was obtained at conservative tillage and the lowest at no tillage because of the trend in number of grains per cob. For conventional tillage, conservative tillage and no tillage, average 1000 grain weight of 291.5g, 295.5g and 158g respectively was obtained. This is not in agreement with Anjum et al.,(2019) where highest 1000 grain weights of 265g at conventional tillage and lowest 1000 grain weight of 204g at no tillage were obtained. The difference in results was as a result of soil type in the study areas.

4.26.4 Cob weight (wet)

This is the weight of each corn cob in gram for all the treatments, the values are tabulated in Table 4.17

Table 4.17 Result for Cob Weight (wet)

	Conventional tillage(g)	Conservative tillage(g)	No tillage(g)
10% MAD/600kg/Ha NPK	406	406	370
10% MAD/500kg/Ha NPK	397	399	370
10% MAD/400Kg/Ha NPK	370	391	354

	Conventional tillage(g)	Conservative tillage(g)	No tillage(g)
30% MAD/600Kg/Ha NPK	401	405	367
30% MAD/500Kg/Ha NPK	397	397	361
30% MAD/400Kg/Ha NPK	379	390	360

	Conventional tillage(g)	Conservative tillage(g)	No tillage(g)
50% MAD/600Kg/Ha NPK	400	405	359
50% MAD/500Kg/Ha NPK	395	403	351
50% MAD/600Kg/Ha NPK	390	395	347

From the result of the cob weight in Table 4.17, average cob weight values of 392.g, 399g and 283.3g were recorded for conventional tillage, conservative tillage and no tillage respectively, with the highest cob weight of 406g obtained in conventional and conservative tillage/10%MAD, 600Kg/Ha NPK. The lowest cob weight of 347g was also obtained in no tillage/50%MAD, 600Kg/Ha NPK. The values in the tillage methods was as a result of 1000 grain weight and cob weights in the tillage methods. This is in agreement with Leghari et al., 2017 were maximum cob weight of 455g was obtained for conventional tillage, followed by cob weight of 408 for reduced tillage and lowest cob weight of 234g for no tillage.

4.26.5 Grain yield

This is the crop yield for the treatments and is presented in Table 4.18

Table 4.18 Result for crop yield

	No tillage (Kg/Ha)	Conservative tillage (Kg/Ha)	Conventional tillage (Kg/Ha)
10% MAD/600Kg/Ha NPK	1401.73	2540.09	2195.03
10% MAD/500Kg/Ha NPK	1390.36	2505.19	2059.64
10% MAD/400Kg/Ha NPK	1334.9	2345.24	1643.89

	Conventional Tillage (Kg/Ha)	Conservative Tillage (Kg/Ha)	No Tillage (Kg/Ha)
30% MAD/600Kg/Ha NPK	1354.16	2475.1	1976.09
30% MAD/500Kg/Ha NPK	1323.7	2401.09	1904.57
30% MAD/400Kg/Ha NPK	1301.23	2395.19	1701.67

	Conventional Tillage (Kg/Ha)	Conservative Tillage (Kg/Ha)	No Tillage (Kg/Ha)
50% MAD/600Kg/Ha NPK	1301.34	2309.9	1860.49
50% MAD/500Kg/Ha NPK	1291.67	2345.24	1791.19
50% MAD/400Kg/Ha NPK	1234.67	2301.06	1506.91

From grain yield result in Table 4.18, highest crop yield of 2540Kg/Ha was obtained in conservative tillage/10%MAD/600Kg/Ha NPK, while lowest crop yield of 1234.67Kg/Ha was obtained in no tillage/50%MAD/400Kg/Ha NPK, average grain yields of 1848.8Kg/Ha, 2135.8Kg/Ha and 1325.9Kg/Ha were obtained in conventional tillage, conservative tillage and no tillage respectively.

In the study, maximum crop yield of 6221.08Kh/Ha was obtained in conservative tillage and lowest crop yield of 5372.0 was obtained in conventional tillage. The values in the tillage methods was as a result of the yield components (1000 grain weight, cob weight, leaf area) which followed the same trend as the yield components In contrast, Asenso et al.,(2014) obtained highest crop yield of 7.34ton ha^{-} in subsoiling and lowest crop yield of 6.70 ton ha^{-} in zero tillage.

4.27 Development of regression model

Central Composite Design (CCD) was used to optimize properties. The statistical combination of the independent variables along with the experimental response are presented in Table 4.19

Table 4.19 Experimental setup for 3Level factorial response surface design

		Factor 1	Factor 2	Factor 3	Response1	Response 2	Response 3
Std	Run	A:Irrigation deficit%	B:NPK Application rate	C:Tillage	Crop Yield	Soil moisture content	Soil temperature
		%	Kg/Ha		Kg/Ha	%	°C
22	1	50	600	3	1860.49	10.93	28
17	2	30	600	2	2475.1	9.25	25
10	3	10	400	2	2345.24	11.31	25
18	4	30	500	2	2401.09	9.11	23
23	5	10	500	3	2059.64	12.01	26
24	6	50	500	3	1791.19	10.28	27
7	7	30	400	1	1301.23	12.4	28
21	8	10	600	3	2195.03	12.57	26
14	9	10	500	2	2505.19	10.12	23
25	10	30	400	3	1701.67	10.39	26
8	11	30	600	1	1354.16	13.5	28
2	12	50	400	1	1234.67	11.31	28
12	13	10	600	2	2540.09	12.88	23
20	14	50	400	3	1506.91	9.37	29
4	15	50	600	1	1301.34	12.4	28
11	16	50	400	2	2301.06	9.24	25
19	17	10	400	3	1643.89	11.6	26
3	18	10	600	1	1401.73	14.96	27
27	19	30	500	3	1904.57	11.21	27
13	20	50	600	2	2309.9	9.82	24
16	21	30	400	2	2395.19	10.29	25
5	22	10	500	1	1390.36	14.06	25
1	23	10	400	1	1334.9	13.6	25
15	24	50	500	2	2345.24	9.98	23
26	25	30	600	3	1976.09	12.35	27
6	26	50	500	1	1291.67	11.91	27
9	27	30	500	1	1323.7	12.72	26

The crop yield ranges from 1301.23 Kg/Ha – 2540.09 Kg/Ha which is within the range for maize yield in Nigeria (Table 2.4). Experimental runs 7 and 13 gave the minimum (1301.23 Kg/Ha) and maximum (2540.09 Kg/Ha) crop yields respectively.

To develop a statistically significant regression model, the significance of the coefficient was evaluated based on the p-values. The coefficient terms with the p-value more than 0.05 are insignificant because the p value of ≤ 0.005 was used.

Table 4.20 Design Summary

Factor	Name	Units	Type	Min	Max	Coded Low	Coded High	Mean	Std. Dev.
A	Irrigation Deficit	%	Numeric	10.00	50.00	-1 ↔ 10.00	+1 ↔ 50.00	30.00	16.64
B	NPK App.	KG/HA	Numeric	400.0	600.0	-1 ↔ 400.00	+1 ↔ 600.00	500.00	83.21
C	Tillage		Categoric	1	3		**Levels:**	**3**	

Response	Name	Units	Observations	Analysis	Min	Max	Mean	Std. Dev.	Ratio	Transform	Model
R1	Crop Yield	KG/HA	27	Polynomial	1234.67	2540.09	1858.94	466.62	2.06	None	Reduced Cubic
R2	Soil moisture content	%	27	Polynomial	9.11	14.96	11.47	1.60	1.64	None	Quadratic
R3	Soil temperature	°C	27	Polynomial	23	29	25.93	1.75	1.26	None	Quadratic

The values presented in Table 4.26 were used for the design of the experiment. The factors are Irrigation deficit%, NPK Application Rate(Kg/Ha) and tillage, while the responses are crop yield (Kg/Ha), soil moisture content (%) and soil temperature(°C). Irrigation deficit, which is a numeric factor with minimum range of 10% and maximum of 50% has a mean of 30% and standard deviation of 16.64. NPK application rate which is also a numeric factor with a minimum value of 400Kg/Ha and maximum of 600Kg/Ha has mean of 500Kg/Ha and standard deviation of 83.21. Tillage is a numeric factor with three levels; no tillage, conservative tillage and conventional tillage. Crop yield has the maximum value as 2540.09 and minimum as 1234.67, a mean of 1858.94 and standard deviation of 466.62. The maximum moisture content was 14.96% and minimum of 9.11%, mean of 11.7% and standard deviation of 1.60. the minimum soil temperature was 23°C, maximum of 29°C, mean of 25.93°C and standard deviation of 1.75

4.28 Statistical analysis for crop yield

Table 4.21 Sequential model sum of squares for crop yield

Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Mean vs Total	9.330E+07	1	9.330E+07			
Linear vs Mean	5.483E+06	4	1.371E+06	169.81	< 0.0001	
2FI vs Linear	**1.291E+05**	**5**	**25817.90**	**9.05**	**0.0002**	**Suggested**
Quadratic vs 2FI	15019.15	2	7509.58	3.36	0.0621	
Cubic vs Quadratic	22533.64	8	2816.71	1.80	0.2268	Aliased
Residual	10961.18	7	1565.88			
Total	9.896E+07	27	3.665E+06			

From the sequential model (linear, two factor interactions 2FI, quadratic and cubic polynomial), the 2FI and linear model were selected by design expert 11.1.2.0 version due to its highest order polynomial. The cubic vs quadratic model was aliased which means that the design was too small to estimate the cubic vs quadratic model or may be as a result of experimental runs not completed by the design.

Table 4.22 Analysis of variance (ANOVA) for the fitted quadratic model for crop yield

Source of variables	Sum of squares	df	Mean Square	F-value	p-value	
Model	5.645E+06	17	3.320E+05	182.70	< 0.0001	Significant
A-Irrigation deficit%	1.206E+05	1	1.206E+05	66.38	< 0.0001	
B-NPK Application rate	1.511E+05	1	1.511E+05	83.14	< 0.0001	
C-Tillage	5.212E+06	2	2.606E+06	1433.80	< 0.0001	
AB	12270.73	1	12270.73	6.75	0.0288	
AC	16990.60	2	8495.30	4.67	0.0405	
BC	99828.17	2	49914.08	27.46	0.0001	
A^2	1746.03	1	1746.03	0.9607	0.3526	
B^2	13273.12	1	13273.12	7.30	0.0243	
ABC	6136.70	2	3068.35	1.69	0.2385	
A^2C	1031.88	2	515.94	0.2839	0.7594	
B^2C	9969.09	2	4984.55	2.74	0.1175	
Residual	16357.15	9	1817.46			
Cor Total	5.661E+06	26				

Std. Dev.	42.63	**R^2**	0.9971
Mean	1858.94	**Adjusted R^2**	0.9917
C.V. %	2.29	**Predicted R^2**	0.9690
		Adeq Precision	37.6191

The analysis of variance (ANOVA) was carried out to determine the significance of the fitness of the selected quadratic model as well as the significance of individual terms and their interaction on the chosen responses. From Table 4.22 the regressors incorporated in the model F-value of 182.70 with P-value of <0.0001 implies that the model is significant at 95% confidence level. The P-value (probability of error value) is used to check the significance of each regression coefficient and the interaction effect of each cross product. In the case of the model terms, the p-value less than 0.05 shows that the model terms are significant, In this case A, B, C, AB, AC, BC, and B^2, are significant model terms.

The model as fitted presents an R- square of 0.9971 and standard deviation of 42.63. The three factors (irrigation deficit, NPK application rate, and tillage) were found to be statistically important (significant) at confidence level of 95%. A low value of coefficient of variation (0.073%), showed a high degree of precision and reliability of the values. The predicted values versus actual value for the crop yield with R^2 value of 0.9917 shows a model with 99.17% of variability (Fig. 4.11). The predicted R-Squared of 0.9690 is in reasonable agreement with the adjusted R-Squared of 0.9917; i.e. the difference is less than 0.2 and their R^2 values close to unity. This indicates that the data fits with the model. Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 37.6919 indicates an adequate signal. This model can be used to navigate the design space.

