UNIVERSITY FOR DEVELOPMENT STUDIES

PERFORMANCE EVALUATION OF CENTER PIVOT IRRIGATION SYSTEM AT MAMPRUGU MUADURI DISTRICT IN NORTH EAST REGION OF GHANA

Jean Damascene HAKIZIMANA

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TOPIC: PERFORMANCE EVALUATION OF CENTER PIVOT IRRIGATION SYSTEM AT MAMPRUGU MUADURI DISTRICT IN NORTH EAST REGION OF GHANA.

BY

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Bachelor of Science (Honors) (Irrigation and Drainage)

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THESIS SUBMITTED TO THE DEPARTMENT OF AGRICULTURAL ENGINEERING SCHOOL OF ENGINEERING IN PARTIAL FULLFILEMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF PHILLOSOPHY DEGREE IN IRRIGATION AND DRAINAGE ENGINEERING

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DECLARATION

DECLARATION BY CANDIDATE

I hereby declare that this thesis is the result of my own original work and that no part of it has been presented for another degree in this University or elsewhere. The work of others which served as sources of information for this study has been duly acknowledged in the form of references.

Jean Damascene HAKIZIMANA — 06th September 2023

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DECLARATION BY SUPERVISORS

I hereby declare that the preparation and presentation of the thesis was supervised in accordance with the guidelines on supervision of thesis laid down by the University for Development Studies.

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ABSTRACT

The main objective of this study was to evaluate performance of center pivot irrigation systems at the irrigation scheme of Integrated Water and Agriculture Development (IWAD) in Ghana. The study was carried out during dry season 2022/23. The system was evaluated using selected hydraulic performance. This study was conducted under system of eight (8) spans and one overhang for different running speed 100%, 80%, 60% and 40%. 84 catch cans were fixed in the field to identify hydraulic performance. The average collected depth of water in catch cans were 6.5mm, 10.01 mm, 12.87 mm, 19.63 mm for 100 %, 80 %, 60 %,40 % running speed of the system respectively. However, coefficient of uniformity, irrigation efficiency and scheduling coefficient of twelve irrigation number in growing season were 82.7 %, 69.4 % and 1.35 respectively and which were below recommended value. Distribution uniformity was good with 74.49 % while application efficient of 92.68 % was greater than recommended value. The soil moisture content was measured gravimetrically. The results indicated that soil moisture content value before and after irrigation were highly positively correlated with correlation coefficient of 99%. The rate of water losses of system was 7.21 % corresponding to 7.3 m^3 per hectare. Approximately 213.922 US Dollars ($) was used for pumping 1 Mega liter (ML) of water to 1ha of irrigable land. Approximately 1 Mega liter of water was required to produce 3640.684 kg of maize grain, 447.451 kg of cow peas, 19659.910 kg of onion, 5008.239 kg of sorghum and 824.155 kg of groundnuts. Therefore, to improve system efficiency, we recommend using flow meter, soil sensors, and operating pressure regulators should be checked and computer system to control water flows, finally performance evaluation of center pivot irrigation system should be done every two years.

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Whoever who contributed in whatever to the achievement of this work may God bless them.

DEDICATION

I dedicate this work to my mother, brother and Sisters for their relentless support.

Table of Contents

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

ABBREVIATIONS AND ACRONYMS

AE	Application Efficiency
ASABE	Amercican Sociaty of Agricultural and Biological Engineers
AWC	Available water capacity
CU	Coefficient Uniformity
DU	Distribution Uniformity
E	Irrigation Efficiency
ETc	Crop water requirement/evapotranspiration
ETo	Reference crop evapotranspiration
FAO	Food and Agricultural Organization
FC	Field capacity
GHC	Ghana cedis
Ha	Hectare
IWAD	Integrated Water and Agriculture Development
Kc	Crop coefficient
Kg	Kilogram
LEPA	Low Energy Precision Application
LESA	Low Elevation Spray Application
LPIC	Low Pressure in Canopy
M^3	Cubic meter
MC	Soil moisture content
Md	Weight of the dry sample
MESA	Mid Elevation Spray Application
Ml	Mega liter
Mm	Millimeter
Mm	Weight of the wet sample
MoFA	Ministry of Food and Agriculture
PPP	Public Private Partnership
Psi	Pounce per Square Inch
PWP	Permanent wilting point
RH	Relative Humidity
SADA	Savannah Accelerated Development Authority
SAEZ	Savannah Agro-Ecological Zone
Sc	Scheduling Coefficient
SKIS	Sisili-Kulpawn Irrigation Scheme
T or Mt	Ton or Metric Tones
UDS	University for Development Studies
USDA	United States Department of Agriculture
WACWISA	West African Centre for Water, Irrigation and Sustainable Agriculture

CHAPTER ONE: INTRODUCTION

1.1Background

Food insecurity and hunger have become major problems in many countries in the world. FAO (2022) predicts that around 702 to 828 million people worldwide, making up roughly 8.9% to 10.5% of the population, will face hunger in 2021. The data shows that Africa will be the most affected region, indicating ongoing regional inequalities. A report revealed that hunger rates in 2021 differed among regions. Africa had the highest proportion, with 20.2% of the population experiencing hunger. In comparison, hunger rates were 9.1% in Asia, 8.6% in Latin America and the Caribbean, 5.8% in Oceania, and less than 2.5% in Northern America and Europe. A report suggests that around 2.3 billion people worldwide, making up about 29.3% of the population, experienced moderate to severe food insecurity in 2021, with severe food insecurity affecting 11.7 % of the population, or 923.7 million people. However, digital automation technologies can benefit small-scale agriculture in many ways, they also present numerous challenges (FAO, 2022a). In Ghana, where agriculture is the main industry, population growth is anticipated to hit 32.37 million by the end of 2022 (Sekher, 2022) which could increase the desire for food (Martin *et al.*, 2017). Rainfall intensity and distribution in some areas of the globe are insufficient to give crops the moisture they need to produce enough food to meet human demand (Madh, 2020).

ALLah (2015) the main goal of irrigation is to provide the right amount of water to the roots of crops, ensuring they have enough water to grow properly, especially when rainfall is not enough. There are different techniques for applying water in irrigation. The center pivot sprinkler irrigation method is a system that uses pressure to distribute water from a source and release it as small droplets into the air. Sprinkler irrigation imitates natural rainfall when applying water. Typically, pumps are used to disperse water through a network of pipes. Sprinklers are used to spray it into the air where it fragments into tiny water droplets that land on the ground. There are two main types of sprinkler irrigation devices: set systems and continuous-move systems. Set systems have stationary sprinklers, while continuous-move systems have sprinklers that move in either a circular or straight path (Moshinsky, 1959). According to Zhao et *al.* (2020), In any agricultural development, irrigation is a crucial practice that helps keep yields and increase productivity. As one of Ghana's primary economic sectors, agriculture has a significant impact on the country's growth. Every area and the different crops grown there have a very different context. Most farmers in Ghana operate small, two (2) hectare or fewer fields. Farmers still use a plough and a cutlass, and there is little use of machinery. The lack of services in many farming areas is one of the causes. Costs have been a limiting factor in other regions where they are present. According to MoFA estimates, only 2.4 million hectares, or around 30 %, of the eight million hectares of potentially marketable agricultural land are mechanized as cited by Darko *et al.*(2020). Rainfall and soil characteristics greatly influence overall output. The challenges are related to climate change and food insecurity. Future solutions to the agricultural problems facing Ghana may result from the growth and adaptation of irrigation (Aiccra, 2022).

(Aiccra, 2022) reported that in Ghana, nearly 6.8 million hectares are planted, but only 31.8 % of that territory is irrigated and little over 220,000 hectares, with an estimated 84% (189,000 ha) of informal irrigation systems built by farmers themselves. The development of small-scale irrigation could help over 700,000 farmers; the irrigation potential is thought to range between 0.36 and 1.9 million hectares. In the Upper Region, between 130,000 and 190,000 hectares might be appropriate for small-scale irrigation development

According to Jha *et al.* (2019) Irrigation is the act of providing water to the soil in order to help crops grow. Irrigation systems are tools that distribute water from a main source to agricultural fields, ensuring that crops receive the necessary moisture. In Ghana, the main type of irrigation used is surface irrigation. The surface irrigation method is more labor-intensive compared to modern irrigation systems like sprinkler and drip irrigation. These modern systems are known for being more efficient in terms of labor and require less manual work to operate (Grewal *et al*., 2021).

Ayelazuno (2019) collaboration between IWAD, Wienco Ghana Ltd, SADA, and Wageningen University and Research Centre-Altera led to the creation of a modern irrigation scheme in Yagaba. The scheme covers a total area of 400 hectares, with a main farm of 250 hectares and an additional out-grower section of 150 hectares. The scheme includes four main irrigation systems: a center pivot system covering 260 hectares, a modified dragline system covering 99 hectares, a furrow system covering 39 hectares, and 15 hectares of drip irrigation

De Wet (2021) stated that a center pivot has sprinklers equally spaced along its length and is made of several pipe segments that have been connected together. It is supported by trusses on wheeled towers. The central pivot irrigation system rotates and gets water from the center of the field. In the US, a common size for this system is made to fit a 160-acre field, which is about 65 hectares or a quarter-section, with a length of around 400 meters. They are usually shorter than 500 meters as stated by (USDA, 2016), the length and movement of the main lateral affect how much land the end section can irrigate. Consequently, from the pivot to the overhang, the water release rate must gradually rise in order to provide a uniform application (CAI *et al.,* 2020). Regularly evaluating the uniformity of center pivot irrigation systems is crucial for owners and operators. This practice helps ensure that the systems are working at their best and distributing water evenly throughout the field (C. R. Camp et al., 1998).

Ali (2011) the center pivot irrigation system is popular because it has many benefits. It can water large areas, usually between 40 and 70 hectares. It is easy to use and automated, which reduces the need for labor. It also helps conserve water by controlling the amount used and distributes water evenly

The center pivot irrigation system helps users improve the efficiency of their irrigation scheduling methods, resulting in less water and electricity usage. To operate effectively, the system needs a substantial amount of consistent energy to create the required pressures. Having high-pressure systems is crucial for achieving efficient water distribution and ultimately conserving more water. As a result, it will continue to get more expensive over time to efficiently move water through center-pivot irrigation systems (Zybach, 2008).

1.2. The Problem Statement and Justification

Farmers in Sub-Saharan Africa, including Ghana, are being adversely affected by climate change. The region is dealing with issues like limited water supply and irregular rainfall, which have a major impact on food production and the sustainability of agriculture. Since the 1990s, public investment in irrigation development in Ghana has significantly decreased, and the returns on these huge investments are becoming more questionable (Darko *et al.*, 2020). In view of this, different programs and measures are being taken to eradicate food insecurity. Performance evaluation of center pivot irrigation system is a step to bring the lack of water and erratic rain and huge investment under control. There is limited information on baseline data for the project region under consideration. The center pivot irrigation system can be affected by issues like leaks, tire deflection, and wind drift, which can disrupt the efficient and reliable distribution of water on the field and reduce the system's effectiveness (Gross & Pennink, 2018). Ghana's irrigation schemes administrations have struggled with issues such as poor record keeping and expensive operational and maintenance costs. Ghana's irrigation potential is largely unrealized and neglected (Darko *et al.,* 2020). The area under sprinkler irrigation system in Ghana was 580 ha in 1994 (Brier & lia dwi jayanti, 2020).

Since 2013 in Sisili-kulpawn irrigation scheme, IWAD has established four (4) Reinke pivots to supply water to the farm field (Gross & Pennink, 2018). This scheme helps to increase the water need and available to meet supply demand in Ghana. This means that operation and maintenance of irrigation system should be properly taken care of so as effective water supply needed to meet with the crop water requirement efficiently.

Most farmers ignore maintenance which leads to the irrigation system to works inefficiently, they consider as small problem like pipe leakage repair when it occurred, which escalate into bigger problem requiring more financial cost to repair. Therefore, field evaluation performance of pressurized irrigation system especially center pivot is crucial to maintain operation of the system efficiency. The evaluation data can be usefully to identify the system problem, water distribution and the water losses of system and also at the same time can indicate location and the quantity of water loss.

Yiran *et al.* (2018) remarked that the performance of the center pivots adopted in irrigation project in Ghana has not been evaluated in order to identify whether it is effective or needs to be improved. In the meantime, operational issues with the center pivot such pipe leaks, tower tyre deflation, and wind drift effects have an impact on effective and dependable water delivery and distribution on the field. Owner's control and operate the system according to general operating instructions provided by the manufacturer. Unknown factors include the system's effectiveness, application rates, and uniformity of application.

There has been a lack of research on how well the center pivot irrigation system performs in different irrigation schemes in Northern Ghana. It is important to evaluate the system's effectiveness and find ways to improve it, the success of achieving irrigation goals relies on managers taking into account the performance of the irrigation system. It is essential for managers to evaluate and assess the system's performance to ensure it is in line with desired objectives and functions efficiently (ASABE, 2021).

This study evaluated the performance of center pivot sprinklers to determine how efficiently they irrigate and how much water and nutrients are lost to groundwater and surface water. The results will be useful for guiding the use of center pivot sprinklers in larger areas and improving water usage. The study also aims to add to the current understanding of irrigation practices in Ghana.

1.3. General Objective

The Main Objective: The main objective of this study was to evaluate performance of center pivot irrigation system at the irrigation scheme of Integrated Water and Agriculture Development (IWAD) in Sisili-Kulpawn at Mamprugu-Moagduri District.

1.3.1. Specific Objectives

The Specific Objectives: The specific objectives were:

1. To determine the hydraulic performance of center pivot irrigation system

2. To evaluate water losses of center pivot irrigation system

3. To determine the amount of energy needed to pump water for center pivot irrigation and grow crops such as maize, cowpeas, onion, and sorghum and ground nuts.

1.4 Research Questions

Objectives of this research were to answer the following questions

1. What is hydraulic performance of center pivot irrigation system?

2. What is the quantity of water losses of center pivot irrigation system?

3. How much energy cost that is needed to pump water for center pivot irrigation and grows crops such as maize, cowpeas, onion, sorghum and ground nuts?

1.5 Scope of the Study

The study is divided into five chapters. The first chapter includes the introduction, problem statement, justification, research objectives, research questions, and scope of the study. The second chapter explores the relevant literature on irrigation and the factors used to evaluate and assess the performance of the center pivot sprinkler irrigation system. Chapter three discusses the materials used and the methods employed during the field trials. It also provides information about the characteristics of the study area. In chapter four, the research results are presented and compared with existing literature. Lastly, chapter five presents the conclusions and recommendations based on the findings of the study.

CHAPTER TWO: LITERATURE REVIEW

This chapter discusses irrigation and provides a brief overview of different methods. It specifically focuses on center pivot sprinkler irrigation, discussing its components, advantages, disadvantages, and functionality. The coefficient uniformity, distribution uniformity, application efficiency, irrigation efficiency and irrigation scheduling of the system have also been enumerated. This study emphasizes the importance of understanding soil moisture, soil texture, and crop water needs when using center pivot sprinkler irrigation. It also discusses the potential losses that can occur in these irrigation systems. Furthermore, the study examines how to evaluate the performance of crops and the economic indicators related to this irrigation system.

2.1 Irrigation Systems Overview

Irrigation is generally referred to as, the science of applying water artificially to the land in accordance with crop water requirements during their development phase for fully fledged crop nourishment (Tarekegn, 2020). irrigation can be defined as the act of providing water to fulfill the crop's water requirements, thus reducing crop water stress according to Martin *et al.* (2017). Water is delivered to the land through irrigation. Plants, soil, and water are the three fundamental ingredients in the process.

2.2 Factors Consider on Selection of Irrigation System

The choice of an irrigation system depends on various factors such as the crops being grown, available technology, past experience with irrigation, labor needs, cost and benefits, as well as natural elements like soil type, climate, water availability, and water quality (Abubaker Jamal, 2001).

2.2.1 Climate

No matter the situation, it's essential to gather all the information you can about the climate, with the most helpful information being rainfall, temperature, evaporation, humidity, and daily amounts of sun shine hours.

2.2.2 Soil

The type of irrigation system that is suitable depends on various soil characteristics such as soil type, depth, salinity levels, internal draining capabilities, and coefficient of permeability.

2.2.3 Water

Choosing the right irrigation system is influenced by factors like the amount and quality of water available. The amount of water needed for irrigation depends on factors such as the type of crop, climate, and the total area to be irrigated. Additionally, the presence of suspended materials in the water supply can also affect the choice and effectiveness of the irrigation system.

2.2.4 Types of Crops

Surface irrigation is beneficial for many types of plants, but when it comes to valuable crops like vegetables and fruit trees that require significant investments, methods like sprinkler and drip irrigation are more suitable.

2.2.5 Type of Technology

The level of technology needed typically determines the choice of irrigation techniques. Drip and sprinkler methods usually require more advanced technology than surface irrigation.

2.2.6 Previous Experience with Irrigation

The irrigation practices used historically in a region or nation also influence the technique of irrigation chosen. A conventional irrigation technique can often be improved rather than a completely new technique being introduced.

2.2.7 Required Labor Inputs

Surface irrigation requires more labor for its construction, operation, and maintenance compared to sprinkler or drip irrigation. It necessitates proper land leveling, regular maintenance, and efficient farmer organization for effective management of the irrigation system.

2.2.8 Costs and Benefits

Costs associated with installation, building, operation, and maintenance must all be factored into the irrigation method's cost estimation. Comparisons between these expenses and anticipated gains are necessary.

2.3 Surface Irrigation

Applying water to a field's surface using gravity movement is known as surface irrigation. The water is either fed into tiny channels (furrows) or strips of land, or the complete field is submerged (basin irrigation or borders) (Waseem, 2020). Surface irrigation involves distributing water across a cultivated area using canals, ditches, and furrows. Different materials and conduits can be used to transport water to the furrows, such as plastic or aluminum conduit, lay flat plastic with holes, concrete or plastic lined ditches, or unlined ditches (Waseem, 2020).

2.3.1 Furrow Irrigation

Furrow irrigation is a method where small channels are created to carry water for irrigation. The crops are grown on raised areas between these channels, allowing water to seep into the soil both vertically and horizontally. Water is added until the desired depth and spread of water is achieved (Majumder *et al.*, 2019).

2.3.2 Border Strips Irrigation

There is a method of irrigation where water flows down a hill by using parallel ridges. The land is divided into several lengthy parallel strips known as borders, and these are spaced apart by low ridges. A uniform, gentle incline in the direction of irrigation characterizes the border strip, which has little to no cross slope. The primary goal of border irrigation is to create a level surface that allows water to flow down an incline with a nearly uniform depth (Fabiana , 2019).

2.3.3 Basin Irrigation

There is a method of irrigation where water is applied to small, almost flat areas that are enclosed by bunds. The tiny plots keep the water until the soil is saturated. Bunds around the areas allow for uniformly deep water. It is ideal for uniform land slopes and soils with slow to moderate water infiltration rates (Fabiana, 2019).

2.4 Drip Irrigation

A drip irrigation system is a pressurized piping system that uses valves, pipelines, emitters, and other plumbing components to deliver water slowly and directly to the roots of plants. This method efficiently utilizes water and fertilizer, minimizing water loss from evaporation (Wale, 2022).

2.5 Sprinkler Irrigation

Sprinkler irrigation replicates the process of natural rainfall by providing water to crops, with the goal of imitating the way plants receive water from rain. Typically, pumps are used to disperse water through a network of pipes. Sprinklers are used to spray it into the air where it fragments into tiny water droplets that land on the ground. Set and continuous-move sprinkler irrigation devices are the two main categories. Set systems have stationary sprinklers that deliver water to a specific area, while continuous-move systems have moving sprinklers that cover a larger area as they move in either a circular or straight route (Moshinsky, 1959).

2.5.1 Components Sprinkler Irrigation System

A sprinkler irrigation system is made up of different parts, such as sprinklers, a water source, a pump, pipes, and valves, which work together to distribute water and control its flow. Sometimes added to monitor system efficiency are flow meters and pressure gauges (Ali, 2011).

2.5.1.1 Pump Unit or Pressurized Water Source

The centrifugal pump is typically used as the pressurized water source or pump in a sprinkler irrigation system. Its main function is to draw water from the source and generate enough pressure to distribute it through the pipe network (Majumder *et al.*, 2019).

2.5.1.2 Mainline of Sprinkler System

Main line of sprinklers system is the conduit that transports water from the pump to the laterals, this conduit may occasionally be buried underground or installed permanently on the soil's surface. In other instances, it is transient and can be moved from one area to another. Asbestos cement, plastic, and aluminum alloy are the three primary pipe components used (Majumder *et al.*, 2019).

2.5.1.3 Laterals

The laterals in a sprinkler irrigation system carry water from the mainline to the sprinklers. They are usually designed to be portable and made of materials like plastic or aluminum alloy, which enables them to be easily moved and repositioned when necessary (Majumder *et al.*, 2019).

2.5.1.4 Sprinklers

The sprinkler nozzle is an important part of sprinkler irrigation systems and needs to be chosen and set up correctly. It is responsible for spraying water to cover the desired area and plays a crucial role in distributing water efficiently and effectively.

2.6Types of Sprinkler System

The sprinkler system and device types accessible are many in different types, sizes, prices, and capacities of sprinkler watering systems. According to Majumder *et al.*,(2019) stated that the laterals function, sprinkler watering systems are divided into different groups There are three main types of sprinkler systems: fixed, periodic move, and continuous or self-move. In addition, there are various models of sprinkler irrigation systems, such as solid set or portable systems, hand move laterals, side roll or wheel-line laterals, end tow laterals, hose fed or pull laterals, perforated pipe laterals, high and low-pressure center pivots, linear or lateral move laterals, and stationary or moving gun sprinklers and booms.

2.6.1 Hand-Move Lateral System

The hand-move, portable lateral system in sprinkler irrigation includes buried or portable pipes for the mainline. The valve outlets are placed at appropriate intervals to make it easy to connect portable laterals. This system allows for manual movement and adjustment of the irrigation equipment to ensure efficient water distribution Compared to other set irrigation systems, this one is used to irrigate a larger area, and it can be applied to almost any type of crop and topography (Moshinsky, 1959) as shown in (plate 2.1).

Plate2. 1: Hand-move Sprinkler Lateral in Operation.
(Source : Moshinsky, 1959)

2.6.2 End-Tow Lateral System

The end-tow lateral system in sprinkler irrigation is like a system with hand-move laterals, but the main difference is that it has rigidly connected lateral pipes that are attached to a mainline. This setup makes it easier to move and adjust the irrigation system as a whole, resulting in effective water distribution throughout the field as shown in (plate 2.2).

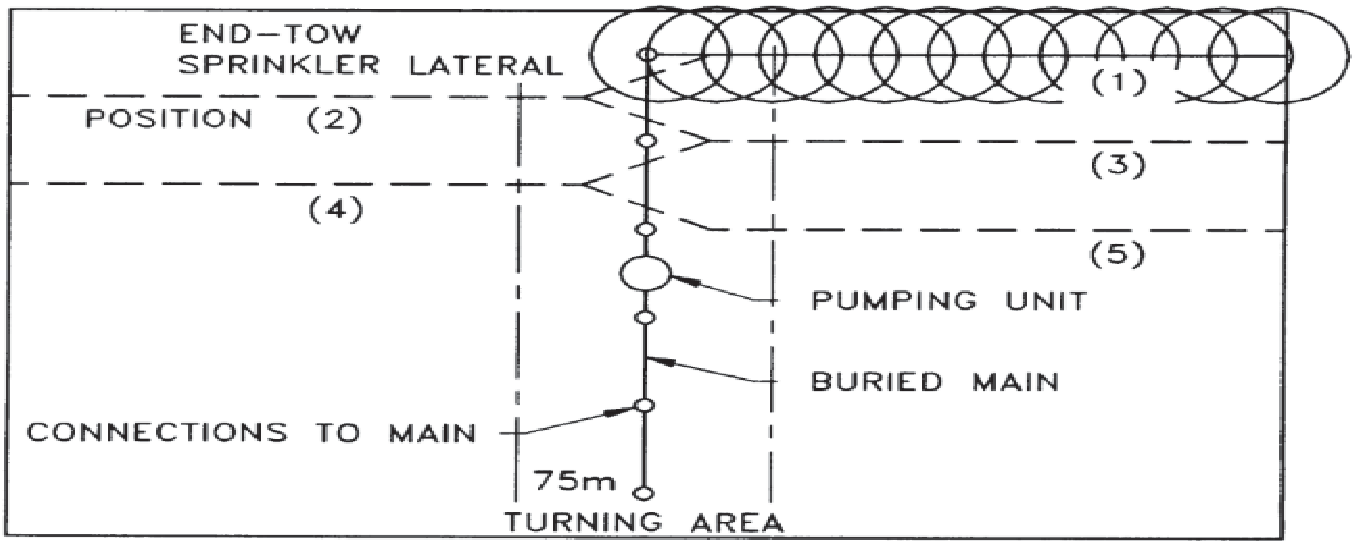

Plate2. 2: Schematic of Move Sequence for End-tow Sprinkler Lateral

(Source: Moshinsky, 1959)

2.6.3 A Side-Roll Lateral System

The side-roll lateral system in sprinkler irrigation is similar to a system using hand-move laterals. In this system, the pipes are connected and supported by large wheels, allowing for easy movement and repositioning of the sprinklers to distribute water effectively (Plate 2.3) (USDA, 2016).

Plate2. 3: Side-roll Sprinkler Lateral (with drag lines, or trail tubes) in Operation
(Source: USDA, 2016)

2.6.4 Side-Move Laterals

The side-move laterals, shown in Plate 2.4, are used in a similar way to side-roll laterals. These laterals are regularly shifted across the field to ensure that water is distributed effectively. The pipes are designed to make it easy to move and reposition the sprinklers for the best irrigation. The pipeline no longer serves as the axle, a significant change being that it is suspended above the wheels on small "A" frames.

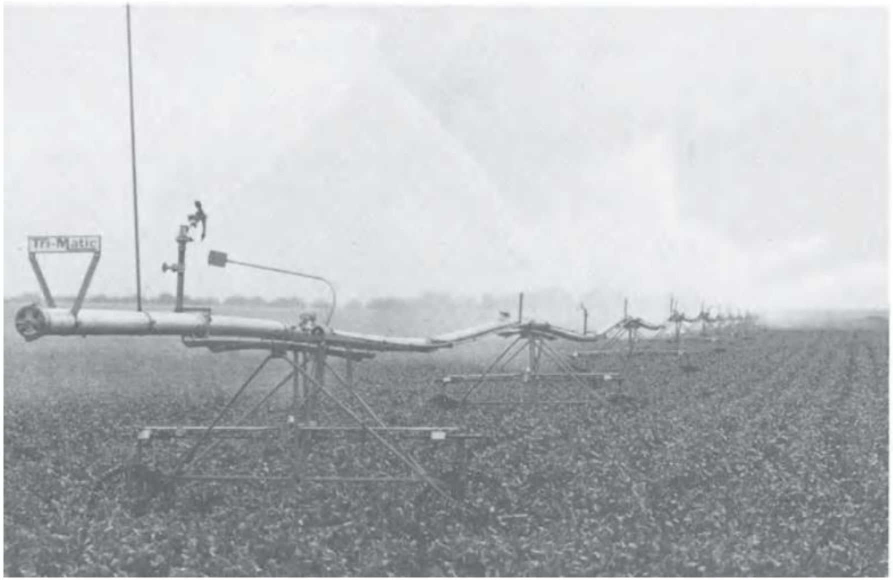

Plate2. 4: Periodic-move Lateral with High Wheel Carriages to Support Gun Sprinklers

(Source: Nelson Irrigation Corp).

2.6.5 Gun and Boom Sprinklers

Rocker arm drives are often used to rotate gun sprinklers, which allow them to be adjusted for partial circle irrigation. Gun sprinklers have nozzles that can spray water up to 16 mm or more, and they are connected to long discharge tubes. In contrast, boom sprinklers have rotating arms of different lengths, ranging from 18 to 36 meters (USDA, 2016) as shown in (plates 2.5 and 2.6).

Plate2. 5: Part-circle Gun Sprinkler with Rocker Arm Drive.
(Source :USDA, 2016)

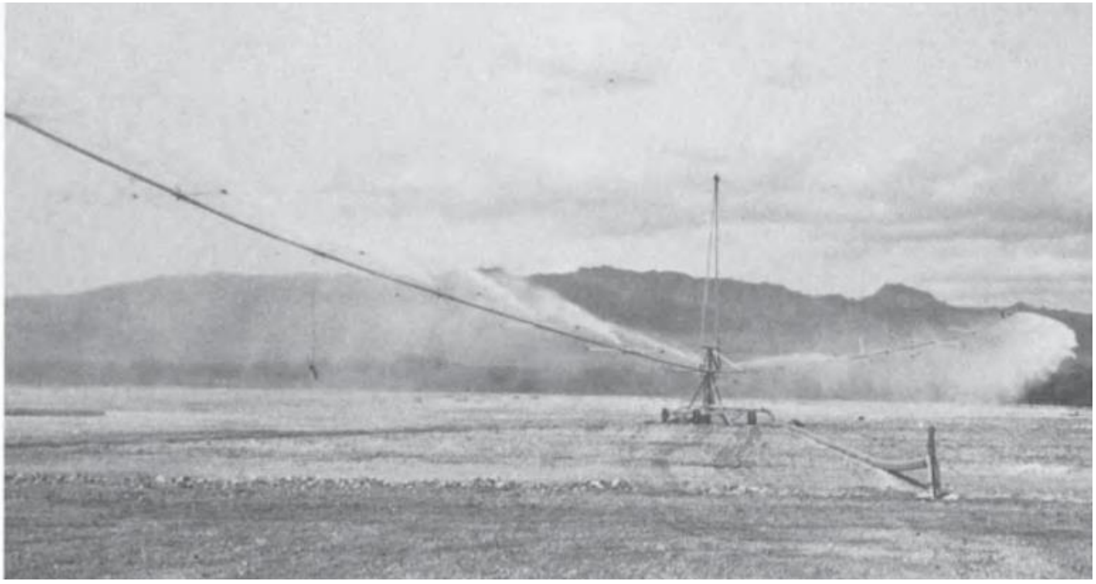

Plate2. 6: Boom Sprinkler in operation.

2.6.6 A Fixed Sprinkler System

A fixed sprinkler system is designed to have enough lateral pipes and sprinkler heads so that they do not need to be moved once they are installed. This setup ensures that all areas that need irrigation can be properly covered without the need for manual repositioning or adjustment of the sprinkler parts (Plate 2.7). The sprinklers or laterals only need to be cycled on and off in order to irrigate the area. There are three major categories of fixed systems: sequencing-valve laterals, buried, or permanent laterals, and portable, solid-set laterals that can be moved by hand (Moshinsky, 1959).

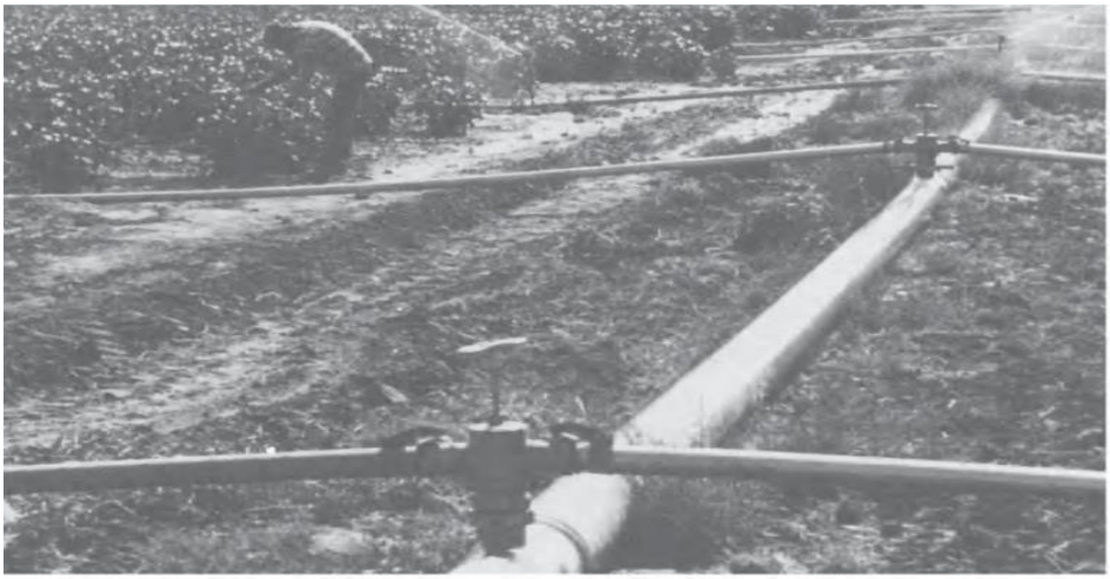

Plate2. 7: **Solid-Set Sprinkler Laterals Connected to Portable Aluminum Mainline.** (Source: Moshinsky, 1959)

2.6.7 Hose-Fed Traveling-Gun Sprinkler

The typical hose used in certain applications is usually 660 feet long (200 m) with a diameter of about 4 inches (100 mm). This design allows the hose to cover distances of up to 1,320 feet (400 m) without needing constant manual monitoring or intervention (Plate 2.8).

Plate2. 8: Hose-fed Traveling-Gun Sprinkler in Operation

(Source: USDA, 2016)

The primary categories of continuous-move systems in irrigation are traveling sprinklers, linear moving laterals, and center-pivot systems. Traveling sprinklers are mobile systems that traverse the field using wheels or tracks. Linear moving laterals involve the linear movement of irrigation equipment throughout the field. Center-pivot systems consist of a central pivot point with rotating sprinkler arms that cover a circular area.

2.6.8 The Traveling Sprinkler

A traveling sprinkler, also called a traveler, is a big sprinkler system that moves on its own and waters in a straight line. It gets water through a flexible hose and is commonly used in American farmland. The most common type of traveler has a gun-style sprinkler that releases water at about 32 L/s. The water for the traveler can come from an open ditch or a high-volume, high-pressure sprinkler called a 'gun' mounted on a trailer (Ali, 2011) (Plate 2.9).

Plate2. 9: Traveling Gun Type Sprinkler Center
(Source : Ali, 2011)

2.6.9 Linear Move Irrigation Systems

Linear move systems are controlled by cables on both ends to guarantee they move in a straight line. The water supply for these systems typically depends on either concrete ditch with lining or movable pipe systems. However, these methods of water supply can be costly and present difficulties in terms of upkeep and operation. They resemble center pivots but move linearly (Waller & Yitayew, 2015b) (Plate 2.10).

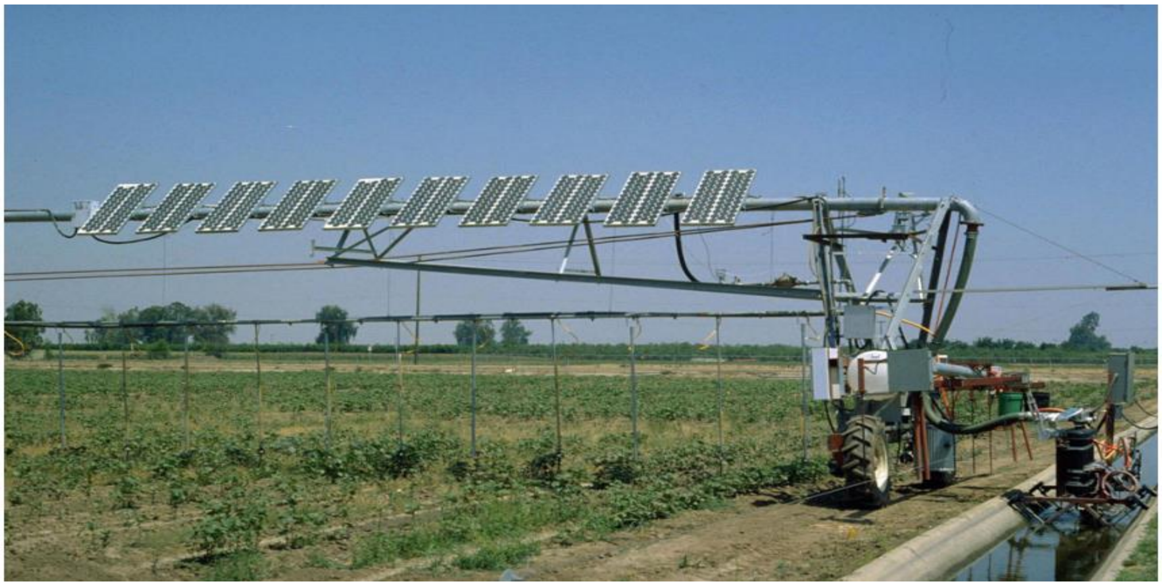

Plate2. 10: Canal Source Linear Move Irrigation System in Use on the Field Colorado

(Source :Waller, 2016)

2.6.10 Center Pivots Irrigation System

The pivot point of a center pivot irrigation system is where the steel pipe and truss structure connect to the water source. These systems use tractor tires powered by electricity to move the structure across the field. Most center pivots are designed to water a quarter of an area, usually around 50 hectares or 160 acres. They work by rotating in a circular motion around a central pivot (Waller, 2016) (Plate 2.11).