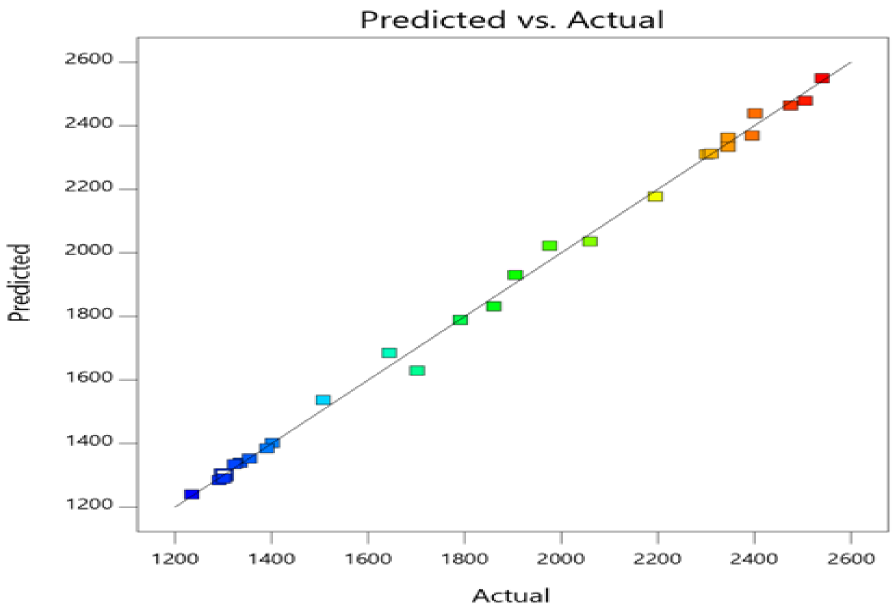


Fig 4.18 Diagnostics plots of the fitted quadratic model for crop yield

Investigation on residuals to validate the adequacy of the model used was performed; residual is the difference between the observed response and predicted response. The plot of actual versus predicted (Fig 4.18) is used to examine the effects. Fig 4.18 shows that there is a very good correlation between the observed value and the values predicted by the model, the model does not show any variation of the constant variance

4.29 Model equation for crop yield

Model equation for crop yield (No tillage) = $905.86125 - 2.39650A + 1.70182B - 0.000020 A * B - 0.001463A^2 - 0.001391B^2$ (4.3)

Model equation for crop yield (Conservative tillage) = $1320.33514 + 12.90729A + 3.44454B - 0.023251A * B - 0.081683A^2 - 0.002274B^2$ (4.4)

Model equation for crop yield (Conventional tillage) = $1889.28653 + 8.86883A + 13.15142B - 0.024695A * B - 0.044796A^2 - 0.010445B^2$ (4.5)

Eliminating the non significant terms will give:

Model equation for crop yield (No tillage) = 905.86125 - 2.39650A + 1.70182B - 0.000020 A * B + 0.001391B² (4.6)

Model equation for crop yield (Conservative tillage) = 1320.33514 + 12.90729A + 3.44454B - 0.023251A * B + 0.002274B² (4.7)

Model equation for crop yield (Conventional tillage) = 1889.28653 + 8.86883A + 13.15142B - 0.024695A * B + 0.010445B² (4.8)

The equations can be used to make predictions about the response for given levels of each factor.

4.29.1 Statistical 3D plots for crop yield

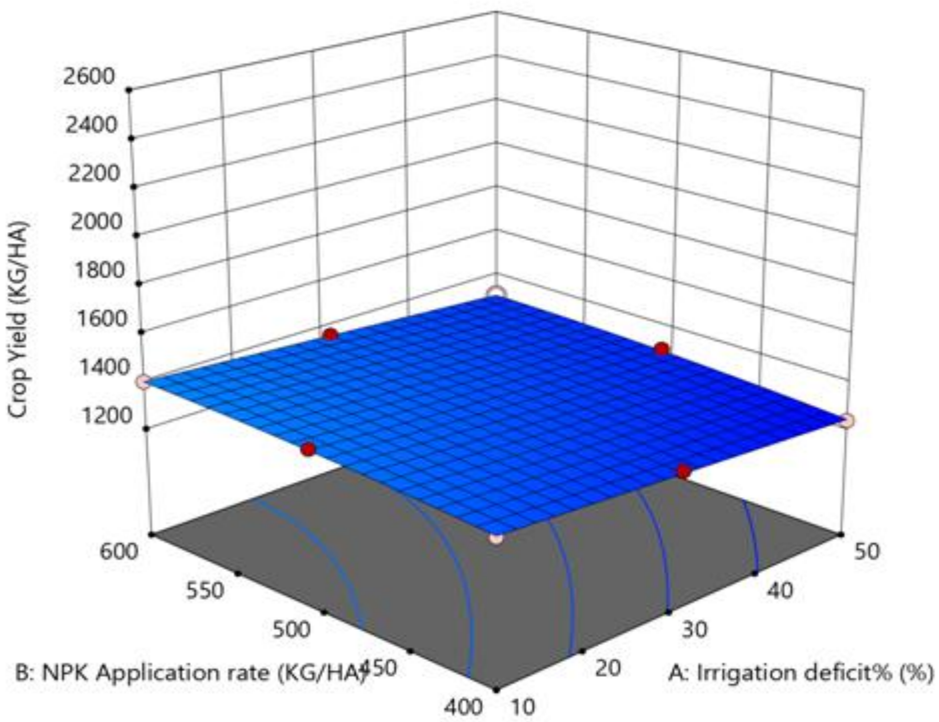


Fig.4.19 Statistical 3D plots for crop yield (No tillage)

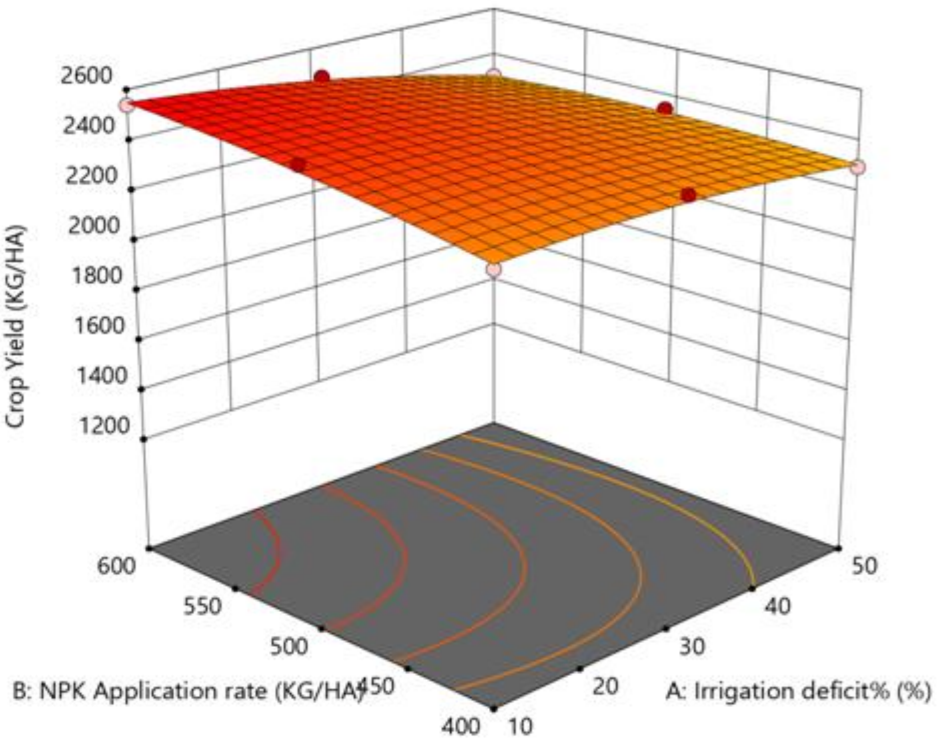


Fig. 4.20 Statistical 3D plots for crop yield (Conservative tillage)

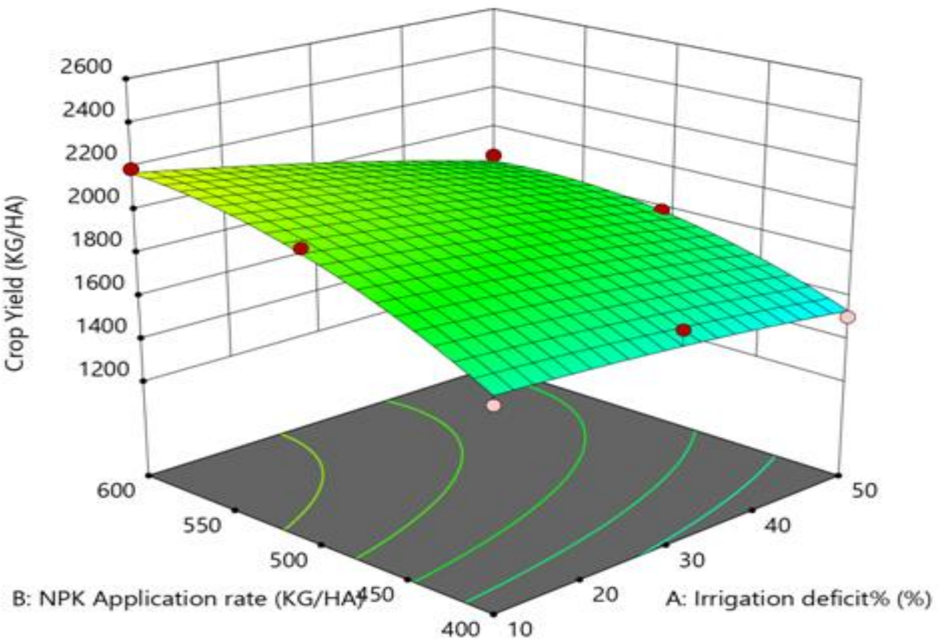


Fig. 4.21 Statistical 3D Plots for crop yield (Conventional tillage)

From the 3D plots of crop yield in Figs 4.19 - 4.21, increasing irrigation deficit and NPK application reduces crop yield, this is because high crop yield occurs when there is adequate supply of water, that is because increasing irrigation deficit means reduction in irrigation frequency and hence less water available for crop growth. High crop yield occurs when soil moisture is not close to permanent wilting point.

4.30 Statistical analysis for soil moisture content

Table 4.23 Sequential Model Sum of Squares Soil Moisture Content

Sources	Sum of Squares	df	Mean Square	F-value	p-value	
Mean vs Total	3549.39	1	3549.39			
Linear vs Mean	**57.75**	**4**	**14.44**	**36.97**	**< 0.0001**	**Suggested**
2FI vs Linear	1.33	5	0.2666	0.6244	0.6834	
Quadratic vs 2FI	1.18	2	0.5904	1.46	0.2641	
Cubic vs Quadratic	3.59	8	0.4493	1.27	0.3843	Aliased
Residual	2.48	7	0.3548			
Total	3615.74	27	133.92			

From the sequential model (linear, two factor interactions 2FI, Quadratic and cubic polynomial) presented in Table 4.23, the linear vs mean model was selected by design expert 11.0.2 version due to its highest order polynomial.

Table 4.24 Analysis of Variance (ANOVA) for the fitted Quadratic Model for Soil moisture content

Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	60.27	11	5.48	13.52	< 0.0001	Significant
A-Irrigation deficit%	17.74	1	17.74	43.78	< 0.0001	
B-NPK Application rate	4.65	1	4.65	11.48	0.0041	
C-Tillage	35.36	2	17.68	43.63	< 0.0001	
AB	0.0374	1	0.0374	0.0923	0.7654	
AC	0.2812	2	0.1406	0.3470	0.7123	
BC	1.01	2	0.5073	1.25	0.3142	
A^2	0.6468	1	0.6468	1.60	0.2257	
B^2	0.5340	1	0.5340	1.32	0.2689	
Residual	6.08	15	0.4052			
Cor Total	66.34	26				

Std. Dev.	0.6366	**R^2**	0.9084
Mean	11.47	**Adjusted R^2**	0.8412
C.V. %	5.55	**Predicted R^2**	0.6726
		Adeq Precision	13.5567

Statistical analysis of variance (ANOVA) was carried out to determine the significance of the fitness of the selected quadratic model as well as the significance of individual terms and their interaction on the Soil moisture content responses. From Table 4.24, the regressors incorporated in the model F-value of 13.52 with p-value of <0.0001 implies that the model is significant at 95% confidence level. The P-value (probability of error value) was used to check the significance of each regression coefficient and the interaction effect of each cross product. In the case of the model terms, the p-value less than 0.05 shows that the model terms are significant, In this case A, B, C are significant model terms, with P-values of 0.001, 0.001 and 0.041 respectively. Values greater than 0.05 indicate the model terms are not significant.