Plate2. 11: Center pivot sprinkler system

(Source :Ali, 2011)

2.6.11 Turf Irrigation System

Water plants not intended for commercial sale. As a result, the criteria for managing irrigation on turf vary from those for managing irrigation in agriculture (Waller, 2016).

2.6.12 Hand Lines and Wheel-Line Irrigation System

Hand lines are small aluminum sprinkler pipes that are usually around 2 to 3 inches in diameter. They are used to water an entire area at once during seed germination. The main goal is to distribute water evenly and effectively to the seedbed. Single lines of sprinklers are rotated through the area once or twice per day to irrigate established row crops or pasture while Wheel-line irrigation system: Instead of moving the pipelines by hand once or twice per day, a tiny motor rotates the pipeline and wheel (Waller, 2016).

2.7 Classification of Performance Indicators for Sprinkler Irrigation

ASABE, (1994) summarized and categorized performance indicators for sprinkler irrigation (Table 2.1) into three namely: performance indicators classes, The Christiansen Uniformity Coefficient and Distribution Uniformity are both measures used to assess the uniformity of a distribution.

Table2. 1: Classification of Performance Indicators for Sprinkler Irrigation

Performance indicator class	Christiansen uniformity coefficient (%)	Distribution uniformity coefficient (%)
Excellent	>90	>84
Good	80-90	68-84
Fair	70-80	52-68
Poor	60-70	36-52
Unacceptable	<60	<36

(Source: ASABE, 1994)

2.8 Causes for Sprinkler System Losses and Inefficiencies

Sprinkler systems should be built to distribute water at a rate that is less than the soil's maximal rate of absorption in order to minimize water loss. With less water wasted and more effective irrigation, this method makes sure that the water is absorbed into the soil without leading to excessive run-off (Majumder *et al.*, 2019).

i. irrigation water losses from sprinkler spray, soil surface, and plant leaves that catch spray water owing to direct evaporation in the air

ii. Depending on the temperature, wind speed, and size of the droplets, the wind's or drift's speed is typically between 5 and 10 percent.

iii. The sprinkler pattern's non-uniform application causes deep percolation, surface runoff, and other effects.

iv. Leaks and system drainage are the causes of water waste.

Sprinkler watering systems have a number of problems that lead to inefficiencies, such as leakage, evaporation, wind drift, interception by plants, runoff, and unequal or excessive water application (ALLah, 2015). Lecler, (2004) a list and classification of losses with typical values for spray irrigation (Table 2.2) into three namely: Losses component, Range and Typical values.

Table2. 2: Losses and Their Typical Values in Spray Irrigation

Losses Component	Range	Typical Values
Leaking Pipes	0 – 10%	0 – 1%
Evaporation in the air	0 – 10%	<3%
Wind Drift	0 – 20 %	<5%
Interception	0 – 10 %	<5%
Surface Runoff	0 – 10 %	<2%
Uneven/ excessive application depth and rate	5 – 80 %	5 – 30%

(Source: Lecler, 2004)

2.9 Operation of Center Pivot Irrigation System

A moving pipe network that revolves around a water supply is known as a center pivot irrigation system. Center pivot irrigation systems are the most used sprinkler irrigation systems in the world due to their high efficiency, high uniformity, capacity to irrigate uneven terrain, and low capital, upkeep, and management expenses. In a machine with a center pivot, a lateral revolves around a predetermined pivot point. The lateral is held above the field by a collection of A-frame towers, each of which has two driven wheels at its base. Depending on how the field is set up, the pivot may complete a full circuit or may only make partial circles. Installed sprinklers or sprayers release water under pressure as they move across the field. The consistency of irrigation application at different points along the lateral and as it moves across the field play a role in the overall evenness of water distribution (Kushwaha & Kanojia, 2018).

Evans (1996) stated that a center pivot machine can be used to water any circular area, even if it is not a complete circle, by rotating around a central base pipe in the field. They can occupy 80–90% of a square area. The recommended maximum slope is 15%, although with proper construction, center pivots can operate on very varied terrain with slopes as high as 30%. A service road is often needed for control adjustment and maintenance, as well as for the filling, running, and monitoring of any chemigation supply tanks and injection pumps located at the pivot.

2.10 Water Application patterns for different center pivots types

2. 10.1 High Pressure Impact

Initially, high pressure impact sprinklers were utilized with center pivots, and they were positioned on top of the conduit (Plate 2.12). The sprinklers required 70-110 psi of pressure at the center point to operate, and they were 20–30 feet apart. It was discovered through studies conducted without any covering that they were 60% successful at irrigating (Peters, *et al.,* 2016).

Plate2. 12: Shown High Pressure Impacts

(Source: Peters *et al.*, 2016).

2.10.2 Mid Elevation Spray Application (MESA)

Since the pressure regulators for these sprinklers are usually set at 15-20 psi, the pivot point pressure must be between 35 and 40 psi for appropriate operation. Without a cover, catch can tests normally reveal an irrigation application efficiency of about 85% at a separation of about 10 feet (Peters et al., 2016). According to Chou *et al*. (1988) this type of water application has 1.5 to 2.4 meter above the ground and has Two main factors: large nozzles and high operating pressure which can causes infiltration problems due to soil crusting and run-off (Plate 2.13).

Plate2. 13: Mid Elevation Spray Application (MESA)
(Source: Peters *et al*., 2016).

2.10.3 Low Elevation Spray Application (LESA)

LEPA and LESA are two methods used for precise and efficient application of low-energy and low-elevation sprays. Use 6-10 psi pressure regulators and require much less pressure to function correctly (Plate 2.14). When tested without crop protection and with water droplets spaced no more than 5 feet apart, irrigation efficiency is approximately 97%. The little amount of wet soil, however, may cause problems with water pooling and runoff in specific soil, slope, and surface conditions (Peters et al., 2016).

Plate2. 14: Low Elevation Spray Application

(Source: Peters *et al*., 2016)

2.10.4 Low Energy Precision Application (LEPA)

The LEPA technique is a special version of technology that can be used on both center pivot and linear move systems (Plate 2.15). LEPA uses low pressure bubblers in lieu of sprinklers in "drop" tubes that extend to the soil's surface every few meters. Since the canopy is not wetted, evaporation losses are kept to a minimum when water is applied straight to the furrow. Although the initial capital costs are higher than standard systems, these systems can be very efficient ranging from 95 to 98 % because evaporation losses are minimal soil evaporation is typically less than 2 % with alternate row irrigation, although runoff may be as much as 50 % with poorly designed and operated systems (Evans, 1996).

Plate2. 15: Shown LEPA on a Row Crop Using Drag Socks to Minimize Erosion to the Furrow Dikes that Limit Water Movement in the Furrows.

(Source: Peters *et al.*, 2016)

2.11Various Components of a Center Pivot System

2.11.1The Pivot Lateral

A pipe that has sprinkler apertures makes up a pivot irrigation system. Tower assemblies stabilize and support the system. These towers contain a framework to hold the pipe and motors to make it move. The pivots in modern systems are typically operated by electricity, while some manufacturers also offer oil-hydraulic motors (Eisenhauer *et al.*, 2021).

2.11.2 The Pivot Base or Pivot Point

The center of the area being irrigated is normally where a pivot irrigation system is installed. A mobile or permanent base can be used if the system is smaller and portable between areas. The base's inlet conduit is in charge of bringing pressurized water from a pump that is placed in front of the pivot. After that, the water ascends the base through a rotating elbow to the pivot lateral. Each tower's motors are powered by a slip-ring assembly, which enables the pivot to take energy from the base as it rotates.

2.11.3 A Control Panel

A pivot irrigation system's control panel is typically found on the pivot base, making it simple for the operator to adjust the pivot's rotational speed and keep track of other crucial elements. For the operator to have easy access to the pivot base, a road is frequently required.

2.11.4 A Span

A pivot irrigation system is made up of different parts, including the pivot lateral, truss support structure, sprinkler devices, and towers. The length of each section in the system can vary, usually between 100 and 200 feet. Longer sections can be more cost-effective to install, but the maximum length depends on factors like pipe size and the shape of the land. The length of each section can be adjusted to fit the field's dimensions. In hilly areas, flexible connectors are needed between section (Eisenhauer *et al.*, 2021)

2.11.5 Overhang

An extra pipe, known as an overhang, is commonly attached after the last tower in many pivot irrigation systems. The overhang's length might vary; some systems even employ overhangs as long as 80 feet.

2.11.6 A Special Sprinkler or End Gun

The area that is irrigated can be expanded by attaching it to the edge of the overhang. A portion of the corners not covered by the last spray on the lateral are watered by this sprinkler, which is typically referred to as an end gun. When the water stays within the restricted area, the end gun of the pivot irrigation system is effective.

2.11.7 Booster Pump

It is set up at the final structure to pressurize the end gun. The terminal gun's operation is controlled by a valve (Plate 2.16).

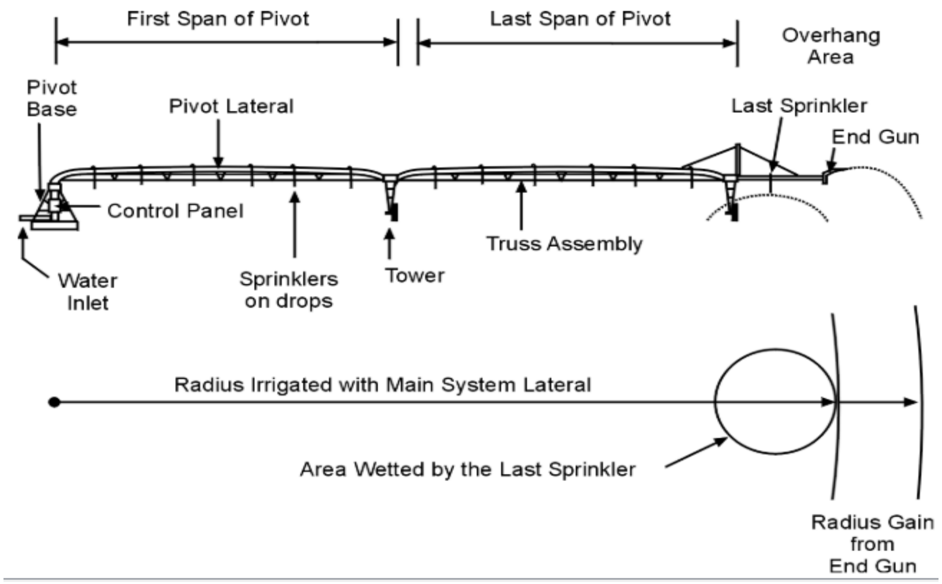

Plate2. 16: Shown Components of a Center-Pivot Sprinkle Irrigation System
(Source : Eisenhauer *et al.*, 2021).

2.12 Advantages of Using Center Pivot Irrigation System

Some of the main advantages of center pivot irrigation systems as mentioned by (Fabiana, 2019) including the following:

i. Utilizing a stable pivot point for water distribution makes things easier

ii. At a following pivot point, direction and alignment are managed.

iii. Under the continuously moving sprinkler, relatively high-water application uniformities are simple to attain

iv. The system is at the beginning point for the subsequent irrigation once one irrigation has been completed.

v. Because it is so simple to apply water correctly and on time, good irrigation management is made possible.

vi. Development of electric load-management schemes is possible due to the flexibility of operation.

vii. Fully automated and managed remotely from a panel at the pivot or another nearby office

viii. Machines are started and stopped using timers, and numerous safety mechanisms are employed for protection.

2.13 Disadvantage of Using Center Pivot Irrigation System

With regard to the use of water, center pivots have the following disadvantages as mentioned (Moshinsky, 1959).

i. In a square field with a pivot point in the middle, irrigation will not reach the corners (above 20 %).

ii. In general, the irrigated circle's outermost edge has a high average application rate. Certain nozzle arrangements in some systems may allow for speeds of beyond 100 mm/h.

iii. Relatively, light and frequent applications must be used on all but sandy soils to reduce or eliminate runoff problems associated with these high application rates. In extra cases to avoid runoff, it may even be necessary to set the travel speed so a center pivot lateral cycles faster than one revolution per day. This increases evaporation losses and center pivot maintenance costs and may decrease crop yield.

iv. The majority of the water must be carried toward the outer end of the lateral since every incremental radius increment irrigates a wide concentric area. As a result, pipe friction losses are comparatively high.

v. The average lateral operating pressure on sloped fields will change dramatically depending on whether the slope is upward or downward. In the absence of sprinklers with pressure- or flow-controlled nozzles, this can cause significant changes in discharge.

vi. Using motors powered from water pressure in the lateral will make the system only move when irrigating.

2.14 Center Pivot System Capacity

2.14.1 Estimation of the System Capacity

System capacity in millimeters per day Divide the amount of crop that the CP and LM installation will cover in any given crop season by the amount of water that is pumped by the system (Zybach, 2008).

$$\text{System capacity} = \frac{\textbf{volume applied in liter per day}}{\textbf{Area irrigated in } \mathbf{m^2} \textbf{ /day}} \text{.................................Equation2. 1}$$

2.14.2 Estimation of Water Applied into the Crop Roots Zone

According to Zybach (2008) Calculations will be done to determine the amount in mm that the machine will typically apply into the crop root zone each day.

$$\text{Avearge amount applied} = \frac{\text{volume applied}\left(\frac{\text{liter}}{\text{day}}\right) * \text{Pumping utilization ratio} * \text{application effeciency}}{\text{Area irrigated in m}^2} \text{...........Equation2. 2}$$

2.14.3 Sprinkler Discharge

The sprinkler or nozzle discharge necessary at any outlet along a center pivot lateral (USDA, 2016) can be calculated by:

$$qr = rS_r\left(\frac{2Q}{R^2}\right) \text{..Equation2. 3}$$

Where

qr is sprinkler discharge required at r, gal/m or l/ sec

r is radius from pivot to outlet under study, ft. or m

Sr is sprinkler spacing at r, which is equal to half the distance to the next upstream sprinkler plus half the distance to the next downstream sprinkler, ft. or m

Q is system capacity, gpm or l/sec

R is maximum radius effectively irrigated by the center pivot, ft. or m

2.14.4 The Distance Traveled by the System

The distance traveled by each sprinkler along a center pivot lateral is equal to

$W = 2\pi r$……………………………………………………………Equation2. 4

Where

W= wetted diameter or width

r is equal to the application rate times the opportunity time, and application depth equals the radial distance of the sprinkler (or spray nozzle) from the pivot point. (i.e., mm/min multiplied by minutes = mm)(USDA, 2016)

2.14.5 Speed of System

Knowing the distance and rotational time of the center pivot allows one to calculate the system's speed r:

$\text{Speed}_r = \frac{2\pi r \text{ or} W}{60\, t_{ratation}}$………………………………………………………Equation2. 5

Where,

$\mathbf{t_{ratation}}$Istime required for one rotation of the center pivot system, h

rIsradius from the center pivot to point r, ft or m

2.14.6 The Discharge of an End Gun

A base circle can be used to estimate the motion of an end gun, corner system, or both by (USDA, 2016)

$Qg = 1.1\left(\frac{R^2}{L^2}\right)Q_b$……………………………………………………Equation2. 6

Where,

Qg= required discharge from the end gun or fully extended corner system, gpm or l/sec

R = radius of area sufficiently irrigated when end gun (and/or comer system) is in operation, ft. or m

L = length of lateral or radius irrigated in the basic circle when the end gun (and corner system) is not operating, ft. or m

Qb= design discharge for the base circle having radius L, gal/m or l/sec

2.15 Center Pivot Irrigation System Performance

The outer structure moves at half its maximum speed when the setting is 50%, while the machine moves at its maximum speed (lowest rotation time) when the setting is 100%. The speed at which a center pivot irrigation system rotates determines how much water is applied. The alignment system ensures that each tower tries to stay in line with the end tower, following certain rules. However, the towers can start and stop moving randomly, with intervals of one to three minutes. Due to the on-off movement, the uniformity coefficients are highest near the pivot and end tower, but lowest towards the center of the irrigation system (Evans, 1996). and Funakawa et *al.*(2012) suggested that the consistency of water distribution across a field, known as irrigation uniformity, is a crucial factor in irrigation management. Due to excessive nutrient leaching or plant water stress, uneven irrigation water distribution may result in over- or under-irrigated areas, which can reduce output.

2.15.1 Coefficient of Uniformity (Cu)

The Christiansen coefficient of uniformity (CU) is a commonly used measure to evaluate how evenly sprinklers water an area. It is expressed as a percentage and takes into account that sprinklers farther from the center of a pivot cover more land than those closer to it. A CU rating of 90% to 95% is considered excellent, but it requires regular upkeep. 85 % to 90 % is regarded as good and wouldn't require significant adjustments; routine maintenance and inspection are needed. The system needs to be inspected and the sprinkler kit checked in 80 %–85 % of cases. If the system's efficiency is 80 % or lower, the sprinkler package needs to be adjusted, the sprinkler pressure changed, and complete system maintenance is needed. (Islam *et al., 2017)*: The Heermann and Hein modified formula is used to compute the center pivot coefficient of uniformity (ASAE S436.1, 2003).

$$CUH = 100\left[1 - \frac{\sum_{i=1}^{n} si|vi-\overline{vp}|}{\sum_{i=1}^{n} visi}\right] \qquad \text{......Equation2. 7}$$

Where:

$CUH =$ The Heermannand Hein uniformity coefficient

$n =$The number of collectors used in the data analysis

$i =$ A number assigned to identify a particular collector beginning with $i = 1$ for the collector located nearest the pivot point and ending with$i = n$ for the most remote collector from the pivot point.

$vi =$ The volume (or alternately the mass or depth) of water collected in the i^{th} collector

$Si =$ The distance of the i^{th} collector from the pivot point

$\bar{V}$ = The weighted average of the volume of water caught.

It is computed as$\bar{\mathbf{v}}$p= $\frac{\sum_{i=1}^{n} ViSi}{\sum_{i=1}^{n} Si}$……………………………………Equation2. 8

2.15.2 Distribution Uniformity (Du)

DU examines the data from the catch cans as a whole and the lowest fourth of the water depth that was captured. As a gauge for the severity of the dispersal issues, DU is helpful. Divided by the average of all samples, the weighted average of the lowest quarter of samples is used to determine DU. An excellent DU is one of 85 % or higher, a very good one of 80%, a good one of 75 %, a middling one of 70 %, and a poor one of 65 % or less. The calculation of distribution uniformity involves dividing the average amount of water collected in the lowest 25% of cans by the average depth of water collected across all the cans (Moshinsky, 1959).

DU (%)= $\frac{\text{Average of the lowest quater of sample}}{\text{Average of all sample}} \times 100$…………………Equation2. 9

2.15.3 Application Efficiency (AE)

is established as the ratio of the water applied to the water leaving the sprinkler emitter, according to equation described by (Elhaj *et al.*, 2022).

$\mathbf{AE\% = 100\left[\frac{M \times Ap}{Vs}\right]}$………………………………………………….Equation2. 10

Where:

$A_p$is plot area (m²)

M is average applied depth (mm)

V_sIs volume exiting from sprinkler during CU test (m³)

2.15.4 Irrigation Efficiency (E %)

Irrigation efficiencies of center pivot irrigation system is calculated using the application efficiency and distribution uniformity (Majumder *et al.*, 2019) By the following formula:

Irrigation Efficiency (E%) = $\boldsymbol{E_a} \times$ DU……………………..…………Equation2. 11

2.15.5 Scheduling Coefficient (S_C%)

The scheduling coefficient is used to find the area in an irrigation zone that receives the least amount of water. This area is determined by dividing the area with the lowest water application by the average water application across the entire irrigation zone (Islam *et al.*, 2017).

$S_C(\%) = \frac{1}{\mathrm{DU}}$…………………………………………………………..Equation2. 12

Where:

$(S_C\%)$ = scheduling coefficient.

DU = uniformity of distribution (in decimal)

This technique allows for precise observation of the water distribution map and the location of the field that gets the smallest amount of water. The $(S_C\%)$ measurement helps with planning irrigation and deciding how much extra water is needed for the field area that receives the least amount of water. The $(S_C\%)$ coefficient is useful for choosing the best solutions, like sprinklers or spacing, which may be better than just looking at CU values. The $(S_C\%)$ measurement is widely regarded as the best, but it can be difficult to measure in the field. One important difference between DU and $(S_C\%)$ is that $(S_C\%)$ considers the surrounding area. This area is typically defined as 1%, 2%, or 5% of the total irrigated area (Islam *et al.*, 2017).

2.16 Field Evaluation of Center Pivot Sprinkler System

To ensure that water is distributed evenly and flows properly, it is advised to regularly evaluate the performance of a center-pivot system. The efficient functioning of sprinkler irrigation systems depends on accurately determining when and how much water should be applied. Understanding how efficiently water is used in the field is important for managing irrigation effectively. It is recommended to regularly assess the field to monitor and evaluate the performance of the irrigation system, as it can change over time (USDA, 2016).

2.16.1 Information Required for Field Evaluation of Center Pivot System

Modern center-pivot systems are typically powered by electric motors or hydraulic drives. The use of water or compressed air for lateral movement is not as common anymore. If water is used for propulsion, it should be considered as part of the total water applied, which may slightly impact the calculated water use efficiency. Most modern center pivots use electric motors for the drive towers, but these systems may have reduced distribution uniformity due to the start-stop action of the drives. Oil-driven systems have more continuous operation. These factors should be considered when planning layout and conducting field tests for distribution uniformity (USDA, 2016).

2.16.2 Catch Can Test and Procedure Required for Field Evaluation of System

The process of evaluating different types of sprinkler systems is the same, The effectiveness and fitness of an irrigation system can be evaluated using a catch can test. The test findings are crucial for evaluating the effectiveness of the center pivot irrigation system. The Plate 2.17 shows the layout of the collectors used to calculate the water distribution (ASAE S436.1, 2003).

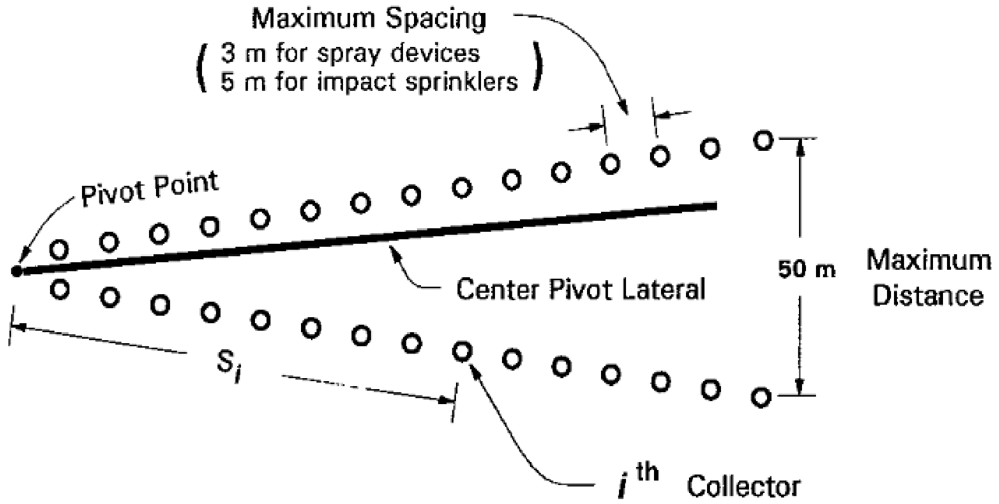

Plate2. 17: Shown Collector Layout for Determining the Water Distribution of Center Pivot Irrigation Machines

(Source: ASAE S436.1, 2003).

In order to prevent water splashing in or out, all collectors used in the test to determine the depth of water applied must be identical. The collector's mouth must be straight and devoid of depressions. The collectors must be at least 120 millimeters tall. The collector's entrance diameter must be at least 60 millimeters and no less than half to one time its height. To deflect solar energy and reduce evaporation, the collector should be painted a light color

When wind speeds surpass 1 m/s, this test procedure's accuracy declines. This test might not be a reliable indicator of the sprinkler package's efficacy or uniformity if the wind speed is greater than 5 m/s. Wind speeds during this test exceeded the criteria ASAE436 should be clearly labeled on any findings obtained when wind speeds exceed 5 m/s. The placement of the collectors must prevent obstacles like the crop canopy from interfering with the measurement of water application. When the obstruction is higher than the elevation of the collector but lower than the nozzle height, at least twice the space between the obstruction's height and the top of the collector must be kept clear on both sides of the collection row (ASAE S436.1, 2003).

2.16.3 Main Component that Affect Uniformity of System

Table2. 3: Shown Main Component Affecting Uniformity of Center Pivot

Component of uniformity	factor creating non-uniformity
flow rates of sprinklers (spray heads) are not proportionate to the area served	inadequate sprinkler control, nozzle plugging, pressure regulator variations, pressure elevation changes, and wear
Non-uniformity in sprinkler overlaps between nearby sprinklers	Variations in wind, the system's travel speed, the sprinkler's elevation (or "spray head"), the crop interface, worn spray plates, and spacing
border impact	alterations in wind direction, soil type, distance from the pivot point, surface conditions (surface ponding, residues), and topographic alterations to the nozzle angles.
Effects of radial arc	failure to properly manage flow rates along the pivot length while activating end guns and corner swing lateral sections or towers
Variation in system flow	Engine performance, pump response to various pressure requirements, and source pressure changes.

(Source : Griffiths, 2006)

Griffiths, (2006) Summarized and Categorized component affecting uniformity of center pivot (Table2. 3) into two namely: uniformity component and factor causing non uniformity

2.17 Soil Moisture Characteristic Measurement

2.17.1 Measurement of Soil Moisture.

The simplest way to test soil moisture is to weigh the moist soil, put it in an oven set at 105° C until all moisture has been driven off, which can be seen by the fact that the weight has not decreased further with more time in the oven, and then weigh the oven-dry soil. The typical way to express soil moisture content is as a percentage on a dry basis (Frevert, 1955).

$\theta = \frac{Ww-Wd}{Wd} \times \frac{\rho b}{\rho w}$..Equation2. 13

Where, θ is the soil water content (cm^3/cm^3),

w_wIs the weight of the soil sample at wet or field condition (g),

dw_d is the weight of the soil sample after drying (g),

ρb is dry bulk density of soil (g/cm^3)

ρ_w is the density of water (1.0 g/cm^3)

Knowing the soil's bulk density is essential in order to use this technique. The size and quantity of samples have an impact on the outcome (Abubaker Jamal, 2001).

(USA soil texture categorization) Typical soil water properties for various soil types in Table 2.4

Table2. 4: Typical soil characteristic for different soil type

Type of soil (US classification of soil texture))	Soil water Characteristics		
	Q_{FC} (m^3/m3)	Q_{PWP} (m^3/m^3)	Q_{FC}–Q_{PWP}(m^3/m^3)
Sand	0.07 – 0.17	0.02 – 0.07	0.05 – 0.11
Loamy Sand	0.11 – 0.19	0.03 – 0.10	0.06 – 0.12
Sand Loamy	0.18 – 0.28	0.06 – 0.16	0.11 – 0.15
Loam	0.20 – 0.30	0.07 – 0.17	0.13 – 0.18
Silt Loamy	0.22 – 0.36	0. 09 – 0.21	0.13 – 0. 19
Silt	0.28 –0. 36	0. 12 – 0.22	0.16 – 0.20
Silt Clay Loamy	0.30 – 0.37	0.17 – 0.24	0. 13 – 0.18
Silt Clay	0.30 – 0.42	0.17 – 0.29	0.13 – 0.19
Clay	0.32 – 0.40	0.20 - 0.24	0.12 – 0.20

(Source :Anderson and French, 2019)

Anderson and French (2019) summarized and categorized soil moisture characteristic in m^3/m^3 of soil at field capacity (Q_{FC}), permanent wilting point (Q_{PWP}) and Soil available water content ($Q_{FC-}Q_{PWP}$) (Table2. 4)

2.17.2 Field Capacity (Fc %)

Field capacity is the amount of water left in the soil after excess water has drained, while available water is the maximum amount of water a crop can take from the soil. The term "soil moisture reservoir" refers to the water within the crop's root zone. Unfortunately, the crop can only access a small portion of the pond without experiencing water stress. To calculate water holding capacity, the sort of soil is crucial (mm of water available to plant) When water is applied in excess of a field's capacity, runoff occurs and the earth becomes saturated. It is more probable that the water that seeped in will be lost to deep percolation. Plant stress will come from applying too little water. The scheduling of irrigation can be used to monitor the moisture content of the soil (Abubaker Jamal, 2001).

2.17.3 Permanent Wilting Point (PWP %)

At 15 atmospheres, the plant begins to wilt. Because the soil's moisture potential at this level equals that of the plant roots' capacity to absorb moisture, the plant cannot access the soil's moisture. When root zone moisture reaches the wilting point, plants will become permanently wilted. 20,000 atmospheres of moisture can be found in oven-dry soil (Frevert, 1955).

2.17.4 Available Water Capacity

The available water capacity of soil is the difference between field capacity and the permanent wilting point. This capacity is measured as a percentage of the soil volume (Chou *et al.*, 1988).

$\mathrm{AWC} = \mathrm{FC} - \mathrm{PWP}$……………………………………………………Equation2. 14

AWC is an acronym for available water capacity, fraction or percentage.

2.17.6 Particle Size Distribution of Soil

A Particle Size Distribution Analysis (PSD) provides information about the size and types of soil particles found in a particular soil. For center pivot irrigation, it is recommended to avoid soils with a water infiltration rate greater than 0.3 inch per hour. Soils with infiltration rates between 0.3 and 0.6 inch per hour require careful planning and management, while soils with infiltration rates below 0.5 inch per hour are ideal for center pivot irrigation (USDA, 2016). Figure 2.1 shows soil particle size distribution in textural triangle.

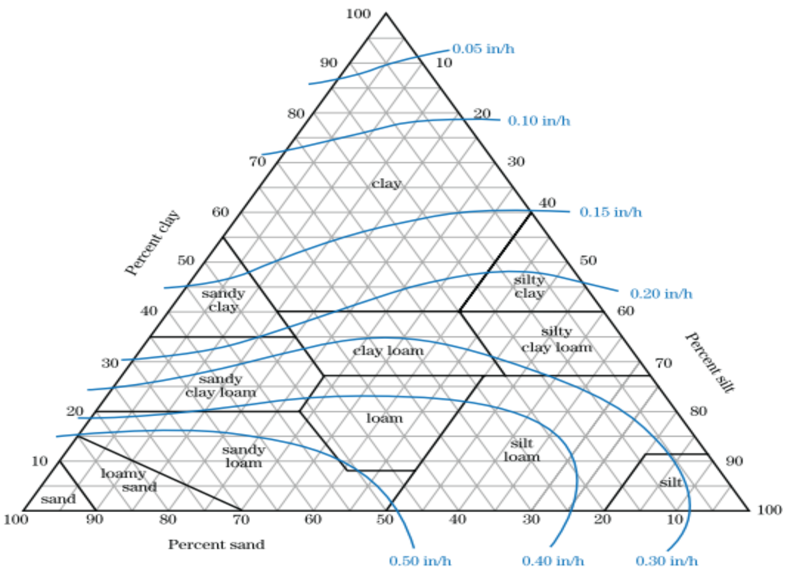

Plate2. 18: Shown Soil Triangle Showing Proportions of Sand, Silt, and Clay for Different Soil Textures, and Approximate Infiltration Rate Contours in in/h

(Source: USDA, 2016)

2.18 Characteristics and Design Criteria of Center Pivot System

The main goal of creating a sprinkler irrigation system is to maximize efficiency while reducing costs. When designing the system, various factors such as crop water needs, soil properties, landscape, water source availability and quality, required water amount, labor requirements, financial considerations, and potential for future system growth are taken into account (Brier and lia dwi jayanti, 2020). The components that distribute water from the center pivot system to the field are often called the sprinkler package, even though they may not look like traditional sprinkler devices. These packages can include impact sprinklers, fixed plate spray nozzles, moving plate spray nozzles, drag hoses, and drip tubes. The wetted diameter of a nozzle indicates how much area it covers. When creating sprinklers or water delivery systems, several factors must be considered to ensure the system works effectively:

2.18.1 Application Rate

The application rate is the amount of water applied to a specific area over a certain time period. It is best if the application rate matches the rate at which the soil can absorb water. As the distance from the center of irrigation increases and more area is covered, the application rate for different nozzles needs to be higher. This is why run-off problems usually occur at the outer edges of a center pivot, unless there are limitations in the inner part of the system due to soil or slope conditions (Rogers & Lamm, 2017).

2.18.2 Depth of Application

To maintain efficient irrigation, it is crucial to avoid using more water than the root zone can hold. If excess water is applied, it can penetrate too deeply and be lost, reducing the effectiveness of irrigation (Rogers & Lamm, 2017).

2.18.3 System Irrigation Capacity

System irrigation capacity refers to the amount of water that would be applied to the entire field if it was irrigated in a single day. A typical management strategy for center pivots is to provide

0.70 to 1.25 inches (SI unit) of water at each irrigation, which results in irrigation every three to four days when evapotranspiration is at its highest. Center pivots have become more and more popular, due to their high water efficiency rate ranging from 85 to 95 % is feasible (Derbala, 2003).

2.18.4 Uniformity of Application

Designing sprinkler irrigation systems that achieve uniform water application is vital. Uneven watering can lead to both under-watered and over-watered areas, causing reduced crop yield and decreased system efficiency. The uniformity of the sprinkler design is influenced by factors such as system package design, operating conditions, and environmental factors, with wind playing a significant role (Rogers & Lamm, 2017).

2.19 Estimation of Water Losses Percentage of Center Pivot System

Water losses from center pivot nozzle package spray heads at the top of the canopy are usually between 0-2% due to droplet evaporation, while wind drift is typically less than 5%. Evaporation from the crop canopy ranges from 4-8%, soil evaporation is less than 2%, and runoff can range from 0-15% depending on slope and soil conditions. However, spray heads mounted on top of the pipe lateral may experience higher losses of up to 15% due to droplet evaporation and wind drift. Evaporation can slightly compensate for the amount of water used by crops, but it is hard to accurately measure and is typically less than 15% of the total evapotranspiration. When using spray irrigation on crops with a full canopy, it is possible to achieve application efficiencies of around 90-92% without any runoff. However, sprinklers placed on top of the pipe may have efficiencies ranging from 80-85% (Evans, 1996). Water loss from a center pivot irrigation system can be calculated by comparing the average depth of water collected in catch cans on the ground to the average depth of water applied as measured by the system flow meter. The difference between these two measurements gives the amount of water lost (Saeed *et al*., 2018).

$$\text{Average depth of application} = \frac{\text{volume of water applied in meter cube}}{\text{irrigated area in meter square}} \ldots\ldots\ldots\ldots \ldots\ldots \text{Equation2. 15}$$

Water loss = Average depth of application – Average depth in catch cans

$$\text{Percentage of water loss (\%)} = \frac{\text{Water loss}}{\text{Avearage depth of aplication}} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\text{Equation2. 16}$$

Water that cannot reach or stay in the root zone of a plant and be used by the crop is considered lost and inaccessible to the plant (Rogers & Lamm, 2017).