The model presents an R- square of 0.9084 and standard deviation of 0.6366. Three main model factors (A) irrigation deficit, (B) NPK application rate, and (C) tillage, were all found to be statistically significant for increase in Soil moisture content at confidence level of 95% . The predicted values versus actual value with R^2 value of 0.9940 shows a model with 99.40% of variability (Fig 4.22). The Predicted R-Squared of 0.6726 is in reasonable agreement with the Adjusted R-Squared of 0.8412; i.e. the difference is less than 0.2 and their R^2 values close to unity. This indicates that the data fits with the model. Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 13.5567 indicates an adequate signal. This model can be used to navigate the design space.

4.31 Model Equation for Soil moisture content

Soil moisture content (No Tillage) = 19.13667 - 0.093625A - 0.023079B - 0.000028A * B + 0.000821A² + 0.000030 B² (4.9)

$$\text{Soil moisture content (No Tillage)} = 19.13667 - 0.093625A - 0.023079B - 0.000028A \cdot B + 0.000821A^2 + 0.000030B^2 \quad (4.9)$$

The equation (4.6) can be used to make predictions about the response for given levels of each factor for Soil moisture content (No Tillage).

Soil moisture content (Conservative Tillage) = $17.97528 - 0.079208A - 0.027146B - 0.000028A * B + 0.000821A^2 + 0.000030B^2$ (4.10)

The equation (4.7) can be used to make predictions about the response for given levels of each factor for Soil moisture content (Conservative Tillage).

Soil moisture content (Conventional Tillage) = $16.2088 - 0.081958A - 0.021512B - 0.000028A * B + 0.000821A^2 + 0.000030B^2$ (4.11)

Eliminating the non significant terms:

Soil moisture content (No Tillage) = $19.13667-0.093625A-0.023079B-0.000028A*B$ (4.12)

Soil moisture content (Conservative Tillage) = $17.97528 - 0.079208A - 0.027146B - 0.000028A * B$ (4.13)

Soil moisture content (Conventional Tillage) = $16.2088 - 0.081958A - 0.021512B - 0.000028A * B$ (4.14)

The equations can be used to make predictions about the response for given levels of each factor for Soil moisture content

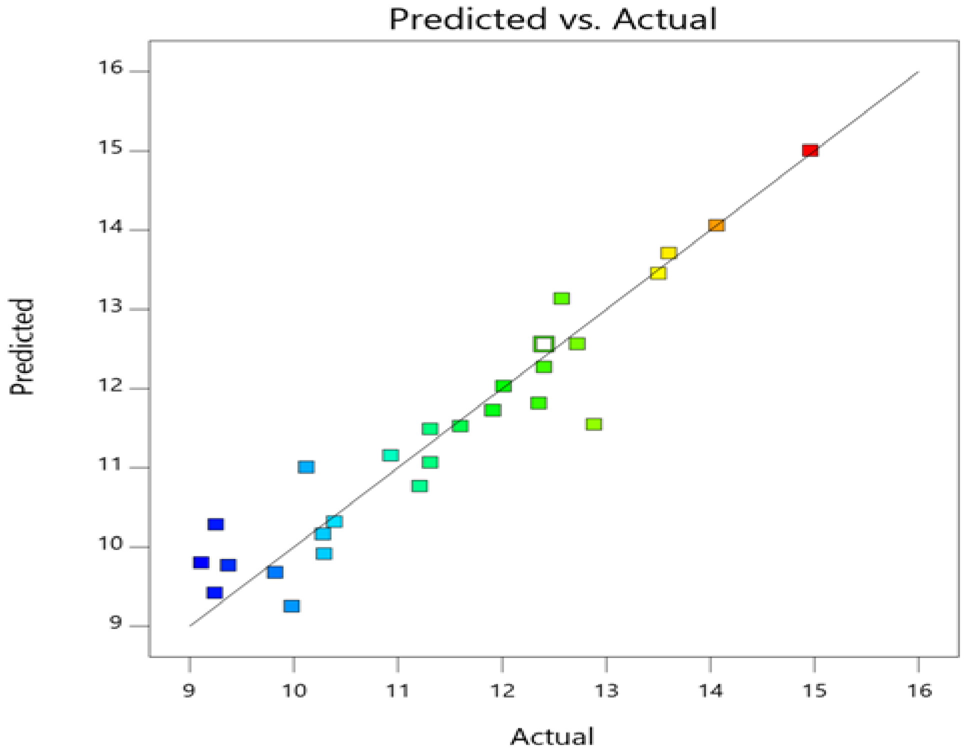


Fig. 4.22 Diagnostics plots of the fitted quadratic model for soil moisture content.

Fig 4.22 shows that there is a very good correlation between the observed value and the value predicted by the model, the model does not show any variation of the constant variance

4.32 Statistical 3D plots for soil moisture content

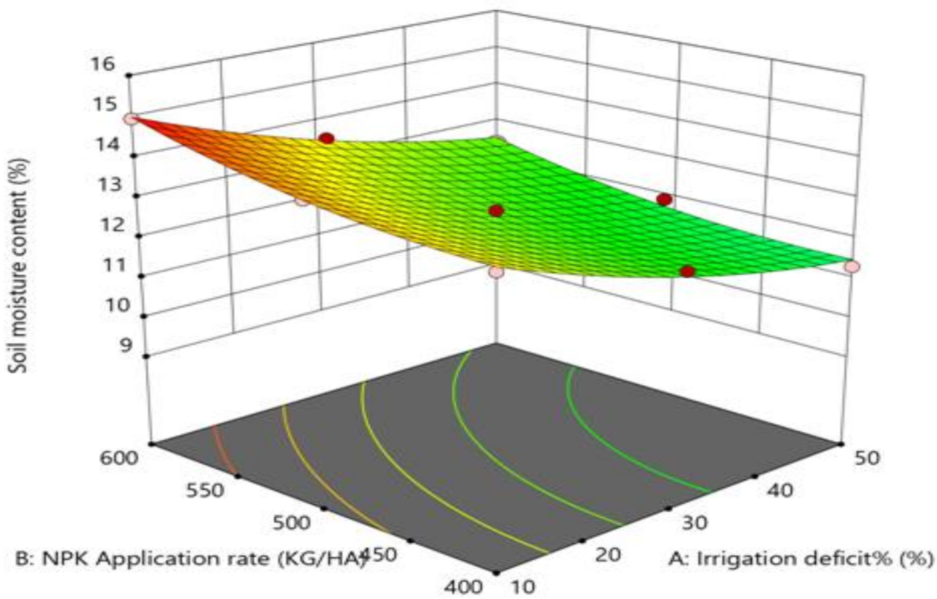


Fig. 4.23 Statistical 3D plots for soil moisture content (No tillage)

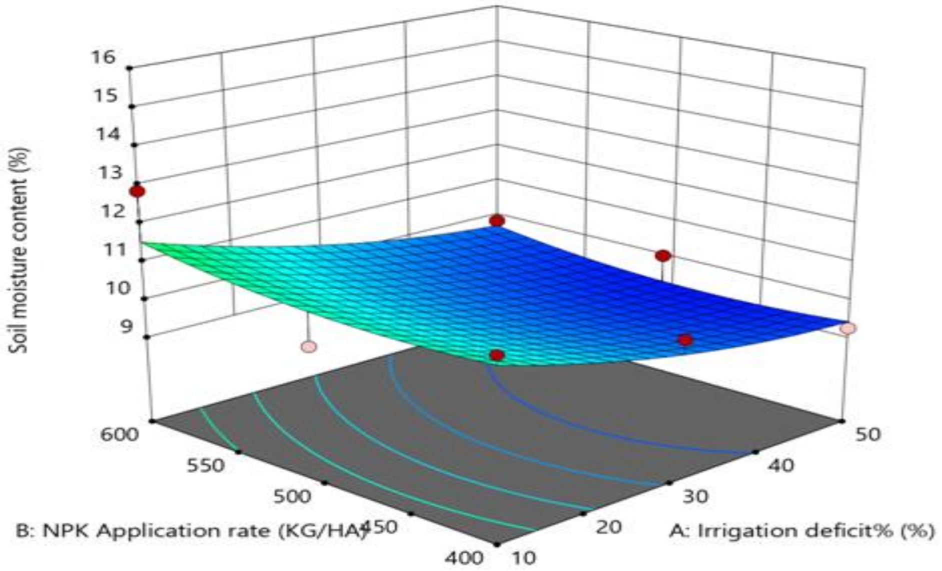


Fig 4.24 Statistical 3D plots for soil moisture content (Conservative tillage)

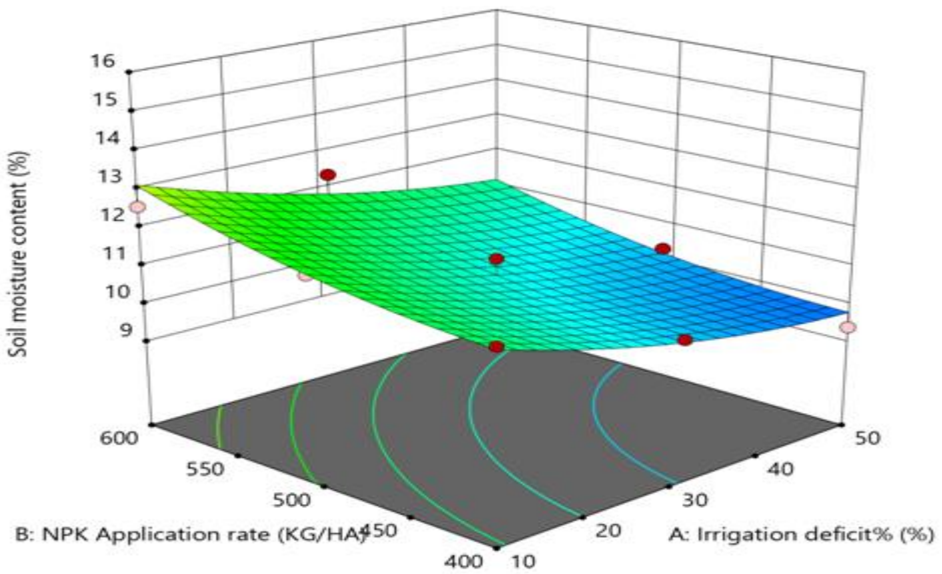


Fig 4.25 Statistical 3D plots for soil moisture content (Conventional tillage)

From Figs 4.23 – 4.25, increasing irrigation deficit and NPK application rate also reduces moisture content, this is because moisture content increases when moisture is not allowed to deplete so much. Highest moisture content was observed at 10% deficit and 400Kg/Ha NPK application rate.

4.33 Statistical analysis for soil temperature

Table 4.25 Sequential model sum of Squares for soil temperature

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Mean vs Total	18148.15	1	18148.15			
Linear vs Mean	59.52	4	14.88	16.10	< 0.0001	
2FI vs Linear	5.22	5	1.04	1.18	0.3617	
Quadratic vs 2FI	**7.15**	**2**	**3.57**	**6.73**	**0.0082**	**Suggested**
Cubic vs Quadratic	4.80	8	0.5995	1.33	0.3617	Aliased
Residual	3.17	7	0.4524			
Total	18228.00	27	675.11			

The sequential model (linear, two factor interactions 2FI, Quadratic and cubic polynomial) above gave the quadratic model vs 2FI as selected Model by design expert 11.0.2.1 version due to its highest order polynomial

Table 4.26 Analysis of variance (ANOVA) for the fitted quadratic model for soil temperature

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	71.89	11	6.54	12.31	< 0.0001	Significant
A-Irrigation deficit%	9.39	1	9.39	17.69	0.0008	
B-NPK Application rate	0.0556	1	0.0556	0.1047	0.7508	
C-Tillage	50.07	2	25.04	47.16	< 0.0001	
AB	0.3333	1	0.3333	0.6279	0.4405	
AC	2.78	2	1.39	2.62	0.1060	
BC	2.11	2	1.06	1.99	0.1714	
A^2	0.4630	1	0.4630	0.8721	0.3652	
B^2	6.69	1	6.69	12.59	0.0029	
Residual	7.96	15	0.5309			
Cor Total	79.85	26				

Std. Dev.	0.7286	**R^2**	0.9003
Mean	25.93	**Adjusted R^2**	0.8271
C.V. %	2.81	**Predicted R^2**	0.6797
		Adeq Precision	10.8655

The result of Statistical analysis of variance (ANOVA) was carried out to determine the significance of the fitness of the selected quadratic model as well as the significance of individual terms and their interaction on the chosen responses. From Table 4.26 the regressors incorporated in the model F-value of 12.31 with P-value of <0.0001 implies that the model is significant at 95% confidence level. The P-value (probability of error value) is used to check the significance of each regression coefficient and the interaction effect of each cross product. In the case of the model terms, the p-value less than 0.05 shows that the model terms are significant, In this case A, C, and B^2 are significant model terms with P-values of 0.0008, 0.0001 and 0.0029 respectively.