2.19.1 Water losses of any irrigation system

1.19.1.1 Air Loss

The loss of water in the air can be attributed to two factors: droplet evaporation and drift. Droplet evaporation happens when water evaporates from droplets while they are in motion, before reaching the crop or soil. Drift occurs when water droplets are carried by wind and end up in unintended areas. This uneven distribution of water can cause some areas to receive less water than needed, potentially stressing the crops. Farmers can reduce water losses by using larger droplets and placing the discharge point closer to the crops. The term "evaporation" is often used by farmers to refer to both droplet evaporation and drift, as they are worried about water loss through the air. However, it is important to understand that in well-designed and properly operated irrigation systems, air losses are not a significant source of water loss compared to other factors (Rogers & Lamm, 2017).

2. 19.1.2 Foliage Loss

After water enters the crop canopy, it can be lost through plant interception and evaporation. Plant interception is when water is captured and evaporates from the surfaces of plants. Foliage evaporation refers to water evaporating from the leaves during irrigation. To reduce water losses within the canopy, discharge points have been moved closer to the ground. This change helps prevent excessive wetting of the crop canopy and reduces the time needed for irrigation at specific locations (Rogers & Lamm, 2017).

2.19.1.3. Ground Loss

Water can be lost after it reaches the ground in different ways. If the rate at which water is applied is too high for the soil to absorb, it can either collect on the surface or flow across it, causing runoff. This runoff can either leave the area or spread within it. This movement of water within the area leads to uneven distribution and decreases the effectiveness of irrigation. If the soil that receives the runoff is already saturated, the excess water can seep into the ground and go deep, resulting in water loss through deep percolation (Rogers & Lamm, 2017).

2.19.1.4. Deep Percolation Loss

Deep percolation loss occurs when water infiltrates the soil beyond what the roots can absorb. It is important to use appropriate irrigation scheduling methods, such as those based on climate or soil, to reduce these losses. By combining these approaches, it is possible to evaluate and manage irrigation schedules more effectively and minimize deep percolation loss (Rogers & Lamm, 2017). Figure 2.2 illustrate how water is lost from any irrigation system

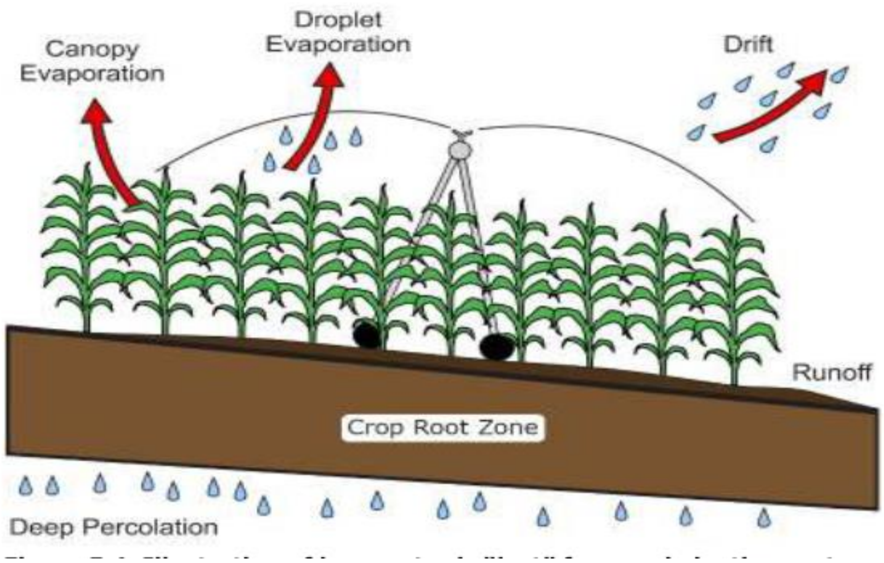

Plate2. 19: Illustration of how Water is Lost from any Irrigation System (Source: ASABE, 2021)

2.20 Pump and Pumping

The pressures and flow rates at which irrigation systems are to operate are predetermined. In order to create enough pressure and bring water from a reservoir or well, pumping is often required. Centrifugal force is a typical method for converting mechanical energy into hydraulic energy in irrigation pumps that pressurize and lift water. This group includes vertical turbine or submersible pumps as well as horizontal centrifugal pumps. Horizontal centrifugal pumps are commonly used when pumping water from an open source or when increasing pressure in an irrigation system. Similar to a submersible pump, a vertical turbine pump has a vertical axle and its power supply is above ground. In contrast, a vertical turbine pump uses an electric motor that is submerged beneath the pump. The most popular pumps for irrigation wells are vertical turbine and submersible pumps (Eisenhauer *et al.,* 2021).

2.20.1 Centrifugal Pump

This passage explains that centrifugal pumps, which are commonly used for irrigation, work by using centrifugal force to expel water. When water enters the pump, it strikes an impeller (similar to a propeller but somewhat different), which gives the water circular motion and makes it spin. The spinning motion created by centrifugal force causes the water to move through the pump and out towards the walls of the pump. The water accelerates during this process, and when it leaves the pump, the speed and pressure are combined. Centrifugal pumps can have multiple stages, with each stage having an impeller and casing. The water is passed from one impeller to the next, gradually increasing pressure. Every impeller/casing combination is referred to as a "stage." Centrifugal pumps are used almost exclusively for turf watering (Ali, 2011).

2.20.2 Total Head of Centrifugal Pump

Combined dynamic suction and discharge heads make the total dynamic head. To ensure effective operation, a pump must be able to withstand the combined pressure from various factors such as suction head, delivery head, velocity head, friction head, and formation loss. By taking these factors into account, the total pressure requirement for the pump can be calculated (Ali, 2011).

That is,

$$HT = DH + SH + VH + FH + FL \qquad \text{Equation2. 17}$$

Where,

DH = delivery head or discharge head (m)

SH = suction head or lift (m)

VH = velocity head (due to velocity of discharging water)

FH = friction losses in the suction pipe and delivery pipe (m)

FL = formation loss (m)

2.20.3 Pump Efficiency

The efficiency of a pump is a measurement of how well it converts the power supplied to it into usable power. It takes into account both the hydraulic and mechanical performance of the pump. Essentially, it determines how effectively the pump converts input power into useful output power.

$EE = \frac{WHP}{BHP} * 100\%$...Equation2. 18.

E = pump efficiency

WHP =Water horsepower

BHP = Brake horsepower

The efficiency range to be expected varies with the pump size, type, and design. However, it is normally between 70 and 80 %

2.20.4 Pumping Energy

Pumping energy refers to the energy transferred to liquid by a running pump. The pump work or energy added to the liquid is determined by the difference in energies between the point where the liquid exits the pump and enters the impeller's eye. The energy in the pumping system is determined at any given position using a random or specified datum. A liquid that cannot be compressed, such as water, is one that can be moved by energy in the form of pressure, elevation, or velocity. Therefore, it is straightforward to describe energy as the pressure or force generated per unit weight of a liquid (GÜlich, 2019).

Bernoulli's theorem states that the energy relative to the datum at any point in the system can be written as:

$$H = \frac{V^2}{2g} + \frac{P}{\rho} + z \quad \text{.......Equation2. 19}$$

Where,

H= the head or Total energy (m)

$\frac{V^2}{2g}$ = velocity head (m)

$\frac{P}{\rho}$ = pressure head (m)

And Z is the elevation or potential head (m)

ρ = the liquid to be pumped unit weight

This energy generated by the pump represents the work done on the liquid, which may include an increase in the fluid's velocity (Hv), pressure (Hp), or elevation (He).

As a result, the pump's total energy or total head (H) may be expressed as (GÜlich, 2019).

$$H = H_e + H_p + H_v \quad \text{.......Equation2. 20}$$

2.20.5 Solar Driven Center Pivot

Center pivots have traditionally been used for extensive irrigation systems. Solar pumps provide water to center pivots in a new construction. Even if the water is being delivered by solar energy, the majority of present systems still require an external energy source for their operation, control, and motor components (Dawson *et al.*, 1979).

CHAPTER THREE: MATERIAL AND METHODS

This chapter focuses on the materials and methods that were employed in the study, in order to get some reliable data and information and it deals with some information about area of the study like geographical description, climate and soils and other relevant points on site are given in this chapter.

3.1 Description of the Study Area

The study took place in Mamprugu Moagduri District, which is one of the many districts in Ghana and is located in the North East Region. The district has a land area of 2,150 square kilometers and its capital is Yagaba. It is located at longitude 0°35′ and 1°45′ W and latitude of 9°55′ and 10°35′N. The district is situated 4 km to the west of Integrated Water and Agriculture Development (IWAD), which is a large-scale irrigation initiative in northern Ghana.

IWAD has 18,000 cubic meter capacity reservoir, the distribution pumps, pump control unit and the IWAD Solar hybrid installation. The Sisili-kulpawn irrigation scheme (SKIS) installed four center pivot irrigation systems. These systems use solar pumps to draw water from the Sisili-Kulpawn river. The water is stored in a reservoir that has the capacity to irrigate 400 hectares of land. Out of the total land area, 250 hectares are dedicated to a nucleus/demonstration farm, while the remaining 150 hectares are allocated for smallholder irrigation farmers. Figure 3.1 depict the map of the study area.

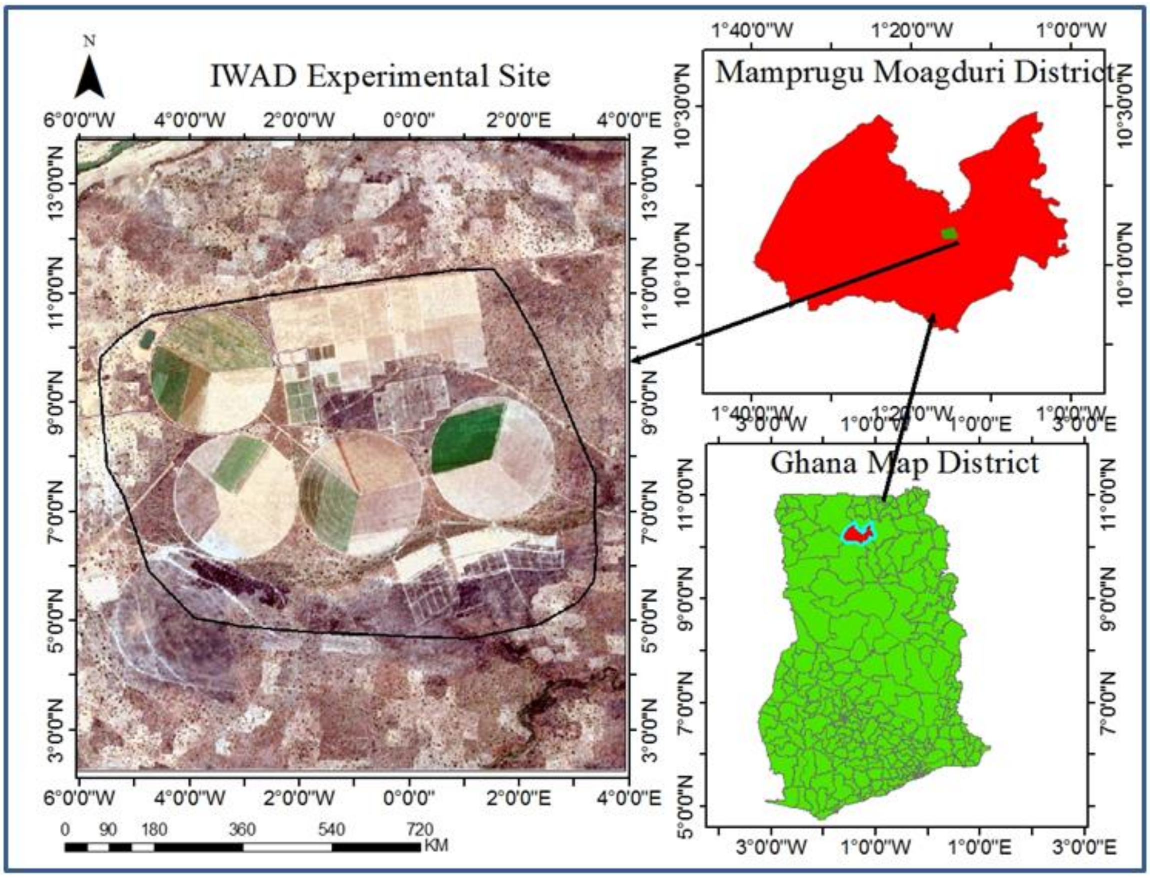

Figure3. 1: Maps of Ghana Showing Mamprugu Moagduri District, and the Experimental Site

(Source: Authors work, 2023)

As stated by IWAD (2016) The Sisili-Kulpawn irrigation scheme in Northern Ghana faces challenges due to difficult agro-ecological conditions, including flooding, drought, poor soils, and unpredictable rainfall, worsened by climate change. The scheme utilizes the Sisili and Kulpawn Rivers, which are tributaries of the Volta River. The Sisili River originates in Burkina Faso and flows into the Kulpawn River after 300 kilometers. The Kulpawn River originates in Ghana near the border with Burkina Faso and has a length of 290 kilometers until it meets the Sisili River. The Kulpawn catchment covers 11,737 km^2 before it joins the Sisili River, and an additional 625 km^2 after it joins the White Volta River (Gross & Pennink, 2018) (IWAD, 2016). The climate in this area is a tropical Savannah, with a dry season from November to April where temperatures can reach 30 to 40°C. The rainy season occurs from May to October. The average rainfall per year is about 1,000 to 1,200 mm. In November and December, desert Harmattan winds blow from the north, causing cooler nights and less humidity during the day. The region has fertile land and abundant sunlight, making it suitable for growing various crops, depending on the availability of water. Climate change is affecting agricultural production in different ways around the world, depending on the agro ecology and farming system. In particular, Farmers in the North East Region of Ghana are experiencing the negative effects of severe weather conditions, such as floods and droughts, leading to decreased soil quality and lower crop production. If the farmers don't adapt any measures to improved agricultural productivity, their yields will drop significantly (Gross & Pennink, 2018). Table 3.1 presents the Sisili-Kulpawn Irrigation project PPP structure

Table3. 1: **Sisili-Kulpawn Irrigation Project PPP Structure**

Partner	Sector	Strategic Role
Wienco Ghana Ltd	Private	Coordinator
Integrated Water and Agricultural Development(IWAD)	Private	Coordinator and Implementation
Savannah Accelerated Development Authority (SAD)	Public	Governmental representation, facilitation of processes
Wageningen University and Research centre –Alterra	Research	Capacity building ,training and research ,knowledge development
Rebel Group International BV	Private	Transaction advice and scaling up of the project

(Source: Gross & Pennink, 2018)

Gross & Pennink (2018) reported that Public Private Partnership (PPP) in Sisili-Kulpawn Irrigation Scheme was summarized and categorized (Table 3.1) into three namely: Partner, Sector and their Strategic Roles.

3.2. Materials

Materials used to carry out this study were: 84 catch cans (12 cm height and 8 cm width), stop watch, graduated measuring tape (50 m), Record book, pen and calculator, Digital camera, Ghana Post GPS device, syringe 10 ml, two graduated Measuring cylinder (50 ml and 100 ml), sensitive balance, polyethylene bags, electrical oven at 105 ℃, soil auger, mini disk infiltrometer, project agronomist record and farmer information or design specification.

3.3 Observation and Measurement

The physical structures, including the water source control, pump, flow meter, and sprinkler system, were observed and found to be in good condition. This included the control panel, reservoir, pumping house, pivot center, drive unit or towers, main line pipe, operating sprinklers, and electric motors of the center pivots. Various measurements were taken, including soil sampling and measuring the discharge rates of sprinklers. The operating pressures were kept consistent at different speeds of travel (100%, 80%, 60%, and 40%), and data on water output was collected by using catch cans on one of the pivots.

3.4 The Center Pivot System Features

The Sisili-Kulpawn irrigation project, managed by Integrated Water and Agriculture Development, utilizes a center pivot irrigation system with four Reinke pivots; the main characteristic of the center pivot sprinkler irrigation system utilized in this plan is comprised of:

3.4.1 Power Source and Pumping Plant

A Volvo Pentad internal combustion engine with 150 horsepower was used to operate a pump that supplied water from the Sisili-Kulpawn river to the system. Simultaneously, the engine also powered an electrical generator with a capacity of 150 kilowatts, providing the necessary electrical power for the system's operation (Plate 3.2 and 3.3)

3.4.2 Pivot Point

The foundation is made of concrete and designed in a quadruped chain shape. There is a vertical pipeline with a diameter of 200 mm that connects to a rotating elbow shaped fitting at ground level (Plate 3.10).

3.4.3 Drive Unit (Towers)

This device includes a beam with a motor and two wheels attached to it. Each tower has an electrical box that transfers power to the motor. The wheels are controlled by the motor using a connecting rod and gearbox (Plate 3.9).

3.4.4 Pipe Line

The drive unit suspends a pipe line above the ground to transport water from the pivot to the edges of the field. The center pivot in the study has eight spans and one overhang. Each tower is 50 meters long and has a diameter of 21.91 cm, while the overhang has a pipe with a diameter of 54.86 cm (Plate 3.8)

3.4.5 Sprinkler System

There are 156 sprinklers connected at the top of the pipe line. They are evenly spaced three meters apart from each other. At the end of each section, there is a nozzle installed to prevent wheels from getting stuck in the wet soil (Plate 3.12)

3.4.6 Fertilizer Applicator

The system includes a tank made of fiberglass. Water can be used to dissolve chemical fertilizers like urea, and the solution can be released through a pipeline with irrigation water using an injector pump (Plate 3.10).

3.4.7 Control Panel

The primary benefit of this device is its ability to be completely automated and controlled either from a nearby panel or from a remote office. Time locks are utilized to initiate and halt the machine, and numerous safety mechanisms are implemented to ensure protection (Plate 3.10 and 3.5).