The model as fitted presents an R- square of 0.9003 and standard deviation of 0.7286. The predicted values versus actual value for the Soil temperature with R^2 value of 0.8271 shows a model with 82.712% of variability (Fig 4.26). The Predicted R-Squared of 0.6797 is in reasonable agreement with the adjusted R-Squared of 0.8271; i.e. the difference is less than 0.2 and their R^2 values close to unity. This indicates that the data fits with the model. Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 10.8655 indicates an adequate signal. This model can be used to navigate the design space.

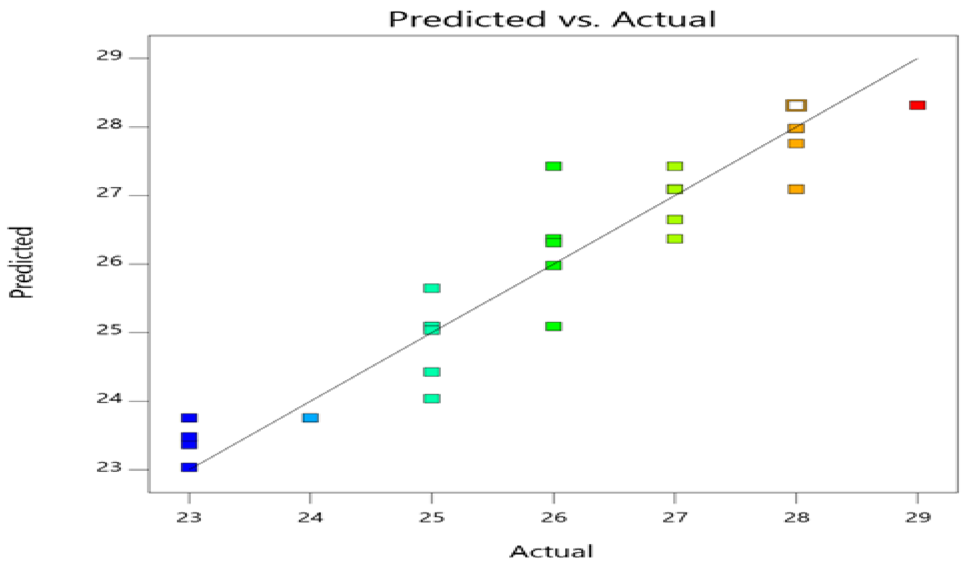


Fig 4.26 Diagnostics plots of the fitted quadratic model for soil temperature

Investigation on residuals to validate the adequacy of the model used was performed; residual is the difference between the observed response and predicted response. The plot of actual versus predicted (Fig 4.26) is used to examine the effects. Fig 4.26 shows that there is a good correlation between the observed value and the values predicted by the model.

4.34 Model Equation for Soil Temperature

Soil Temperature (No tillage) = 47.71759 + 0.133333A - 0.099722B - 0.000083A * B - 0.000694A^2 + 0.000106B^2 (4.15)

Soil Temperature (Conservative tillage) = 50.24537 + 0.091667A - 0.108056B - 0.000083A * B - 0.000694 A^2 + 0.000106B^2 (4.16)

Soil Temperature (Conventional tillage) = 49.38426 + 0.133333A - 0.103056B - 0.000083A * B - 0.000694A^2 + 0.000106B^2 (4.17)

Eliminating the non significant terms:

Soil Temperature (No tillage) = 47.71759 + 0.133333A - 0.099722B - 0.000083A* 0.000106B^2 (4.18)

Soil Temperature (Conservative tillage) = 50.24537 + 0.091667A - 0.108056B - 0.000083A * 0.000106B^2 (4.19)

Soil Temperature (Conventional tillage) = 49.38426 + 0.133333A - 0.103056B - 0.000083A * 0.000106B^2 (4.20)

4.35 Statistical 3D plots for soil temperature

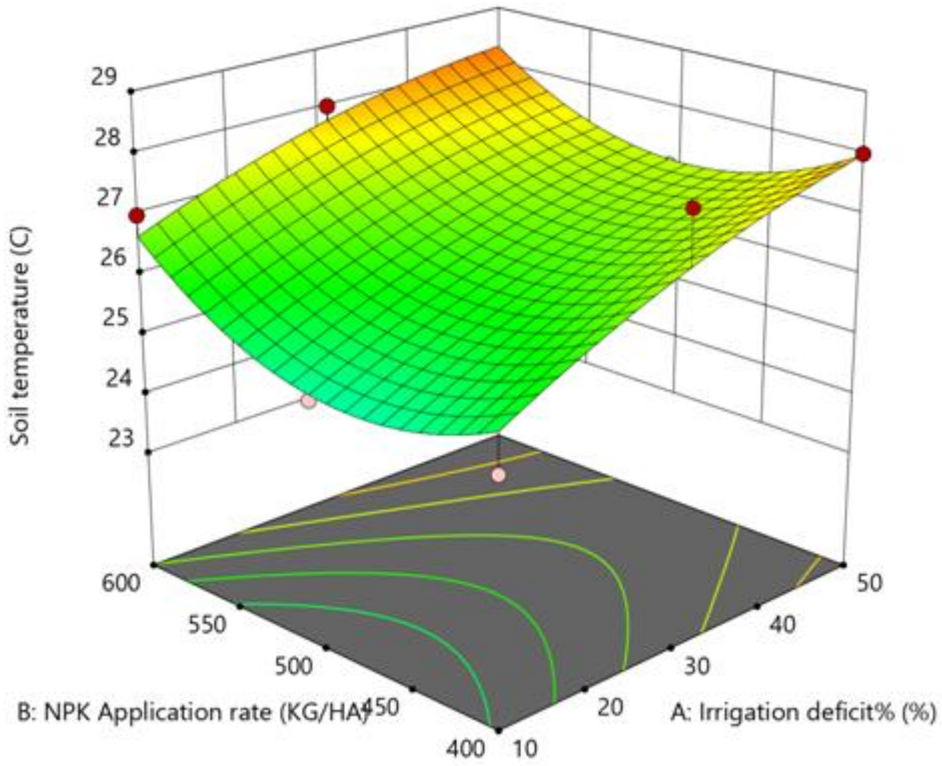


Fig4.27 Statistical 3D plots for Soil temperature (No tillage)

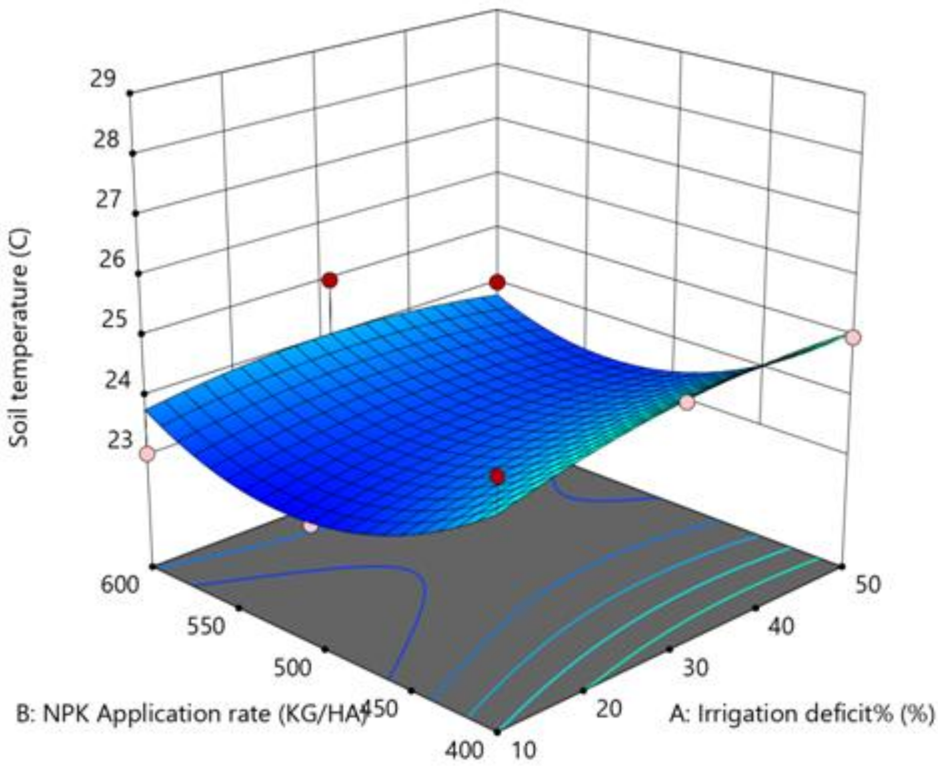


Fig 4.28 Statistical 3D plots for soil temperature (Conservative tillage)

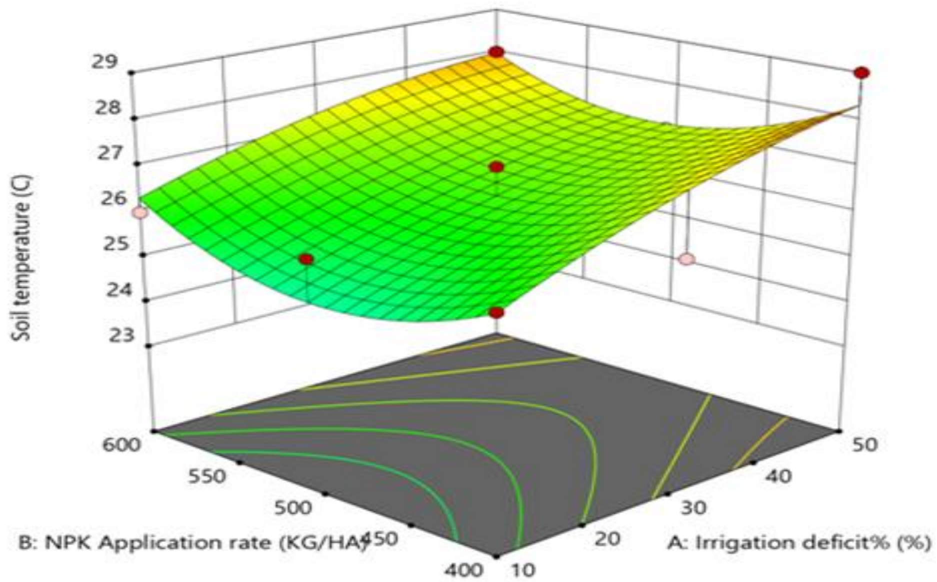


Fig4.29 Statistical 3D plots for soil temperature (Conventional tillage)

From the graphs in Fig 4.27 – 4.29, increasing irrigation deficit and NPK application rate increases soil temperature, this is because the soil becomes hotter and the temperature increases with increased depletion of moisture content.

4.36 Optimisation and evaluation of the optimised process

Optimization of the process was performed to determine the optimum operating conditions at which the maximum responses are achieved.

Table 4.27 Optimisation limits

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A:Irrigation deficit%	is in range	10	50	1	1	5
B:NPK Application rate	is in range	400	600	1	1	3
C:Tillage	is in range	1	3	1	1	3
Crop Yield	maximize	1234.67	2540.09	5	1	5
Soil moisture content	Is in range	9.11	14.96	1	1	5
Soil temperature	is in range	23	29	1	1	4

The variables (irrigation deficit, NPK application rate and tillage) and responses (soil moisture content and soil temperature) were all set at range in order to obtain the best values for the factors and responses, crop yield was maximized to achieve maximum outcome.

Table 4.28 Optimisation solutions

Number	Irrigation deficit (%)	NPK application rate (Kg/Ha)	Tillage	Crop Yield (Kg/Ha)	Soil moisture Content (%)	Soil temperature (°C)	Desirability	
1	**11.594**	**596.406**	**2**	**2543.589**	**10.396**	**23.740**	**1.000**	**Selected**
2	10.154	599.069	2	2548.833	10.530	23.747	1.000	
3	12.194	599.053	2	2543.018	10.372	23.800	1.000	
4	11.048	597.860	2	2545.808	10.450	23.750	1.000	
5	10.428	595.845	2	2546.531	10.482	23.699	1.000	
6	11.750	596.875	2	2543.356	10.388	23.752	1.000	
7	12.039	598.311	2	2543.154	10.378	23.784	1.000	
8	12.016	599.689	2	2543.831	10.391	23.807	1.000	
9	10.820	599.482	2	2547.203	10.481	23.772	1.000	
10	10.000	600.000	2	2549.695	10.550	23.759	1.000	
11	10.487	583.939	2	2540.211	10.385	23.515	1.000	
12	10.792	588.077	2	2541.662	10.392	23.585	1.000	
13	10.174	590.252	2	2544.342	10.458	23.601	1.000	
14	10.741	586.847	2	2541.149	10.387	23.565	1.000	
15	11.969	594.757	2	2541.752	10.354	23.722	1.000	

16	11.116	595.683	2	2544.590	10.427	23.715	1.000
17	12.260	595.550	2	2541.267	10.338	23.742	1.000
18	10.838	596.241	2	2545.621	10.453	23.717	1.000
19	10.984	598.836	2	2546.443	10.463	23.765	1.000
20	11.447	588.702	2	2540.285	10.347	23.612	1.000
21	11.167	596.825	2	2544.991	10.432	23.736	1.000
22	10.422	590.684	2	2543.946	10.442	23.615	1.000
23	10.801	590.689	2	2542.979	10.412	23.625	1.000
24	11.041	599.702	2	2546.682	10.466	23.782	1.000
25	11.849	597.822	2	2543.496	10.388	23.770	1.000
26	12.965	598.985	2	2540.616	10.313	23.818	1.000
27	10.452	589.534	2	2543.275	10.430	23.598	1.000
28	11.083	587.925	2	2540.841	10.369	23.590	1.000
29	10.478	594.946	2	2545.954	10.471	23.685	1.000
30	11.386	589.847	2	2541.019	10.360	23.628	1.000
31	12.353	598.512	2	2542.302	10.355	23.795	1.000
32	11.704	592.802	2	2541.589	10.359	23.683	1.000
33	10.624	589.243	2	2542.692	10.415	23.598	1.000
34	10.086	593.082	2	2546.029	10.487	23.644	1.000
35	11.148	591.386	2	2542.417	10.390	23.646	1.000
36	10.967	590.934	2	2542.669	10.401	23.634	1.000
37	11.261	593.850	2	2543.314	10.401	23.688	1.000
38	12.696	599.081	2	2541.497	10.334	23.813	1.000
39	11.256	590.678	2	2541.777	10.377	23.637	1.000
40	11.742	599.792	2	2544.690	10.412	23.802	1.000
41	10.992	594.513	2	2544.367	10.427	23.692	1.000
42	11.991	593.576	2	2541.141	10.343	23.703	1.000
43	10.225	587.367	2	2542.692	10.431	23.558	1.000
44	10.448	593.888	2	2545.507	10.465	23.667	1.000
45	10.864	591.909	2	2543.428	10.417	23.646	1.000
46	10.498	596.774	2	2546.797	10.484	23.717	1.000
47	11.310	599.088	2	2545.633	10.440	23.778	1.000
48	11.815	590.512	2	2540.181	10.332	23.650	1.000
49	10.403	592.389	2	2544.866	10.456	23.641	1.000
50	11.825	591.744	2	2540.745	10.341	23.669	1.000
51	10.010	597.346	2	2548.370	10.527	23.713	1.000
52	11.249	598.003	2	2545.307	10.436	23.758	1.000
53	10.276	591.252	2	2544.607	10.457	23.620	1.000
54	10.663	597.842	2	2546.865	10.480	23.740	1.000
55	11.397	595.955	2	2543.936	10.408	23.727	1.000
56	11.573	590.853	2	2541.009	10.353	23.649	1.000
57	12.351	596.283	2	2541.326	10.337	23.757	1.000
58	11.412	592.663	2	2542.328	10.380	23.673	1.000
59	10.259	592.189	2	2545.133	10.466	23.634	1.000
60	11.917	595.725	2	2542.347	10.366	23.737	1.000
61	10.657	585.756	2	2540.779	10.385	23.546	1.000
62	11.117	592.980	2	2543.284	10.405	23.670	1.000
63	11.292	589.053	2	2540.870	10.361	23.613	1.000
64	11.677	598.880	2	2544.475	10.410	23.784	1.000

65	11.037	588.745	2	2541.380	10.379	23.602	1.000
66	14.127	600.000	2	2537.254	10.236	23.862	0.989
67	10.000	600.000	3	2177.282	10.136	26.315	0.196
68	10.000	599.010	3	2176.905	12.123	26.292	0.196
69	10.000	598.295	3	2176.621	12.113	26.276	0.196
70	10.940	600.000	3	2170.808	12.060	26.379	0.190
71	10.000	585.000	3	2169.381	11.933	25.997	0.188
72	10.000	576.223	3	2162.578	11.820	25.833	0.181
73	10.000	565.000	3	2151.534	11.683	25.647	0.171
74	15.638	600.000	3	2137.270	11.699	26.684	0.158

The responses of the variables in Table 4.28 were generated by Design Expert 11.0 software for the optimization based on the model obtained and the experimental data input. From Table 4.28, the run 1 order gave the optimum condition and was selected. The selected marked in run 1 order shows that it contains the best optimization results. Runs 66-74 recorded desirability less that 1, desirability range from 0 to 1 for any given response, a value of 0 represents the ideal case, a zero indicates that one or more responses fall outside desirable limits. The optimum values based on the run order 1 gave irrigation deficit as 11.594%, NPK application rate as 596.406 KG/HA, best tillage method as conservative tillage, Crop yield of 2543.589KG/HA, Soil moisture content of 10.396% and Soil temperature of 23.740°C. The Crop yield obtained falls in range of maize yield in Nigeria as presented in Table 2.4, the soil temperature is also in agreement with observation by Onwuka (2016) in South Eastern Nigeria, soil temperature ranging from 10°C - 28°C is good for maize growth, Broadbent (2015) also observed that soil temperature between 21°C - 38°C increases organic matter decomposition. Conservative tillage was also selected as the best tillage method, Alteri (2011) observed conservative tillage to be the best tillage method because it creates suitable soil environment for crop growth, and conserves soil and water energy through the reduction in tillage intensity, he also stated that conservative tillage leaves at least 30% of the soil residue on the soil surface, which slows water movement which reduces erosion.

The optimum conditions were compared with observed values from published works and they are, Hossene et al., (2015) selected irrigation deficit closer to field capacity of 7%, ADP recommended NPK rate is 500Kg/Ha, Soil moisture content of 14% in a sandy loam soil was also used by Shittu et al., (2017), Average maize yield in Nigeria 1705.7 in Table 2.4, the soil temperature of 28°C recorded by Onwuka (2016) in South Eastern Nigeria, Conservative tillage by Broadent (2015).

The optimised and observed parameters for evaluation are shown in Table 4.36.

Table 4.29 Optimised and Observed values

	Tillage	Irrigation Deficit (%)	NPK Application rate (Kg/Ha)	Crop Yield Kg/Ha	Soil Temperature (°C)	Soil Moisture Content (%)
Optimised Parameters	Conservative	11.594	596.406	2543.589	23.740	10.396
Observed Parameters	Conservative	7	500	1705.7	28	14

The evaluation was done using coefficient of determination (R^2), root means square error (RMSE), index of agreement (d) and coefficient of performance (CP^1_A), the result of the evaluation is presented in Table 4.29.

Table 4.30 Evaluation Results

Evaluation Metrics	R^2	RMSE	d	CP^1_A
Value	0.86	0.92	0.74	0.26

From the evaluation result in Table 4.30, 0.86, 0.92, 0.74 and 0.26 were obtained for coefficient of determination (R^2), Root mean square error (RMSE), index of agreement (d), and coefficient of performance (CP^1_A) respectively. The value of 1 for the coefficient of determination means that the dispersion for prediction is equal to that of the observation, R^2 value up to 0.6 is acceptable but R^2 value of 0.86 was obtained in the evaluation which is a high coefficient of determination. Root mean square error has a better agreement close to 0.0

(El-Sadek et al, 2003), RMSE value of 0.92 was obtained in the evaluation and this is within the acceptable range of RMSE.

The index of agreement falls between 0 and 1 (Yaun et al, 2008), d value of 0.74 obtained in the evaluation is acceptable. Coefficient of performance approaches zero as the observed and predicted values get closer, CP^1_A value of 0.26 obtained in the evaluation is within acceptable range.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

- The study showed that it was possible to produce good crop yield from drip irrigation in the study area located at department of Agricultural and Bioresources Engineering Experimental Farm, Nnamdi Azikiwe University, Awka.
- Soil physio-chemical properties, irrigation parameters and performance evaluation carried out helped in the better performance of the drip irrigation at the site.
- The least limiting water range determined from the field capacity, wilting point, moisture content at penetration resistance and moisture content at 10% aeration, can be a measure of management effects on soil productivity and when maximized, can be the potential of soil crop production. It also identified critical periods of stress on the plant that can reduce production.
- The crop yield determined from the experiment shows that there was greater crop yield in conservative tillage than conventional and no tillage conditions, this is because of minimum disturbance of the soil that did not further reduce soil quality. Increase in NPK application and decrease in irrigation deficit increased crop yield in all the tillage practices.
- The Central Composite Design (CCD) optimization model was used for finding the best levels of the process factors. The model shows that for Irrigation deficit of 11.594%, at NPK Application rate of 596.406KG/HA, and conservative tillage, the optimum response values obtained are Crop yield of 2543.589KG/HA, Soil moisture content of 11.396% and Soil temperature of 23.740°C.

5.2 Recommendations

As the research was carried out in one year, it is recommended to carry out similar experiment continuously for up to a period of five years, to know the effects on soil physic-chemical properties and crop yield. As this research was carried out under sandy loam soil using drip irrigation, data for sandy loam and drip irrigation alone was obtained, there is need to study other soil types using other forms of irrigation and test crops. Exploring the variables and responses using other types of irrigation such as Sprinkler and Surface irrigation is necessary to obtain the information from other water application sources. It is also necessary to replicate the work in other environments and other soil types to determine the effects. It is also necessary to replicate the work using other test crops to obtain the irrigation requirements for the crops.

5.3 Contribution to Knowledge

The formulation of mathematical models for crop yield, soil temperature and soil moisture content.

The optimisation of process variables (irrigation deficit, NPK Application rate and Tillage) to determine the optimum operating conditions at which the maximum responses were achieved.

Least limiting water range under different tillage practices and soil depths were obtaining using moisture content at field capacity, permanent wilting point, 10% aeration and penetration resistance at 2MPa for the area.

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APPENDIX A

Average Daily Climatic Data in Awka Meteorological Station (2008-2017)

Year	**Long.(m)**	**Lat.(m)**	**Elev. (m)**	**Max. Temp. (°C)**	**Min. Temp. (°C)**	**Precip. (mm)**	**Relative Humidity (%)**
2000	7.188	6.089	142	34.95	22.08	6.31	75
2001	7.188	6.089	142	35.21	22.72	7.00	73
2002	7.188	6.089	142	35.19	22.19	6.15	80
2003	7.188	6.089	142	33.02	21.46	6.22	68
2004	7.188	6.089	142	32.68	21.87	7.89	72
2005	7.188	6.089	142	33.07	22.00	7.15	75
2006	7.188	6.089	142	31.94	21.04	6.09	71
2007	7.188	6.089	142	30.89	22.56	6.62	73
2008	7.188	6.089	142	35.07	22.19	6.62	73
2009	7.188	6.089	142	32.35	22.64	6.95	77
2010	7.188	6.089	142	33.31	22.87	6.49	76
2011	7.188	6.089	142	31.86	21.77	7.07	76
2012	7.188	6.089	142	32.97	20.09	6.22	78
2013	7.188	6.089	142	31.3	22.37	7.49	79
2014	7.188	6.089	142	33.5	22.52	6.51	78

2015	7.188	6.089	142	34.6	22.34	6.71	70
2016	7.188	6.089	142	30.3	23.16	6.60	73
2017	7.188	6.089	142	33.6	21.30	6.63	75

Source: Nigerian Meteorological Agency/NIMET, Enugwu Agidi road, near NTA, Amawbia

APPENDIX B

Values for Calculated Daily Evapotranspiration and Consumptive Use.