3.4.8 Flow-Meter

A flow-meter was installed on the main pipe line to measure the operating pressure of the irrigation system, with an average flow rate of 850 to 1000 gallons per minute (Plate3.4)

3.4.9 Experiment Equipment's

Experiment Equipment's were used to collect data (Plate 3.1)

Plate3. 1: Experimental Equipment

Plate3. 2: Water Source

Plate3. 3: Pumps and Power Unit

Plate3. 4: Flow- Meter

Plate3. 5: Control Panel

Plate3. 6: Reservoir

Plate3. 7: Sand Trap

Plate3. 8: Pivot Center

Plate3. 9: Driver Unit or to Towers

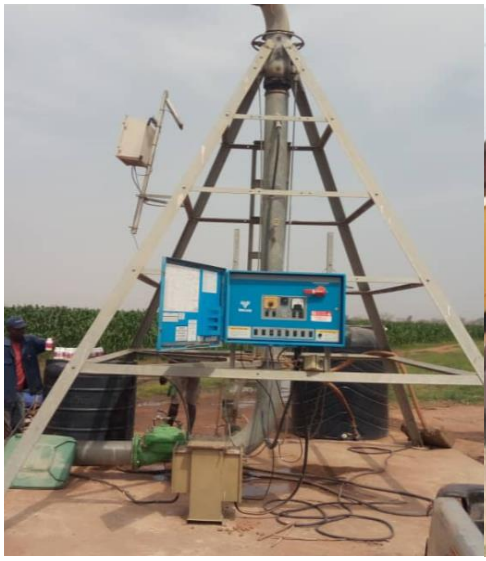

Plate3. 10: Control Panels and Pivot Point

Plate3. 11: Main Supply Line from Reservoir

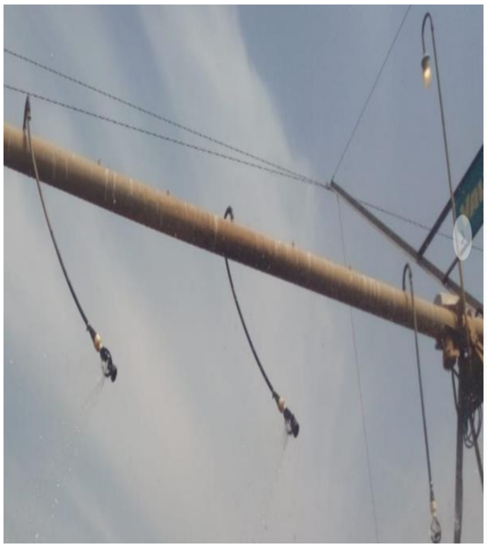

Plate3. 12: Sprinkler Head

Plate3. 13 : Water Depth Measurement

Plate3. 14: Soil Sampling

Plate3. 15: Soil Test Analysis

3.5 Methods of Data Collection

In this experiment data was collected by using different methodology in order to get adequacy and reliable information to reach the specific objectives: The center pivot irrigation with maize crop out of 4 sets of pivots was tested during dry season from November to April 2022/23. The performance indicators, such as coefficient uniformity (CU %), distribution uniformity (DU %), application efficiency (Ea %), irrigation efficiency (E %), scheduling coefficient (SC %), and soil moisture content, were assessed. The tests were conducted by placing the 84 catch cans with the same size and cross section in the row of 5 m at equal distance from each other in direction of pivot to out ward direction of system, to prevent water from evaporating during data collection; all catch cans were placed at the same level as the sprinkler nozzles. The water depth in each catch can was then promptly measured using a graduated measuring cylinder to ensure accurate and timely results. The following hydraulic indicators were measured:

3.5.1 Average Water Depth in Catch Can Measurement

Water depth measurements were taken using catch cans and converted from milliliters (ml) to millimeters (mm). A total of 84 catch cans were used to determine the coefficient of uniformity, distribution uniformity, application efficiency, irrigation efficiency, and scheduling coefficient. Soil samples were also taken to estimate soil moisture content before and after irrigation; climatic data were also collected to analyze the climatic conditions such as average maximum, minimum temperatures (℃), Relative Humidity(%), wind speed (km/h).

3.5.2 Soil Moisture Determination

The effectiveness of the system was assessed by examining how moisture was distributed in the soil. Soil samples were collected both before and after the irrigation cycle from three different locations in lateral; soil moisture points were taken near pivot point, middle and the end, The samples (36 samples before and after irrigation at different running speed of 40 %, 60 %, 80 % and 100 % were taken by an auger from four depths (0 – 5 cm), (5 – 10 cm), (10 – 15 cm) and (15-20 cm). The samples collected were kept in polyethylene bags. The wet samples were weighted using a sensitive balance, and the weight of each soil sample was recorded Plate 3.14 and plate (3.15) (Frevert, 1955)

$$M\,\% = \frac{Mm - Md}{Md} \times 100 \qquad \text{.....Equation3. 1}$$

M% is soil moisture content by weight %,

$M_{m=}$ Weight of the wet sample (g),

M_d = Weight of dry sample (g)

3.6 Performance Measurement of Center Pivot Irrigation System

3.6.1 Coefficient of Uniformity (Cu)

The data caught in 84 catch cans from pivot point to outward of the system were arranged in ascending order in excel format and were used to determine coefficient uniformity, The coefficient of uniformity is a way to measure how evenly a sprinkler system distributes water. The most commonly used measure is the Christiansen coefficient of uniformity, which is expressed as a percentage. The center pivot coefficient of uniformity was calculated using a modified formula developed by Heermann and Hein (ASAE S436.1, 2003).

$$CUH = 100\left[1 - \frac{\sum_{i=1}^{n} si|vi - \overline{v}p|}{\sum_{i=1}^{n} visi}\right] \qquad \text{.....Equation3. 2}$$

Where:

CUH = The Heermann and Hein uniformity coefficient

n =The number of collectors used in the data analysis

$i =$ A number assigned to identify a particular collector beginning with$i = 1$ for the collector located nearest the pivot point and ending with$i = n$ for the most remote collector from the pivot point.

V_i is the volume (or alternately the mass or depth) of water collected in the i[th]collector

S_i is the distance of the ith collector from the pivot point.

v̄p is the weighted average of the volume of water caught.

It is computed as $\overline{VP} = \frac{\sum_{i=1}^{n} ViSi}{\sum_{i=1}^{n} Si}$..Equation3. 3

3.6.2 Distribution Uniformity (Du)

The DU measurement was helpful in determining the extent of distribution issues. It was calculated by dividing the average amount caught in the lowest quarter of cans by the overall average depth caught in all cans (Moshinsky, 1959).

$DU(\%) = \frac{\text{Average of the lowest quater of sample}}{\text{Average of all sample}} \times 100$....................Equation3. 4

3.6 3 Application Efficiency (AE)

The efficiency of the center pivot irrigation system was determined by comparing the average amount of water applied, as measured by the flow meter, to the average amount of water collected in the cans (Evans, 1996).

$\text{Ea} = \frac{\text{Ws}}{\text{Wf}} \times 100$..Equation3. 5

Ws is the average depth of water caught in the cans.

(Wf) is the average depth of water application

Ea is Application efficiency

3.6. 4 Irrigation Efficiency (E %)

The efficiency of the center pivot irrigation system was determined using the following formula:

E (%) = Ea× Du……………………………………………….……Equation3. 6

3.6.5 Scheduling Coefficient (SC %)

The scheduling coefficient was used to identify the critical area in the water application pattern. This area received the least amount of water and was compared to the average amount of water applied in the entire irrigation area (Islam *et* al., 2017).

$\boldsymbol{SC}(\%) = \frac{\mathbf{1}}{\mathbf{DU}}$………………………………………………………….Equation3. 7

Where:

Sc = scheduling coefficient.

DU = uniformity of distribution (in decimal)

3.6.7 Nozzle Discharge

A stopwatch, calibrated containers, and a huge catch can with a 21 cm diameter and 21 cm depth were employed. By attaching the can to the nozzle and directing water into the containers, volumetric measurements of the water output were made. The time was kept track of using the stop watch.

3.6.8 Percentage Water Losses of Center Pivot System

To determine the amount of water lost from the system, the average depth of water measured in the catch cans (representing water that reaches the ground) was subtracted from the average depth of water applied as recorded by the flow meter. By subtracting these two measurements, the water loss from the system could be calculated (Saeed *et al.*, 2018).

$$\text{Average depth of application} = \frac{\text{volume of water applied in meter cube}}{\text{irrigated area in meter square}} \ldots\ldots\ldots\ldots\ldots\ldots \text{Equation3. 8}$$

$$\text{Water loss} = \text{Average depth of application} - \text{Average depth in catch cans} \ldots\ldots\ldots \text{Equation3. 9}$$

$$\text{Percentage of water loss (\%)} = \frac{\text{Water loss}}{\text{Avearage depth of aplication}} \times 100 \ldots\ldots\ldots\ldots \text{Equation3. 10}$$

3.7 Determination of the Soil physical Characteristics of the Irrigable Area

3.7.1 Determination Dry Bulk Density of Soil

The metal core sampler method was used to determine the dry bulk density of the soil. (Abubaker Jamal, 2001)

$$BD = \frac{Wi - Wd}{V} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation3. 11}$$

= volume of sample (cm^3)

$$V = d^2 \frac{\pi}{4} h$$

Wd = Weight of oven dried sample at 105°C until the weight becomes constant (g)

Wi = initial weight of the sample taken at the time of sample (g).

BD is bulk density

π =3.142,

d = diameter of core sampler (cm), and

h = height of core sampler (cm)

3.7.2 Water Content at Field Capacity (FC) and Permanent Wilting Point

A pressure plate was used to apply a suction of -1/3 atmosphere (- 0.3 bar) and (- 15 bars) to a saturated soil sample, which is the most frequent way of evaluating field capacity and permanent wilting point in the laboratory. The soil moisture in the sample was assessed gravimetrically and equated to field capacity and permanent wilting point when water is no longer leaving the sample. (Plate 3.16) illustrates how the field capacity test was conducted using pressure plates in the laboratory.

Plate3. 16: Determination of Field Capacity Using Pressure Plates
(Source: Field Work, 2023)

3.7.3 Available Water Content

The available water capacity of soil, which refers to the amount of water needed to reach field capacity from the wilting point, was measured in a laboratory using a pressure plate and pressure membrane apparatus. This measurement is important for understanding how much water can be stored in the soil and is essential for plant growth and irrigation management. The ability of soil to supply water is determined by its capacity to hold water. This capacity is measured by the difference between the amount of water at Field Capacity (0.3 bar) and the amount of water at the Permanent Wilting Point (15 bars).

3.7.4 Soil Particle Size Distribution

The soil particle size distribution was examined in a laboratory using sieve analysis, following the size categories established by the U.S. Department of Agriculture (2016) for soil classification.

Table3. 2 : Shown Soil Classification

Soil	Diameter (mm)
Gravel	>2 mm
Very coarse sand	< 2 to 1 >1 mm
Medium Sand	0.5 to >0.25 mm
Very Fine Sand	0.1 to >0.05 mm
Coarse Silt	0.05 to >0.02 mm
Fine silt	0.02 to >0.002 mm
Coarse Clay	0.002 to >0.0002 mm
Fine Clay	≤0.0002 mm

(Source: USDA, 2016)

3.7.5 Hydraulic Conductivity Measurement

Hydraulic conductivity refers to the speed at which water can move through the ground based on certain conditions and hydraulic gradients. Applying water more quickly than the soil can absorb it might lead to soil erosion and significant fertilizer losses. Using a mini-disk infiltrometer is crucial for determining the rate of infiltration and the soil hydraulic conductivity in unsaturated soil. The mini-disk infiltrometer is made up of two chambers: a water reservoir and a bubble chamber. These chambers are connected by a Mariette tube, which maintains a constant water pressure head between 0.5 and 7 cm (or 0.05 to 0.7kpa). For this particular study, a suction rate of -2 cm was selected (Zhang, 1997).

$I = C_1\sqrt{t} + C_2t$ ……………………………………………………………Equation3. 12

$K = \frac{C_1}{A}$...Equation3. 13

The parameters C_1 (m/s) and C_2(m/s) represent the sorptivity and hydraulic conductivity respectively. C_1 is the slope of a graph showing cumulative infiltration over square roots of time and A is a value that relates van Genuchten parameters for given soil type to suction rate, and infiltrometer disk radius

3.7.6 PH and Electrical Conductivity Measurement

The pH and salinity of the samples were tested at the University for Development Studies, Spanish Laboratory in Nyankpala Campus. The pH level of water can determine if it is acidic or alkaline. When the water has a pH of 7 at 25℃, it is considered neutral. A pH below 3 is strongly acidic, while a pH between 4 and 6 is weakly acidic. A pH between 8 and 10 is weakly alkaline, and a pH above 11 is strongly alkaline. Conductivity: Electrical conductivity is used to determine the concentration of ions in water, which is important for boiler feed water (GÜlich, 2019).

3.7.7 Determination of Crop Water Requirement

Based on the nearby metrological data, the Penman-Monteith formula was used to determine the consumptive use of the reference crop's evapotranspiration (ETo) for the research area (Anderson & French, 2019). The meteorological data from January to December 2022 will consist of information such as wind speed, sunshine, humidity, temperature, and evaporation, was obtained from the IWAD Weather station

This data was used to calculate crop water requirement using the CROPWAT (Version 8.0) software by following equation:

$ETc = ETo \times Kc$..Equation3. 14

ETc= actual evapotranspiration (mm)

ETo= reference evapotranspiration (mm)

Kc= Crop coefficient it depends on the stage and the season of growth (Chou *et al*., 1988).

3.7.8 Crops Coefficient

The Kc (crop coefficient) changes during the growing season because of changes in the vegetation and ground cover. To create the Kc-curve, only three stages of the crop season are necessary: the early stage, when the crop is about 10% covered, the mid-stage, when it is 80-90% covered, and the late stage, from full maturity to harvest (Anderson and French, 2019).

3.8 Economic and Agronomic Performance of Center Pivot Irrigation System

The center pivots systems economic and crop production performance were assessed using economic and agronomic water usage efficiency, with the goal of maximizing output per unit of water utilized. The Common Water Use Indices (WUI) for crop irrigation were developed based on previous studies by Hirai *et al.* (1978) classified and summarized economic and agronomic water use efficiency.

Table3. 3: Economic and Agronomic Water Use Efficiency

Index	$\frac{\text{Out put}}{\text{Input}}$	Units
Crop water use indices (WUI)		
Crop Economic WUI	$= \frac{\text{Gross return}}{\text{evapotranspiration}}$	$\frac{\$}{\text{mm}}$
Crop WUI	$= \frac{\text{Yield}}{\text{Evapotranspiaration}}$	$= \frac{\text{Kg}}{\text{mm}}$
Irrigation water use indices (WUI)		
Irrigation water use indices	$= \frac{\text{Yield}}{\text{irrigation water applied}}$	$= \frac{\text{Kg}}{\text{ML}}$
Gross Production Economic WUI	$= \frac{\text{Gross return}}{\text{Total Water applied}}$	$= \frac{\$}{\text{ML}}$
Irrigation Economic WUI	$= \frac{\text{Gross return}}{\text{Irrigation water Delivered to the field}}$	$= \frac{\$}{\text{ML}}$
Yield per Drainage volume WUI	$= \frac{\text{Crop production}}{\text{Drainage volume}}$	$= \frac{\text{Kg}}{\text{ML}}$

(Source : Hirai et al., 1978)

The equation to estimate crop water productivity was used to determine the crop water productivity in order to achieve the highest yield possible for each unit of water used throughout the entire irrigation season and the equation to estimate crop water productivity was reported in the book of Bruce et al.,(2019).

$\text{Crop water productivity} = c\frac{\gamma}{ET}$ (kg/ m^3)……………………………….Equation3. 15

Where γ is actually crop yield (kg/m^3)

ET is evapotranspiration or crop water requirement (mm)

C is conversion factor

3.9 Data Analysis

Primary data which were collected from the field: soil samples for moisture determination and water depth collected using the catch cans was analyzed using Microsoft Office Excel. The secondary data like harvested area of Maize, cow peas, onions, sorghum and ground nuts, yield per ha, price per quantity, and cost of production results were analyzed by indicators of gross production economic water use, irrigation economic water use, crop economic water use and economic water productivity equations outlined in this chapter to evaluate economic performance of center pivot irrigation system. The CROPWAT (version 8.0) software was used to obtained crop water requirement and IBM SPPS Statistic 20 was used to simulate soil moisture before and after irrigation and water spray pattern to analysis the collected data. The results obtained were presented in results and discussions section.

CHAPTR FOUR: RESULTS AND DISCUSSIONS

84 catch cans were fixed in the field under pivot irrigation system to identify coefficient uniformity, distribution uniformity, application efficiency, irrigation efficiency and scheduling coefficient. Soil samples were taken to estimate soil moisture content before and after irrigation.

4.1 Average Water Caught in Catch Can

The results showed that depth of water caught in catch cans ranged from 3.45 mm to 36.29 mm and average water depth in catch cans were 6.50 mm, 10.01 mm, 12.87 mm, 19.63 mm for 100 %, 80 %, 60 %, 40 % running speed of system respectively and the average depth of all twelve irrigation in growing season was 12.25 mm (Figure 4.1). During this period, the center pivot irrigation water distribution was not uniform; some part of the irrigated crops got less water while other areas got more due to wind drift, evaporation, pipe leakage, improper pressure variation, nozzle size and its discharge. To avoid the negative effects of incorrect nozzle selection, farmers should make sure that all nozzle sizes on the system match the size recommended in the manufacturer's sprinkler chart. The 40 and 60% running speed gave extremely high water depth because of electricity cutting off and incorrect nozzle size, pump pressure variation, and system flow rate during data correction which leads to the increase of irrigation water. The water distribution pattern above the soil surface for center pivot test using catch cans was shown in the figure 4.1

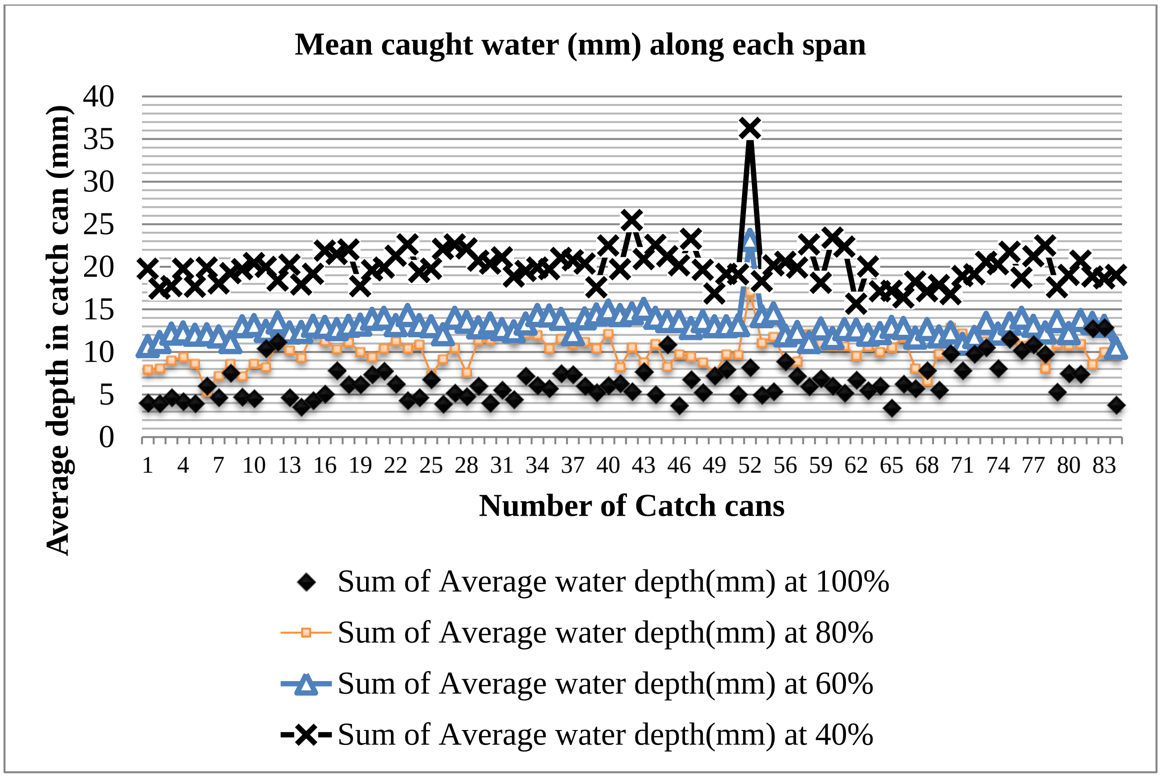

Figure4. 1: Mean Caught Water in Catch Can along Each Span

4.2 Performance Measurement of Center Pivot Irrigation System

4.2.1 Coefficient Uniformity (Cu %)

The study found that the average coefficient of uniformity was 82.7% for twelve different irrigation numbers during the growing season. A range between 80 and 85 % is regarded as fair and the determined value was lower than the recommended standard value of 90 % for center pivot irrigation system as stated by ASABE (2021) and Kushwaha and Kanojia (2018). These values were associated with wrong nozzles under water application and leakage. Hence the system needs to be inspected and the sprinkler kit should be checked regularly. Table 4.1 presents coefficient uniformity.

Table4. 1: Coefficient Uniformity Value (Cu %)

No of Irrigation	Cu %
1	70.00
2	71.00
3	72.00
4	81.95
5	83.00
6	85.68
7	87.16
8	89.68
9	92.00
10	87.80
11	82.24
12	90.00
AVERAGE	82.70

(Source: Own Field work, 2023)

4.2.2 Distribution Uniformity (Du %)

The results showed that the average value of Distribution uniformity of twelve irrigations in growing season was 74.49 % (Table 4.2), which is regarded as good one and it was ranging between 68 and 84 % as stated by ASABE (1994). This value was greater than recommended lowest acceptable uniformity value of 70 % as stated by (ASABE, 2021), The better the uniformity, the higher the distribution uniformity value. The distribution uniformity is influenced by factors such as sprinkler size, nozzle type, pressure, sprinkler spacing, and wind speed, which is the main variable that cannot be controlled (Mohammed and Ahmed, 2022).

Table4. 2: Distribution Uniformity Results (Du %)

No of Irrigation	Du%
1	65.00
2	61.00
3	66.00
4	72.00
5	72.60
6	76.76
7	80.79
8	84.50
9	85.00
10	75.00
11	71.45
12	83.85
AVERAGE	74.49

(Source: Own Field work, 2023)

4.2.3 Application Efficient (Ea%)

The results showed that the average value of water application efficiency of twelve irrigations in growing season was 92.685 % (Table 4.3). This value was greater than other values considered. According to Evans (1996), Spray irrigation can achieve application efficiencies of around 90 to 92% without any surface runoff when applied to a fully covered crop. This value recorded was high application efficiency because average the depth of water collected in catch can from sprinklers were almost the same with average depth supplied, this value was associated with sprinkler discharge, and sprinkler rotation from the system.

Table4. 3: Application Efficiencies Results Ea (%)

No of Irrigation	Ea (%)
1	80.70
2	80.70
3	80.49
4	96.00
5	96.00
6	97.86
7	95.90
8	95.15
9	96.79
10	97.80
11	96.67
12	98.16
AVERAGE	92.69

(Source: Own Field work, 2023)

4.2.4 Irrigation Efficiency (E%)

The average value of irrigation efficiency was 69.4 % for twelve irrigations during the dry season (Table 4.4). This value was less than recommended value of 90 % as stated by (ASABE, 2021), The main reasons why irrigation was not effective were because the nozzles became blocked due to the use of fertilizers and pesticides, and there were also leaks in the joints of the pipes. The lower value may have been also resulted from improper installation and irregular maintenance of the system.

Table4. 4: Irrigation Efficiency (E%)

No of Irrigation	E (%)
1	52.40
2	49.00
3	53.00
4	69.00
5	70.00
6	75.00
7	77.47
8	80.40
9	82.20
10	73.30
11	69.00
12	82.30
AVERAGE	69.40

(Source: Own Field work, 2023)

4.2.5 Scheduling Coefficient (Sc %)

The average scheduling coefficient for twelve irrigations during dry season cultivation was found to be 1.35%(Table 4.5) and according to ASABE (2021), 1.35% was within the recommended value. The highest recommended value is 1.43%. SC was employed because it requires uniform distribution. It is important to measure the SC because it provides the irrigation scheduling time and also SC indicates the areas that receive less or more water depth. Islam *et al.* (2017) indicated that a successful irrigation system should strive to attain at least a SC which is less than 1.3 %, the maximum SC is equal to 1 and the minimum SC is equal to 1.5. If SC is equal to 1, it means that no deviation and, the entire field is uniform. If SC is not between 1 and 1.5%, it means that the irrigation system is inefficient, so the SC calculated on the field was appropriate.

Table4. 5: Scheduling Coefficient (Sc %)

No of Irrigation	Sc%
1	1.50
2	1.60
3	1.50
4	1.40
5	1.40
6	1.30
7	1.20
8	1.20
9	1.20
10	1.30
11	1.40
12	1.20
AVERAGE	1.35

(Source: Own Field work, 202)

4.3 Comparison between Performance Parameters

The three lines of catch cans and soil moisture point were considered as replication for center pivot test in sandy loam soil type. The value for each performance parameters was shown in Table 4.6

Table4. 6: Hydraulic Performance Indicators

Parameters /No of irrigation	1	2	3	4	5	6	7	8	9	10	11	12	Average
Cu (%)	70.00	71.00	72.00	81.95	83.00	85.68	87.16	89.68	92.00	87.80	82.24	90.00	82.70
Du (%)	65.00	61.00	66.00	72.00	72.60	76.76	80.79	84.50	85.00	75.00	71.45	83.85	74.49
Ea (%)	80.70	80.70	80.49	96.00	96.00	97.86	95.90	95.15	96.79	97.80	96.67	98.18	92.69
E (%)	52.40	49.00	53.00	69.00	70.00	75.00	77.47	80.40	82.20	73.30	69.00	82.30	69.40

Sc (%)	1.50	1.60	1.50	1.40	1.40	1.30	1.20	1.20	1.20	1.30	1.40	1.20	1.35

(Source: Own Field work, 2023)

4.4 Comparison between Coefficient Uniformity and Distribution Uniformity

The impact of different operating speeds (100%, 80%, 60%, and 40%) on coefficient uniformity and distribution uniformity (DU) can be found in tables 4.7 and 4.8, respectively. ASABE (1994) summarized and categorized performance indicators for sprinkler irrigation into three namely: performance indicators classes, Christiansen Uniformity Coefficient and Distribution Uniformity as follows $Cu \geq 90$ is excellent, $85 \leq Cu < 90$ is good, $80 \leq Cu < 85$ is fair and $Cu < 80$ is poor and $DU \geq 85$ is excellent, $75 \leq DU \leq 85$ is very good, $70 \leq DU < 75$ is good, $65 < DU < 70$ is fair and $DU \leq 65$ is poor. The average distribution uniformity is good for 80% and very good for 60 and 40% speeds. Furthermore, results of average Cu ranged 71 to 89.6 % and DU ranged 64 to 83.4%

Table4. 7: Variation of Coefficient Uniformity (Cu %) With Different Operating Speed

No of replication	Cu %	Cu%	Cu%	Cu%
	S1:100%	S2:80%	S60%	S4:40%
1	70	82	87.2	87.8
2	71	83	89.7	82.2
3	72	85.7	92	90
Average	71	83.5	89.6	86.7
Evaluation	Poor	Fair	Good	Good

(Source: Own study 2023)

Table4. 8: Variation of Distribution Uniformity with Different Operating Speed

No of replication	Du %	Du %	Du %	Du %
	S1: 100%	S2:80%	S3:60%	S4:40%
1	65	72	80.8	75
2	61	72.6	84.5	71.5
3	66	76.8	85	83.9
Average	64	73.8	83.4	76.8
Evaluation	Poor	Good	Very good	Very good

(Source: Own study 2023)

The results showed that coefficient uniformity was poor for 100 %, 80 % was fair and 60 to 40 % were good. Distribution uniformity for 100 % was poor, 80 % was good and 60 to 40 % were very good, these results for 100 % were associated with leakage pipe and clogging of nozzle caused by sedimentation.

4.5. Percentage of Water Losses (%) of center pivot irrigation system

The results presented in Table 4.9 indicated that the average percentage of water losses for twelve irrigation cycles during the growing season was 7.21%. This could be due to wind drift, droplet evaporation and leaking pipe. Funakawa *et al*. (2012) indicated that the evaporation and wind drift during application might result in irrigation water loss of 1.5 % to 7.6 %; the percentage of water losses at 100 % was high up to 19.25 %, due to leakage at the joint of pivot during water application time.

Table4. 9: Percentage of Water Losses (%)

No. Running speed	Different Speed (%)	Flow meter measurement (m^3/h)	Rotational time (min)	Average depth of application (mm)	Average Depth in Catch can (mm)	Water loses (mm)	Percentage of water loses (%)
1	100	80.50	17.00	8.05	6.50	1.55	19.25
2	80	103.20	21.00	10.32	10.01	0.31	3.00
3	60	134.20	28.00	13.42	12.87	0.55	4.10
4	40	201.30	42.00	20.13	19.63	0.50	2.48
Average		129.80	27.00	12.98	12.25	0.73	7.21

(Source: Own study 2023)

Anderson and French (2019) stated that a loss of 1mm of water equals to a loss of 10 m^3 of water per hectare. The result showed that, on average, each of the twelve irrigations lost 0.73 mm of water over the growing season, or 7.3 m^3 per hectare was accepted.

4.6 Soil Moisture Content (mm) in Depth 0 – 5 Cm, 5 – 10 Cm, 10 – 15 Cm, and 15 – 20 Cm Before and After Irrigation

The results of soil moisture (MC %) were 11, 9, 7 and 5% before irrigation while soil moisture (MC %) after irrigation were 13, 10, 8 and 6% in depth of (0 – 5), (5 – 10), (10 – 15) and (15 – 20) cm. The soil moisture distribution along the soil profile in depth of 0 – 5cm, 5 – 10 cm, 10 – 15 cm and 15 – 20 cm was shown in (Figure 4.2) and the values of soil moisture content before and after irrigation were tabulated in Table 4.10

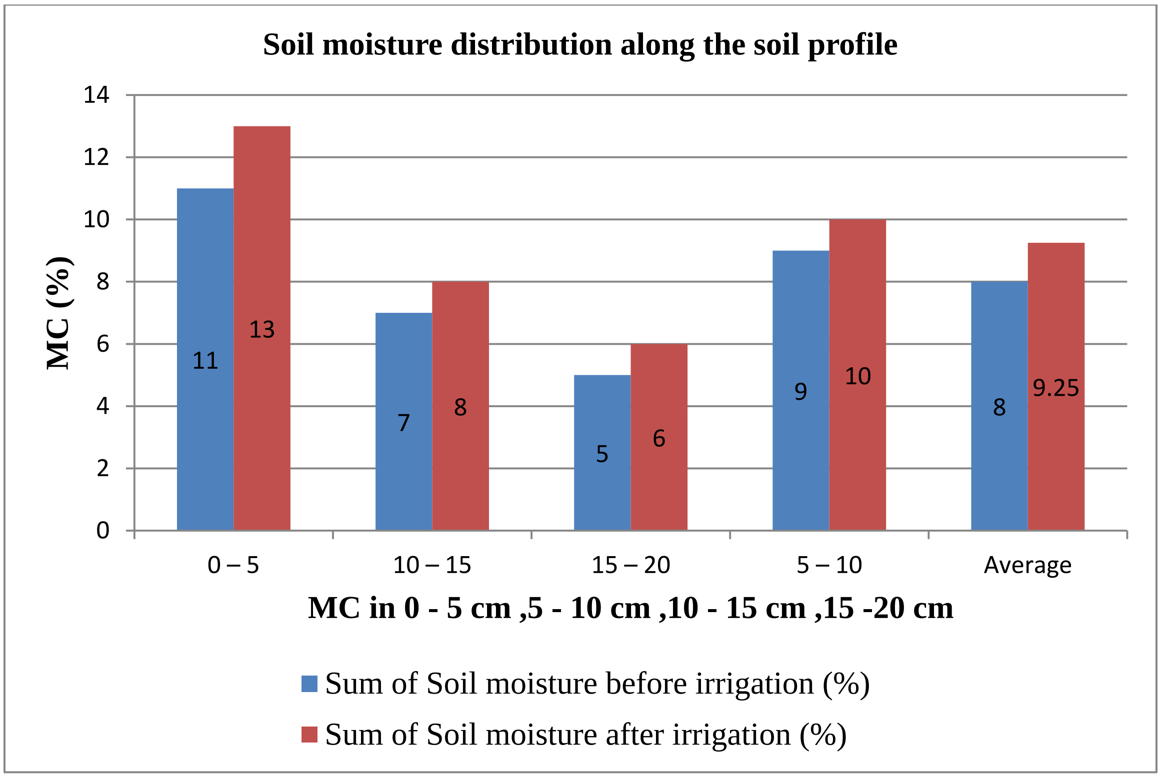

Figure4. 2: The Soil Moisture Distribution along the Soil Profile in Depth of 0 – 5 cm, 5 – 10 cm, 15 – 15 cm and 15 – 20 cm

The results indicated that soil moisture content value before and after irrigation correlation was significant at 0.01 levels which means there was no deficit or incomplete supplementary irrigation in available water for the crop. The soil moisture content was measured gravimetrically and average soil moisture before and after irrigation were 8 and 9.25 % compared with average field capacity and permanent wilting point measured were 8.118 and 3.67 % respectively. This demonstrated that the soil was wet at the field capacity of 8.118% and dry at the permanent wilting points of 3.67%, beyond which the plant can no longer draw any more water. According to (Busscher, 2009) stated that direct soil sampling is time-consuming, difficult, expensive, and frequently harmful to a field study area. However, this technique typically yields an exact and accurate measurement of soil water content. It serves as the benchmark by which all other methods are evaluated and calibrated. Jeremaiho and Loung, (2016) was obtained soil moisture content ranged from 13.8 % to 7.1 % by using the same methods. According to Funakawa et al., (2012) stated that Understanding the soil moisture content at field capacity and permanent wilting point is crucial for determining when to irrigate, evaluating how much water plants need, and determining if the soil is suitable for various land uses.

4.6.1 Soil Moisture before Irrigation and After Irrigation

The results stated that average soil moisture content before irrigation and after irrigation was ranging from 5 to 13 % for twelve irrigations in growing season (Table 4.10). Gravimetric method was used to determine soil moisture content with 36 soil samples before and after irrigation, soil moisture content is high where coefficient uniformity and Distribution uniformity are high, therefore this result of average soil moisture content indicated that the type of soil is sand soil. According to Frevert (1955) a sandy soil may hold less than 12.7 mm of available moisture per 30.48 cm of depth corresponded to 41.7mm/m; a clay loam may hold 50.8 mm of available moisture per 30.48 cm of soil.

Table4. 10: Soil Moisture before Irrigation and After Irrigation

Depth (cm)	Soil moisture before irrigation (%)	Soil moisture after irrigation (%)
0 – 5	11	13
5 – 10	9	10
10 – 15	7	8
15 – 20	5	6
Average	8	9.25

(Source: Own Field work, 2023)

4.6.2 Available Water before Irrigation

Table4. 11: Available Water Before irrigation

Depth (Cm)	Moisture content (%)	Dray Bulk Density (g/cm^3)	Volumetric water content of soil (%)	Total Water (m^3)
0 – 5	11	1.15	12.66	160.24
5 – 10	9	1.17	10.56	111.47
10 – 15	7	1.19	8.35	69.68
15 -20	5	1.19	5.92	35.08

(Source: Own Field work, 2023)

4.6.3 Available Water after Irrigation

Table4. 12: Available Water After irrigation

Depth (cm)	Moisture content (%)	Dray bulk Density (g/cm^3)	Volume (%)	Total Water (m^3)
0 – 5	13	1.13	14.66	214.83
5 – 10	10	1.16	11.60	134.60
10 – 15	8	1.18	9.46	89.58
15 – 20	6	1.20	7.19	51.70

(Source: Own Field work, 2023)

The results in Table 4.12 indicates that soil moisture content value before and after irrigation correlation was significant at 0.01level which means there was no deficit or incomplete supplemental irrigation in available water for the crop.

4.7. Determination of Soil Physical Characteristic of Irrigable Area

4.7.1 Estimation of FC and PWP

The results indicated that average value of field capacity ranged from 6.29 and 9.25 % while average permanent wilting point of irrigable are arranged from 3 to 4.4 % in sand soil and average values of FC and PWP in irrigated area were 8.118% and 3.67% respectively. Therefore average soil available water was 4.45% by weight corresponding to 44.5 mm/m, this value was accepted by Anderson and French (2019) who reported that the average value of field capacity and permanent wilting point was ranging from 0.07 to 0.17 m^3/m^3 and 0.02 to 0.07 m^3/m^3 respectively was founded in sandy soil. The Table 4.13 tabulated average values of field capacity and permanent wilting point in percentage.