DAY	Evapotranspiration (mm/day)	K	CU (mm/day)
1	4.6	0.86	4.0
2	4.2	0.86	3.6
3	4.4	0.86	3.8
4	5.8	0.86	5.0
5	6.5	0.86	5.6
6	2.2	0.86	1.9
7	4.7	0.86	4.0
8	6.2	0.86	5.3
9	4.3	0.86	3.7
10	5.1	0.86	4.4
11	5.4	0.86	4.6
12	5.0	0.86	4.3
13	5.1	0.86	4.4
14	5.3	0.86	4.6
15	5.5	0.86	4.7
16	3.7	0.86	3.2

17	5.1	0.86	4.4
18	4.0	0.86	3.4
19	5.7	0.86	4.9
20	4.4	0.86	3.8
21	4.8	0.86	4.1
22	5.3	0.86	4.6
23	4.3	0.86	3.7
24	5.1	0.86	4.4
25	6.0	0.86	5.2
26	6.3	0.86	5.4
27	4.9	0.86	4.2
28	4.9	0.86	4.2
29	5.8	0.86	5.0
30	5.0	0.86	4.3
31	6.0	0.86	5.2
32	5.1	0.86	4.4
33	4.4	0.86	3.8
34	5.0	0.86	4.3
35	4.4	0.86	3.8

36	5.2	0.86	4.5
37	5.9	0.86	5.1
38	7.3	0.86	6.3
39	6.0	0.86	5.2
40	3.8	0.86	3.3
41	2.5	0.86	2.2
42	4.0	0.86	3.4
43	5.1	0.86	4.4
44	5.6	0.86	4.8
45	5.0	0.86	4.3
46	4.7	0.86	4.0
47	5.4	0.86	4.6
48	6.4	0.86	5.5
49	6.2	0.86	5.3
50	6.4	0.86	5.5
51	6.2	0.86	5.3
52	1.8	0.86	1.5
53	5.9	0.86	5.1
54	3.3	0.86	2.8

55	4.2	0.86	3.6
56	2.9	0.86	2.5
57	5.2	0.86	4.5
58	6.7	0.86	5.8
59	6.9	0.86	5.9
60	5.9	0.86	5.1
61	6.8	0.86	5.8
62	5.9	0.86	5.1
63	4.7	0.86	4.0
64	3.3	0.86	2.8
65	3.0	0.86	2.6
66	6.2	0.86	5.3
67	5.14	0.86	4.4
68	2.9	0.86	2.5
69	2.4	0.86	2.1
70	2.5	0.86	2.15
71	5.02	0.86	4.3
72	4.8	0.86	4.1
73	6.1	0.86	5.2

74	5.04	0.86	4.3
75	4.8	0.86	4.1
76	5.4	0.86	4.6
77	3.7	0.86	3.2
78	4.8	0.86	4.1
79	3.7	0.86	3.2
80	4.6	0.86	4.0
81	5.4	0.86	4.6
82	3.2	0.86	2.8
83	1.0	0.86	0.86
84	1.89	0.86	1.6
85	5.8	0.86	5.0
86	5.9	0.86	5.1
87	5.4	0.86	4.6
88	3.3	0.86	2.8

APPENDIX C

Results of Bulk Density, Particle Density and Porosity

Bulk Density

	Weight of dry sample(g)	**Volume of container(cm^3)**	**Bulk Density(g/cm^3)**
NT(0-25cm)	108.2	68	1.592
NT(25-50cm)	107.9	68	1.587
NT(50-75cm)	106.1	68	1.561
NT(75-100cm)	104.2	68	1.533
CST(0-25cm)	106.0	68	1.55
CST(25-50cm)	105.5	68	1.55
CST(50-75cm)	104.9	68	1.540
CST(75-100cm)	104.4	68	1.535
CVT(0-25cm)	99.96	68	1.470
CVT(25-50cm)	99.62	68	1.465
CVT(50-75cm)	99.21	68	1.459
CVT(75-100cm)	97.30	68	1.431

Particle Density

	Weight of dry soil (g)	Volume of sand particle (cm^3) Volume of wet soil – volume of dry soil	Particle Density (g/cm^3)
NT(0-25cm)	108.2	41.1	2.63
NT(25-50cm)	107.9	41.6	2.59
NT(50-75cm)	106.1	41.7	2.54
NT(75-100cm)	104.2	42.1	2.57
CST(0-25cm)	106.0	41.0	2.58
CST(25-50cm)	105.5	41.5	2.54
CST(50-75cm)	104.9	42.1	2.49
CST(75-	104.4	42.6	2.45

100cm)			
CVT(0-25cm)	99.96	38	2.63
CVT(25-50cm)	99.62	38.5	2.58
CVT(50-75cm)	99.21	38.9	2.55
CVT(75-100cm)	97.30	39.1	2.48

Porosity

	Bulk Density	**Particle Density**	**Porosity(%)**	**10% porosity (cm^3/cm^3)**
			$\left(1-\frac{BD}{PD}\right)X\ 100$	$1-\frac{BD}{PD}$ - 0.1
NT(0-25cm)	1.592	2.63	39.5	0.295
NT(25-50cm)	1.587	2.59	38.8	0.288
NT(50-75cm)	1.561	2.54	38.6	0.286
NT(75-100cm)	1.533	2.57	40.4	0.304
CST(0-25cm)	1.55	2.58	40	0.3
CST(25-50cm)	1.55	2.54	39	0.29
CST(50-75cm)	1.540	2.49	38.2	0.282
CST(75-	1.535	2.45	37.4	0.274

100cm)				
CVT(0-25cm)	1.470	2.63	44.2	0.342
CVT(25-50cm)	1.465	2.58	43.3	0.333
CVT(50-75cm)	1.459	2.55	42.8	0.328
CVT(75-100cm)	1.431	2.48	42.3	0.323

APPENDIX D

Net Irrigation Water Requirement

Tillage method	**Soil depth (cm)**	**MAD (%)**	**NIWR (cm)**
Conservative	0-25	10	0.19
		30	0.6
		50	1
Conventional	0-25	10	0.19
		30	0.6
		50	1
No Tillage	0-25	10	0.317
		30	1
		50	1.6
Conservative	25-50	10	0.43
		30	1.29
		50	2.15
Conventional	25-50	10	0.51
		30	1.5
		50	2.5
No Tillage	25-50	10	0.605

		30	1.81
		50	3.0
Conservative	50-75	10	0.7
		30	2.1
		50	3.5
Conventional	50-75	10	0.234
		30	0.70
		50	1.17
No Tillage	50-75	10	0.79
		30	2.4
		50	4
Conservative	75-100	10	0.77
		30	2.31
		50	3.9
Conventional	75-100	10	0.77
		30	2.31

		50	3.9
No Tillage	75-100	10	0.924
		30	2.77
		50	4.6

APPENDIX E

Gross Irrigation Water Requirement

Tillage method	**Soil depth (cm)**	**MAD (%)**	**GROSS IRRIGATION (cm)**
Conservative	0-25	10	0.21
		30	0.7
		50	1.1
Conventional	0-25	10	0.21
		30	0.7
		50	1.1
No Tillage	0-25	10	0.35
		30	1.11
		50	1.77
Conservative	25-50	10	0.5
		30	1.43
		50	2.77
Conventional	25-50	10	0.6
		30	1.7
		50	2.77

No Tillage	25-50	10	0.67
		30	2.01
		50	3.34
Conservative	50-75	10	0.77
		30	2.33
		50	3.9
Conventional	50-75	10	0.26
		30	0.77
		50	1.9
No Tillage	50-75	10	0.87
		30	2.67
		50	4.4
Conservative	75-100	10	0.9
		30	2.6
		50	4.33
Conventional	75-100	10	0.9

		30	2.6
		50	4.3
No Tillage	75-100	10	1.03
		30	3
		50	5.1

APPENDIX F

Irrigation Run Time

Tillage method	**Soil depth (cm)**	**MAD (%)**	**Irrigation Run Time (hr)**
Conservative	0-25	10	0.07
		30	0.23
		50	0.4
Conventional	0-25	10	0.4
		30	0.2
		50	0.06
No Tillage	0-25	10	0.1
		30	0.37
		50	0.6
Conservative	25-50	10	0.2
		30	0.43
		50	0.7
Conventional	25-50	10	0.2
		30	0.6
		50	1
No Tillage	25-50	10	0.2

		30	0.7
		50	1.1
Conservative	50-75	10	0.3
		30	0.8
		50	1.3
Conventional	50-75	10	0.09
		30	0.3
		50	0.6
No Tillage	50-75	10	0.3
		30	0.9
		50	1.5
Conservative	75-100	10	0.3
		30	0.9
		50	1.4
Conventional	75-100	10	0.3
		30	0.9

		50	1.4
No Tillage	75-100	10	0.3
		30	1
		50	1.7

APPENDIX G

Soil temperature (°C) for the growing period

Plot 1			
	CST	**CVT**	**NT**
0-25cm	29	28	29
25-50cm	28	28	28
50-75cm	27	27	28
75-100cm	27	27	27
Average		28	

Plot 2			
	CST	**CVT**	**NT**
0-25cm	26	25	26
25-50cm	25	25	26
50-75cm	25	25	25
75-100cm	24	24	24
Average		25	

Plot 3			
	CST	**CVT**	**NT**
0-25cm	26	26	26
25-50cm	25	25	25
50-75cm	25	24	25
75-100cm	24	23	25
Average		25	

Plot 4			
	CST	**CVT**	**NT**
0-25cm	24	24	24
25-50cm	23	23	24
50-75cm	23	23	23
75-100cm	22	22	22
Average		23	

Plot 5			
	CST	**CVT**	**NT**
0-25cm	27	26	27
25-50cm	26	26	27
50-75cm	26	25	26
75-100cm	25	24	25
Average			

Plot 6			
	CST	**CVT**	**NT**
0-25cm	28	27	28
25-50cm	27	27	28
50-75cm	27	26	27

75-100cm	26	26	26
Average		27	

Plot 7			
	CST	**CVT**	**NT**
0-25cm	29	28	29
25-50cm	28	28	29
50-75cm	27	27	28
75-100cm	27	26	27
Average		28	

Plot 8			
	CST	**CVT**	**NT**
0-25cm	27	27	28
25-50cm	26	26	29
50-75cm	26	25	26
75-100cm	25	25	25
Average		26	

Plot 9			
	CST	**CVT**	**NT**
0-25cm	25	24	25
25-50cm	24	23	24
50-75cm	23	22	23
75-100cm	22	21	22
Average		23	

Plot 10			
	CST	**CVT**	**NT**
0-25cm	27	26	27
25-50cm	26	25	27
50-75cm	26	24	26
75-100cm	25	24	26
Average		26	

Plot 11			
	CST	**CVT**	**NT**
0-25cm	29	29	30
25-50cm	27	28	28
50-75cm	27	27	27
75-100cm	26	26	27
Average		28	

Plot 12			
	CST	**CVT**	**NT**
0-25cm	29	27	30
25-50cm	28	27	29
50-75cm	27	27	28
75-100cm	27	26	27
Average		28	

Plot 13			
	CST	CVT	NT
0-25cm	24	24	25
25-50cm	23	23	24
50-75cm	23	22	23
75-100cm	22	21	22
Average		23	

Plot 14			
	CST	CVT	NT
0-25cm	30	29	31
25-50cm	29	28	30
50-75cm	29	27	29
75-100cm	28	27	28
Average		29	

Plot 15			
	CST	CVT	NT
0-25cm	29	28	29
25-50cm	28	28	28
50-75cm	27	27	28
75-100cm	27	26	27
Average		28	

Plot 16			
	CST	CVT	NT
0-25cm	26	25	27
25-50cm	25	24	26
50-75cm	24	24	25
75-100cm	24	23	24
Average		25	

Plot 17			
	CST	CVT	NT
0-25cm	27	26	28
25-50cm	27	25	27
50-75cm	26	24	26
75-100cm	24	24	25
Average		26	

Plot 18			
	CST	CVT	NT
0-25cm	28	28	29
25-50cm	27	27	28
50-75cm	27	26	27
75-100cm	26	25	27
Average		27	

Plot 19			
	CST	CVT	NT

0-25cm	28	27	28
25-50cm	27	26	28
50-75cm	26	26	27
75-100cm	26	25	26
Average		27	

Plot 20			
	CST	**CVT**	**NT**
0-25cm	26	24	24
25-50cm	24	24	24
50-75cm	24	23	23
75-100cm	23	23	23
Average		24	

Plot 21			
	CST	**CVT**	**NT**
0-25cm	25	25	26
25-50cm	25	24	25
50-75cm	24	23	24
75-100cm	24	22	24
Average		25	

Plot 22			
	CST	**CVT**	**NT**
0-25cm	27	27	25
25-50cm	26	25	23
50-75cm	24	24	23
75-100cm	24	23	23
Average		25	

Plot 23			
	CST	**CVT**	**NT**
0-25cm	27	26	27
25-50cm	25	25	26
50-75cm	25	24	25
75-100cm	24	23	24
Average		25	

Plot 24			
	CST	**CVT**	**NT**
0-25cm	24	24	25
25-50cm	24	23	24
50-75cm	23	22	23
75-100cm	22	21	22
Average		23	

Plot 25			
	CST	**CVT**	**NT**
0-25cm	28	27	29
25-50cm	27	26	26
50-75cm	26	26	26

75-100cm	26	25	25
Average	27		

Plot 26			
	CST	**CVT**	**NT**
0-25cm	28	27	28
25-50cm	27	26	28
50-75cm	26	25	27
75-100cm	26	24	27
Average	27		

Plot 27			
	CST	**CVT**	**NT**
0-25cm	27	26	28
25-50cm	26	25	26
50-75cm	25	24	26
75-100cm	25	23	25
Average	26		

APPENDIX H
Soil Moisture Content (%) for the Growing Period

Plot 1			
	CST	CVT	NT
0-25cm	10.01	9.46	9.81
25-50cm	10.56	10.4	10.14
50-75cm	10.62	11.12	10.36
75-100cm	12.91	13.0	12.73
Average		10.12	

Plot 2			
	CST	CVT	NT
0-25cm	9.91	9.30	8.05
25-50cm	10.5	10.91	9.35
50-75cm	11.0	11.15	10.04
75-100cm	11.69	12.10	10.54
Average		9.25	

Plot 3			
	CST	CVT	NT
0-25cm	11.03	11.41	10.45
25-50cm	11.56	11.77	11.01
50-75cm	12.11	12.35	11.49
75-100cm	12.65	12.79	11.9
Average		11.31	

Plot 4			
	CST	CVT	NT
0-25cm	8.55	8.75	8.15
25-50cm	9.56	9.91	9.06
50-75cm	10.05	10.54	9.51
75-100cm	10.76	11.01	10.01
Average		9.11	

Plot 5			
	CST	CVT	NT
0-25cm	11.14	12.34	11.67
25-50cm	12.53	12.79	12.14
50-75cm	13.40	13.63	12.96
75-100cm	13.9	14.01	13.53
Average		12.01	

Plot 6			
	CST	CVT	NT
0-25cm	10.21	10.65	9.76
25-50cm	10.74	11.46	10.6
50-75cm	11.33	11.85	11.04
75-100cm	11.84	12.05	11.43
Average		10.28	

Plot 7			
	CST	CVT	NT
0-25cm	11.69	11.93	11.51

25-50cm	11.63	12.9	11.91
50-75cm	12.7	13.03	12.01
75-100cm	13.01	13.09	12.59
Average		12.4	

Plot 8			
	CST	**CVT**	**NT**
0-25cm	11.53	11.56	11.31
25-50cm	12.11	13.10	11.73
50-75cm	12.93	13.31	11.94
75-100cm	13.23	13.71	12.41
Average		12.75	

Plot 9			
	CST	**CVT**	**NT**
0-25cm	9.59	11.15	8.14
25-50cm	10.65	11.69	9.56
50-75cm	11.05	12.01	9.95
75-100cm	11.73	12.35	10.35
Average		10.12	

Plot 10			
	CST	**CVT**	**NT**
0-25cm	9.98	10.09	9.25
25-50cm	10.11	10.76	9.89
50-75cm	10.54	11.06	10.31
75-100cm	11.17	11.54	10.79
Average		10.39	

Plot 11			
	CST	**CVT**	**NT**
0-25cm	12.07	12.35	11.76
25-50cm	12.36	12.79	12.15
50-75cm	12.99	13.36	12.69
75-100cm	13.81	14.06	13.14
Average		13.5	

Plot 12			
	CST	**CVT**	**NT**
0-25cm	11.04	11.56	9.68
25-50cm	11.35	11.96	10.21
50-75cm	11.46	12.35	10.63
75-100cm	11.93	12.53	11.42
Average		11.31	

Plot 13			
	CST	**CVT**	**NT**
0-25cm	12.01	12.35	11.65
25-50cm	12.60	12.80	12.01
50-75cm	13.03	13.03	12.88
75-100cm	14.54	14.65	13.16
Average		12.88	

Plot 14			
	CST	CVT	NT
0-25cm	8.93	8.40	7.05
25-50cm	9.5	9.70	8.45
50-75cm	10.01	10.05	9.07
75-100cm	10.60	10.90	9.64
Average		9.37	

Plot 15			
	CST	CVT	NT
0-25cm	10.95	11.14	10.41
25-50cm	12.34	12.61	11.96
50-75cm	12.91	12.93	12.69
75-100cm	13.85	14.00	13.01
Average		12.4	

Plot 16			
	CST	CVT	NT
0-25cm	9.01	8.54	7.01
25-50cm	9.63	9.31	8.36
50-75cm	9.91	9.69	8.93
75-100cm	10.14	10.51	9.54
Average		9.24	

Plot 17			
	CST	CVT	NT
0-25cm	10.87	11.21	10.48
25-50cm	11.11	11.57	11.01
50-75cm	11.87	12.18	11.43
75-100cm	12.27	12.97	12.04
Average		11.6	

Plot 18			
	CST	CVT	NT
0-25cm	13.91	14.24	13.05
25-50cm	14.57	14.71	13.74
50-75cm	14.80	15.09	15.74
75-100cm	26.40	16.79	15.97
Average		14.96	

Plot 19			
	CST	CVT	NT
0-25cm	8.95	10.14	8.21
25-50cm	11.34	11.61	10.96
50-75cm	11.91	11.92	11.69
75-100cm	12.85	13.36	12.01
Average		11.21	

Plot 20			
	CST	CVT	NT
0-25cm	8.95	9.14	8.41
25-50cm	10.34	10.61	9.96
50-75cm	10.91	10.93	10.67
75-100cm	11.85	11.16	11.41
Average	9.82		

Plot 21			
	CST	CVT	NT
0-25cm	9.89	10.07	9.33
25-50cm	11.27	11.54	10.89
50-75cm	11.84	11.86	11.95
75-100cm	12.78	12.42	12.35
Average	10.29		

Plot 22			
	CST	CVT	NT
0-25cm	13.34	13.6	12.96
25-50cm	14.05	13.98	13.2
50-75cm	14.44	14.48	13.74
75-100cm	15.21	15.28	14.45
Average	14.06		

Plot 23			
	CST	CVT	NT
0-25cm	13.14	13.37	12.34
25-50cm	13.47	13.80	12.6
50-75cm	13.77	14.06	12.94
75-100cm	14.02	14.70	13.02
Average	13.6		

Plot 24			
	CST	CVT	NT
0-25cm	8.54	8.73	8.00
25-50cm	9.93	10.2	9.55
50-75cm	10.5	10.62	10.22
75-100cm	11.44	10.93	11.01
Average	9.98		

Plot 25			
	CST	CVT	NT
0-25cm	10.97	11.1	10.67
25-50cm	12.3	12.57	11.92
50-75cm	12.78	12.89	12.59
75-100cm	13.36	13.36	13.38
Average	12.35		

Plot 26			
	CST	**CVT**	**NT**
0-25cm	10.9	11.1	10.21
25-50cm	12.3	12.5	11.9
50-75cm	12.7	12.9	12.5
75-100cm	13.7	13.3	13.3
Average		11.91	

Plot 27			
	CST	**CVT**	**NT**
0-25cm	10.68	11.02	10.32
25-50cm	13.00	13.40	12.01
50-75cm	13.63	14.05	12.88
75-100cm	14.54	14.65	13.16
Average		12.72	

APPENDIX I

Irrigation Frequency

For Conventional Tillage

	0-25cm depth @10%MAD	**25-50cm depth @10%MAD**	**50-75cm depth @10%MAD**	**75-100cm depth @10%MAD**
Irrigation frequency(days)	3	4	1	4
	0-25cm depth @30%MAD	**25-50cm depth @30%MAD**	**50-75cm depth @30%MAD**	**75-100cm depth @30%MAD**
Irrigation frequency(days)	4	4	3	4
	0-25cm depth @50%MAD	**25-50cm depth @50%MAD**	**50-75cm depth @50%MAD**	**75-100cm depth @50%MAD**
Irrigation frequency(days)	4	10	6	5

For Conservative Tillage

	0-25cm depth @10%MAD	25-50cm depth @10%MAD	50-75cm depth @10%MAD	75-100cm depth @10%MAD
Irrigation frequency(days)	3	3	4	3
	0-25cm depth @30%MAD	**25-50cm depth @30%MAD**	**50-75cm depth @30%MAD**	**75-100cm depth @30%MAD**
Irrigation frequency(days)	4	4	5	3
	0-25cm depth @50%MAD	**25-50cm depth @50%MAD**	**50-75cm depth @50%MAD**	**75-100cm depth @50%MAD**
Irrigation frequency(days)	6	7	10	5

For No Tillage

	0-25cm depth @10%MAD	**25-50cm depth @10%Ymad**	**50-75cm depth @10%MAD**	**75-100cm depth @10%MAD**
Irrigation frequency(days)	5	4	4	3
	0-25cm depth @30%MAD	**25-50cm depth @30%MAD**	**50-75cm depth @30%MAD**	**75-100cm depth @30%MAD**
Irrigation frequency(days)	5	5	5	4
	0-25cm depth @50%MAD	**25-50cm depth @50%MAD**	**50-75cm depth @50%MAD**	**75-100cm depth @0%MAD**
Irrigation frequency(days)	5	6	4	4

APPENDIX J

Moisture Content at 2MPa

Conventional Tillage	Soil Depth(cm)	Volumetric water content cm^3/cm^3
	0-25	0.021
	25-50	0.026
	50-75	0.046
	75-100	0.051
Conservative Tillage	0-25	0.031
	25-50	0.029
	50-75	0.0282
	75-100	0.0274
No Tillage	0-25	0.009
	25-50	0.013
	50-75	0.019
	75-100	0.02

APPENDIX K

Soil Sampling Result

For sample A,

Uniformity coefficient,

$CU = \frac{D_{60}}{D_{10}} = \frac{1.23}{0.67} = 1.8$

- Coefficient of Gradation,

$$C_C = \frac{D_{30}^2}{D_{10}\ X\ D_{60}} = \frac{(0.81)^2}{1.23\ X\ 0.67} = 0.8$$

- Soil Fractionation

The soil fractionation test gave 15% clay, 25% silt and 60% sand

The soil textural triangle fig 2..coefficient of gradation ($C_C \leq 1.5$) shows that the soil is a sandy loam in which the soil grains from the different samples are uniformly graded to enable proper irrigation

For sample B

Uniformity coefficient,

$CU = \frac{D_{60}}{D_{10}} = \frac{1.23}{0.61} = 2.01$

- Coefficient of Gradation,

$C_C = \frac{D_{30}^2}{D_{10}\ X\ D_{60}} = \frac{0.87^2}{0.61\ X\ 1.23} = 1.01$

- Soil Fractionation

The soil fractionation test gave 17% clay, 20% silt and 63% sand

The soil textural triangle fig 2..coefficient of gradation ($C_C \leq 1.5$) shows that the soil is a sandy loam in which the soil grains from the different samples are uniformly graded to enable proper irrigation

For Sample C

Uniformity coefficient,

$$CU = \frac{D_{60}}{D_{10}} = \frac{1.31}{0.65} = 2.01$$

- Coefficient of Gradation,

$$C_C = \frac{D_{30}^2}{D_{10}\ X\ D_{60}} = \frac{0.83^2}{0.65\ X\ 1.31} = 0.8$$

- Soil Fractionation

The soil fractionation test gave 17% clay, 19% silt and 64% sand

The soil textural triangle fig 2..coefficient of gradation ($C_C \leq 1.5$) shows that the soil is a sandy loam in which the soil grains from the different samples are uniformly graded to enable proper irrigation

APPENDIX L

Moisture Content at Different Matric Potentials

Tillage	Depth interval (cm)	Matric Potential (MPa)						
		--0.01(FC)	-0.03	-0.07	-0.1	-0.2	-0.5	-1.5(PWP
Conservative	0-25	11.42% $0.11cm^3/cm^3$	9.9% $0.09cm^3/cm^3$	8.7% $0.08cm^3/cm^3$	7.9% $0.07cm^3/cm^3$	7.3% $0.07cm^3/cm^3$	6.4% $0.06cm^3/cm^3$	5.51% $0.05cm^3/cm^3$
Conservative	25-50	11.27% $0.11cm^3/cm^3$	9.61% $0.09cm^3/cm^3$	8.79% $0.08cm^3/cm^3$	7.10% $0.07cm^3/cm^3$	6.10% $0.06cm^3/cm^3$	5.31% $0.05cm^3/cm^3$	4.75% $0.04cm^3/cm^3$
Conservative	50-75	11.32% $0.11cm^3/cm^3$	11.15% $0.11cm^3/cm^3$	10.9% $0.10cm^3/cm^3$	10.45% $0.10cm^3/cm^3$	10.13% $0.10cm^3/cm^3$	9.91% $0.09cm^3/cm^3$	9.49% $0.09cm^3/cm^3$
Conservative	75-100	14.67% $0.14cm^3/cm^3$	12.51% $0.12cm^3/cm^3$	11.1% $0.11cm^3/cm^3$	10.69% $0.10cm^3/cm^3$	9.34% $0.09cm^3/cm^3$	8.79% $0.08cm^3/cm^3$	7.24% $0.07cm^3/cm^3$
No Tillage	0-25	7.8% $0.07cm^3/cm^3$	6.1% $0.06cm^3/cm^3$	5.9% $0.05cm^3/cm^3$	4.73% $0.04cm^3/cm^3$	4.1% $0.04cm^3/cm^3$	3.43% $0.03cm^3/cm^3$	2.73% $0.02cm^3/cm^3$
No Tillage	25-50	11.43% $0.11cm^3/cm^3$	10.44% $0.10cm^3/cm^3$	9.56% $0.09cm^3/cm^3$	8.55% $0.08cm^3/cm^3$	7.43% $0.07cm^3/cm^3$	6.79% $0.06cm^3/cm^3$	5.56% $0.05cm^3/cm^3$
No Tillage	50-75	12.05% $0.12cm^3/cm^3$	10.9% $0.11cm^3/cm^3$	9.76% $0.09cm^3/cm^3$	8.95% $0.08cm^3/cm^3$	7.31% $0.07cm^3/cm^3$	6.96% $0.06cm^3/cm^3$	5.67% $0.05cm^3/cm^3$
No Tillage	75-100	14.39% $0.14cm^3/cm^3$	13.3% $0.13cm^3/cm^3$	12.67% $0.12cm^3/cm^3$	11.49% $0.11cm^3/cm^3$	10.36% $0.10cm^3/cm^3$	9.63% $0.09cm^3/cm^3$	8.99% $0.08cm^3/cm^3$
Conventional	0-25	9.64% $0.09cm^3/cm^3$	8.3% $0.08cm^3/cm^3$	7.1% $0.07cm^3/cm^3$	6.7% $0.06cm^3/cm^3$	4.3% $0.04cm^3/cm^3$	2.31% $0.02cm^3/cm^3$	1.60% $0.01cm^3/cm^3$
Conventional	25-50	13.28% $0.13cm^3/cm^3$	12.01% $0.12cm^3/cm^3$	10.31% $0.10cm^3/cm^3$	9.61% $0.09cm^3/cm^3$	7.5% $0.07cm^3/cm^3$	6.34% $0.06cm^3/cm^3$	5.71% $0.05cm^3/cm^3$

Conventional	50-75	15.73% $0.15 cm^3/cm^3$	14.5% $0.14 cm^3/cm^3$	13.64% $0.13 cm^3/cm^3$	12.70% $0.12 cm^3/cm^3$	11.61% $0.11 cm^3/cm^3$	10.49% $0.10 cm^3/cm^3$	9.01% $0.09 cm^3/cm^3$
Conventional	75-100	17.08% $0.17 cm^3/cm^3$	16.7% $0.16 cm^3/cm^3$	15.5% $0.15 cm^3/cm^3$	14.36% $0.14 cm^3/cm^3$	13.1% $0.13 cm^3/cm^3$	12.31% $0.12 cm^3/cm^3$	11.05% $0.11 cm^3/cm^3$

APPENDIX M

Calculation of Application rate

Total of all containers = 8.83cm

$$Zone's\ average\ water\ depth = \frac{8.83}{6} = 1.5cm$$

Application rate = 0.6 inches/0.5hrs = 1.2 inch/hr = 3.0cm/hr

1.5cm= 0.6 inches

APPENDIX N

Basic hydraulics of the drip irrigation system

Energy Drop by Friction for mainline (m)	$1.29 X 10^{-6}$
Total Energy Drop by the friction at the end of the Lateral (m)	$3.6 X 10^{-9}$

APPENDIX O

Grain size analysis

Sieve Size (mm)	Wt. of sieve (g)	Wt of sieve and sample (g)			Wt of sample retained (g)			Cumulative			% passing		
		A	B	C	A	B	C	A	B	C	A	B	C
4.75	490.5	490.5	490.5	490.5	-	-	-				100	100	100
2.00	410.0	410.73	411.3	410.69	0.73	1.3	0.69	0.73	1.3	0.69	99.27	98.7	99.31
1.180	395.6	434.72	440.7	434.74	39.12	45.1	39.14	39.85	46.4	39.83	60.15	53.6	60.17
0.600	339.4	394	385	394.3	54.6	45.6	54.9	94.45	92	94.73	5.55	8	5.27
0.425	327.5	330.69	331.6	330.26	3.19	4.1	3.01	97.64	96.1	97.74	2.36	3.9	2.26
0.300	303.6	304.3	305.1	304.5	0.7	1.5	0.9	98.34	97.6	98.64	1.66	2.4	1.36
Tray	295.6	297.26	298	296.96	1.66	2.4	1.36	100	100	100	0	0	0

APPENDIX P

Least limiting water range

Critical Points for determination of least limiting water range (LLWR) for root growth for conventional tillage

Parameters	CVT 0-25cm	CVT 25-50cm	CVT 50-75cm	CVT 75-100cm
Bulk Density – ρb(g/cm^3)	1.47	1.46	1.45	1.43
FC-ψ_m = -0.001MPa(θ_{vfc})	0.09	0.13	0.15	0.17
WP- ψ_m = -1.5MPa (θ_{vwp})	0.016	0.057	0.090	0.11
PR-Q = 2MPa	0.021	0.026	0.046	0.051
10% porosity-ε_a = 0.10 (aeration limit)	0.342	0.333	0.328	0.323
LLWR(cm^3/cm^3)	0.074	0.073	0.06	0.06

Critical points for determination of least limiting water range (LLWR) for root growth for conservative tillage

Parameters	CST 0-25cm	CST 25-50cm	CST 50-75cm	CST 75-100cm
Bulk Density – ρb(g/cm^3)	1.55	1.55	1.54	1.53
FC-ψ_m = -0.001MPa(θ_{vfc})	0.1	0.11	0.11	0.14
WP- ψ_m = -1.5MPa (θ_{vwp})	0.056	0.048	0.094	0.072
PR-Q = 2MPa	0.031	0.029	0.0282	0.0274
% porosity-ε_a = 0.10 (aeration limit)	0.3	0.29	0.282	0.274
LLWR	0.044	0.062	0.068	0.051

Critical points for determination of least limiting water range (LLWR) for root growth for no tillage

	NT 0-25(cm)	NT 25-50(cm)	NT 50-75(cm)	NT 75-100(cm)
Bulk Density – ρb(g/cm^3)	1.59	1.58	1.56	1.53
FC-ψ_m = -0.001MPa(θ_{vfc})	0.078	0.11	0.12	0.14
WP- ψ_m = -1.5MPa (θ_{vwp})	0.027	0.056	0.057	0.089
PR-Q = 2MPa	0.009	0.013	0.019	0.02
% porosity-ε_a = 0.10 (aeration limit)	0.295	0.288	0.286	0.304

LLWR	0.05	0.05	0.06	0.05

APPENDIX Q

SOIL CHEMICAL PARAMETERS

Soil pH

Soil Depth(cm)	pH		
	Conservative Tillage	Conventional Tillage	No Tillage
0-25	7.07	6.79	6.99
25-50	7.05	6.79	6.92
50-75	7.01	6.79	6.10
75-100	6.98	6.78	6.03

Soil Electrical Conductivity

Soil Depth(cm)	EC(µs/cm)		
	Conservative Tillage	Conventional Tillage	No Tillage
0-25	53.9	54.4	55.6
25-50	52.1	53.5	54.4
50-75	51.8	52.1	54.0
75-100	50.6	51.9	53.7

Soil Potassium

Soil Depth(cm)	Potassium(ppm)		
	Conservative Tillage	Conventional Tillage	No Tillage
0-25	7.975	8.975	9.376
25-50	7.757	8.013	8.209
50-75	7.565	7.576	7.399
75-100	7.105	6.623	6.314

Soil Phosphorous

Soil Depth(cm)	Phosphorous(mg/kg)		
	Conservative Tillage	No Tillage	Conventional Tillage
0-25	2.83	5.065	3.095
25-50	4.69	4.956	3.594
50-75	6.154	4.649	6.045
75-100	7.93	4.411	6.514

Soil organic carbon

Soil Depth(cm)	Organic Carbon(g/kg)		
	Conservative Tillage	Conventional Tillage	No Tillage
0-25	9.1	9.3	10.6
25-50	6.4	6.1	6.3
50-75	6.0	5.4	5.5
75-100	5.9	5.0	5.1

Table 4.15 Table of soil Nitrogen

Soil Depth(cm)	Nitrogen(g/kg)		
	Conservative Tillage	Conventional Tillage	No Tillage
0-25	1.6	1.5	1.9
25-50	1.6	1.3	1.9
50-75	1.5	1.2	1.5
75-100	1.3	1.0	1.4

Plate 1: Setting up the tank stand

Plate 2: Site set up

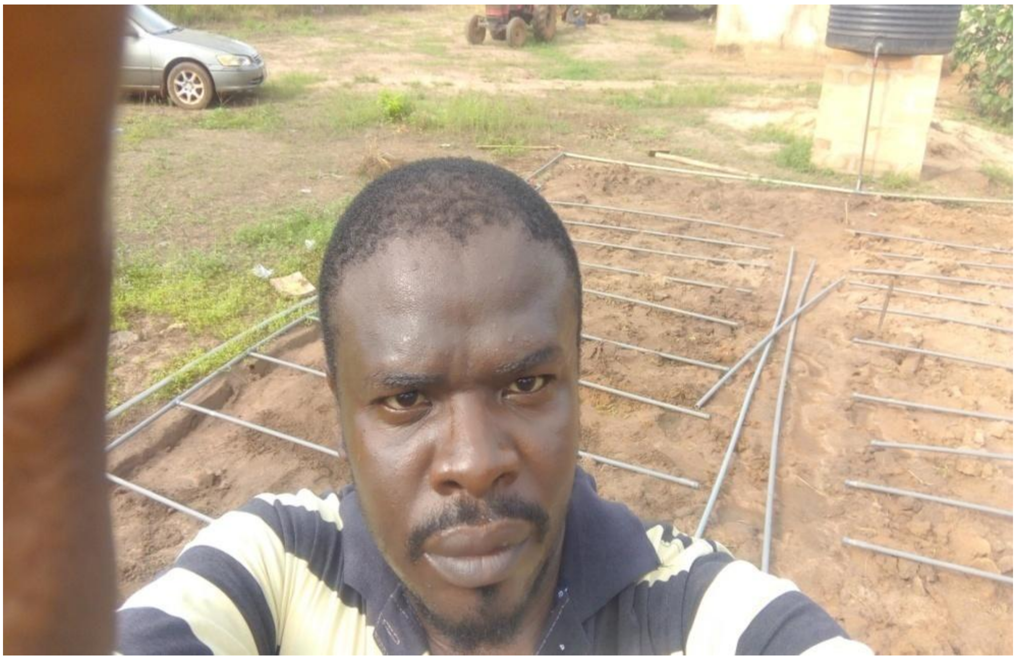

Plate 3: Site set up

Plate 4: Plant early stage

Plate 5: NPK Application

Plate 6: Investigation of the plots

Plate 7: Soil sample collection using auger

Plate 8: Crop maturity stage

Plate 9: Maturity stage

Plate 10: Determination of Soil matric potential using pressure plate apparatus at Soil lab, ABE dept, UNN

Plate 11: Determination of soil strength using penetrometer

Plate 12: Irrigation