Table4. 13: Estimation of FC and PWP

Soil sample	FC (%)	PWP (%)	FC- PWP (%)
1	6.29	3.00	3.29
2	7.70	3.20	4.50
3	7.38	3.30	4.08
4	9.61	4.30	5.31
5	8.48	3.80	4.68
6	9.25	4.40	4.85
Total	48.71	22.00	26.71
Average	0.08	0.04	4.45

(Source: Own Field work, 2023)

4.7.2 Determination of Soil Particles Distribution

Soil particles distribution was determined by laboratory test analysis. Soil laboratory results indicated that 89.96 % was sand, 9.44 % was silt and 0.6 % was clay, given sand. Funakawa *et al*(2012) reported that due to the high sand content, it is exceedingly difficult to manage irrigation water since sands are characterized by wide pores that have a low capillary holding capacity. As a result, if sandy soil receives too much water, the excess falls below the root zone and may result in nutrient leaching.

4.7.3 Measured Hydraulic Conductivity

The field-measured hydraulic conductivity of the soil was $3.462 \times 10^{-2}\ cm/sec$ and vanu Genuchten parameter in sand soil was 1.73. Therefore, the application rate observed on the field was lower than the hydraulic conductivity, no soil erosion or fertilizer losses occurred during the field experiment. Figure 4.3 presents the typical infiltration of the soil

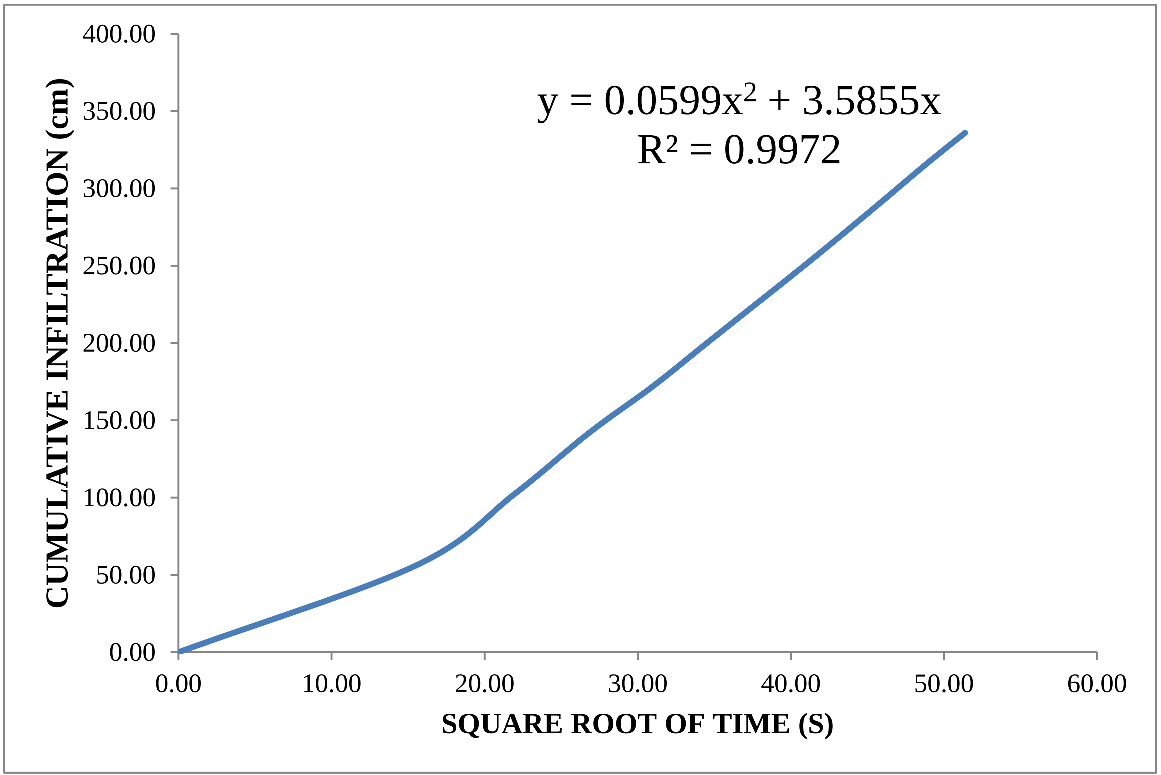

Figure4. 3: Quadratic Equation Graph

4.7.4 Determination of pH and ECs

Hydrogen positive and electrical conductivity were measured by laboratory test analysis, the results indicated that average value of pH and ECs were 5.86 and 13.56 Microsiemems/cm at room temperature 25°C. These values indicated that irrigable area was slightly acidic and saline resulting from continuously inorganic fertilizers applications. Proper management and monitoring of soil pH is necessary as it affects the solubility of compounds and the ability of soil to support microbial activities. Most crops prefer a pH range of 6.0 to 7.5 for optimal growth and development (GÜlich, 2019).

4.8 Determination of Crop Water Requirement (ETC)

From the inputs of IWAD weather parameters and soil laboratory analysis, the amount of water needed by maize, ground nuts, and sorghum and vegetable crops such as cowpeas and onions as predominated crops in the irrigable area of center pivot irrigation system were calculated using CROPWAT computer model (version.8). CROPWAT results (Table4.14) show the average daily crop water requirement 6.344 mm/day for maize, 5.720 mm/day for grounds nuts, 5.2mm/day for sorghum and 5.460 mm/day for vegetable at peak water requirement. Average ETo of the area was 5.20 mm/day.

Table4. 14: Estimated Daily Crop Water Requirement

Crops	Average ETo (mm/day)	KC	ETc (mm/day)
Maize	5.200	1.220	6.344
Ground nuts	5.200	1.100	5.720
Sorghum	5.200	1.000	5.200
vegetable	5.200	1.050	5.460

(Source: Own Field work, 2023)

Maize, cow peas, onions, sorghum and ground nuts were the primary crops cultivated in the irrigated area of the center pivot irrigation system, and the water requirement for each crop was calculated using the CROPWAT computer program (version 8). As presented in Table 4.15, the center pivot sprinkler irrigation system's net and gross water requirements of maize, ground nuts, sorghum, (cow peas, onions are vegetable) were 783.5, 300.6, 168.9, 299.5, 299.5 and 1119.3, 429.4, 241.2, 427.9 , 427.9 mm/season, respectively. The efficiency of the irrigation system was 69.4%. Roth et al., (2013) stated that the estimation of water requirements would help farmers to improve water use efficiency on the agricultural land, avoid water losses and reduce irrigation cost.

Table4. 15: Estimated Irrigation Water Requirement

Crops	Water application system	Net irrigation (mm/season)	Irrigation efficiency (%)	Gross irrigation (mm/season)	Volume needed (m^3/ha)
Maize	center pivot	783.500	69.400	1119.300	11193.000
Ground nuts	center pivot	300.600	69.400	429.400	4294.000
Sorghum	center pivot	168.900	69.400	241.200	2412.000
cow peas	center pivot	299.500	69.400	427.900	4279.000
Onions	center pivot	299.500	69.400	427.900	4279.000
	Total	1852.000	347.000	2645.700	26457.000
	Average	370.400	69.400	529.140	5291.400

(Source: Own Field work, 2023)

4.9 Average Solar Power Generation for Pumping Water from River to Irrigate Crops

Average calculated values generated by solar panels such as total solar power per month, grid import per month, solar power usage, total power export, total power net, solar power usage cost in dry season was tabulated in Table:4.16

Table4. 16: Average Solar Power Generation

Monthly	Total Solar Power Per Month(Kwh)	Grid Import Per Month(Kwh)	Solar Power Usage(Kwh)	Total Power Export(Kwh)	Total Power Net(Kwh)	Solar Power Usage Cost USD (	Solar Usage Cost ($/Kwh/Ha)

						$/Kwh)	
Nov	44847.460	8201.109	15822.748	29024.710	20823.603	1408.225	10.026
Dec	44724.437	17392.943	18686.623	26037.810	8644.871	1663.109	11.840
Jan	48782.630	25892.224	20376.228	28406.400	2514.179	1813.484	12.911
Feb	50958.013	21357.940	21171.787	29786.230	8428.286	1884.289	13.415
Mar	49426.880	12513.849	16730.806	32696.080	20182.225	1489.042	10.601
Apr	46236.065	5795.482	15592.991	30643.070	24847.592	1387.776	9.880
May	42120.118	6889.209	17242.689	24877.430	17988.219	1534.599	10.925
Total	327095.603	98042.756	125623.872	201471.730	103428.975	11180.525	79.598
Average	46727.943	14006.108	17946.267	28781.676	14775.568	1597.218	11.371

(Source: Author`s work, 2023)

The average power generated by solar panels in dry season for pumping water from Sisili-kulpawn river to irrigate maize, cow peas, onions, sorghum and ground nuts fields was 46727.943 kwh/season. When there was sunshine available and the crops needed water. The water was directly pumped from the Kulpawn river to the pivot using solar panels. The average of solar power use directly by center pivots was 17946.267 kwh/season. Based on Memorandum of Understanding signed between The Electricity Producers of Ghana and IWAD, excess solar power generated can always be of loaded to be stored in the national grids, so that in an event that IWAD is not able to produce solar power, they can also rely on the national grid for electricity supply in return. Based on that arrangement, the 14006.108 kWh/ season was stored in grids as excess solar power generated. The solar power which was stored in the grids was used in case the center pivot needs excess energy. When there was sunshine without a need of irrigating the crops, the solar power generated was stored in the grids. The average power export and power net were 28781.676 kwh/season and 14775.568 kwh/season respectively. From the data collected in this study, approximately 11.371 $ Dollars was required to generate one kilowatt (KWh) hour per hectare. Ahmed, (2013) stated that the cost of solar panels, measured in terms of peak power produced, dropped dramatically from $33.44 /KWh in 1979 to less than $10.00 /KWh in 2007,which was increasing the technology's potential for use in the irrigation industry and making it a crucial factor in on-site energy production. The cost benefit ratio was not calculated due to the lack of economical information at IWAD.

4.10 Average Diesel Used for River and Booster Pump Station for Pumping Water to Irrigate Crops

Table 4.17 represented the average costs of diesel which was used in pumping certain volume of water from land preparation to harvesting. Approximately 82489.439 m³ of water which was equivalent to 16910.335 US dollars ($) was used to irrigate 140.463 ha. Profits will be maximized if yield/ML is maximized, because water has a constant cost per ML and the cost/ha depends on the application rate. According to each machine's power source, operating pressure, and motor efficiency, fuel or electricity represents the majority of operational costs and is relatively fixed cost per ML (North, 2016a).

Table4. 17: Average Diesel Used For River and Booster Pump Station

Monthly	Total litres of Diesel	Total cost of of diesel($)	Total hours	Diesel used L/h	Water used Day (m³)	Cost of water ($)L/h/(m³)	Water used by pivots (m³)	Water used by pivot(m³/ha)
Nov	1929.500	6077.925	45.056	37.591	13971.740	0.014	13598.692	96.813
Dec	909.227	2864.065	35.990	33.050	13293.454	0.014	14363.667	102.259
Jan	298.000	938.700	9.858	32.349	4190.800	0.069	921.840	6.563
Feb	324.500	1022.175	11.144	33.309	5992.460	0.042	662.400	4.716

Mar	645.000	2031.750	16.779	40.548	13751.220	0.014	10946.800	77.934
Apr	1599.000	5036.850	36.579	43.650	30342.020	0.009	38148.920	271.594
May	511.000	1609.650	15.254	34.340	9992.360	0.043	3847.120	27.389
Total	6216.227	19581.115	170.660	254.837	91534.054	0.205	82489.439	587.268
Average	888.032	2797.302	24.380	36.405	13076.293	0.029	11784.206	83.895

(Source: Author`s work, 2023)

The water application from diesel powered center pivot irrigation system was all the same with solar power applied, the area irrigated was the same, the crops are the same, and the different was the cost of diesel consumed. The total irrigation water applied for 7 months period from November to May was inclusive to calculate water use efficiency because the last harvest was obtained early May in IWAD farm. The total rain fall was not collected because there was no rain in dry season. The average quantity of water applied in the whole dry season by center pivots system was 11784.206 m^3 and the seasonal average of water productivity was 83.895 m^3 /ha of irrigated area for partial irrigation. The seasonal average was greater than the average (66 m^3 /ha) designed by LORENTZ, (2014). Additionally, LORENTZ (2014) reported that in eleven hours, center pivot completes one 360 degree turn, and provides 3300 m^3 of water/day for partial irrigation, and this value was greater than 2946.051 m^3 of water per day founded on the field. The total volume of water pumped was highest at starting dry season as compared to all entire growth period of irrigated crop; this indicated that before sowing, the system used more water for irrigation during land preparation and the peak water demand was highest in April where crops need maximum water to meet crop water requirement.

4.11 Area Irrigated and Source of Energy

The figure:4.4 represents average irrigated land for each crops and source of energy used to pump certain volume of water for irrigating maize, cow peas, onions, sorghum and ground nuts. IWAD irrigation project produce maize in a large scale as more than 72 %, followed by cowpeas of 15 %, 3 % of onions, 7 % of sorghum and 4 % of groundnuts of total average irrigated area in dry season were irrigated by center pivots. The yield averages of dry seasons from 2017/18 to 2021/22 were 2.656 Mt/ha of maize, 0.26 Mt/ha of cow peas, 13.093 Mt/ha of sorghum, 2.94 Mt of onions and 0.48 Mt/ha of ground nut at IWAD farm. The total average area cultivated was 140.463 ha in dry season and seasonal water consumed was 82489.439 m³ for maize, cow peas, onions, sorghum and ground nuts and the energy cost were approximately 17646.276$. Hence, it cost about 0.214 USD dollars ($) to pump one m³ volume of water for one hectare of irrigable area. The average water productivity was 587.268 m³ /ha and was required to produce crops yield of 2.656 MT/ha of maize, 0.26 MT/ha of cow peas, 13.093 MT/ha sorghum, 2.94 MT/ ha of onion, 0.48 MT/ha of ground nuts.

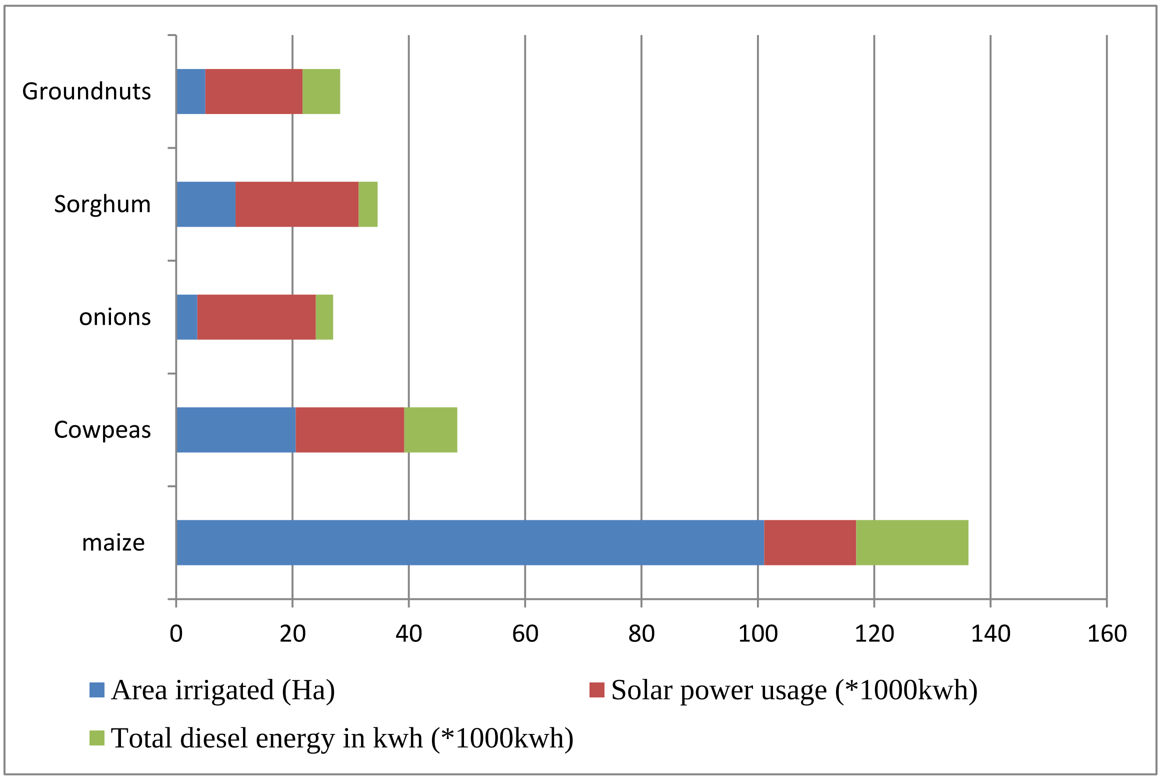

Figure4. 4 : Area Irrigated and Source of Energy.

4.12 Economic Performance of Center Pivot Irrigation System

The economic performance of center pivot irrigation systems was evaluated using indicators such as gross production economic water use, irrigation economic water use, crop economic water use, and economic water productivity (Hirai *et al.*, 1978).

4.12.1 Gross Production Economic Water Use

The approximate cost of releasing a specific amount of water for agricultural purposes from the time of planting until the crops are fully grown (Table4.18). The overall amount of water used on the land from the time of planting until the crops are fully grown. Gross production economic water use includes volume of water applied to irrigate the land before planting. Approximately 213.922 US Dollars ($) was used for pumping 1 mega liter (ML) of water to 1ha of irrigable land. Gross total of 82.489 ML of water was delivered to 140.470 ha of irrigable land. Total volume of water consumed for irrigating the land before planting were 59.366, 12.068, 2.129, and 5.990, 2.936 ML for maize, cowpeas, onions, sorghum and groundnuts cultivation respectively. According to (North, 2016b) recorded gross production economic water use of 360 US Dollars($)was used for pumping one mega liter of water to produce more than 2 tons of wheat. Table 4.18 showed crop production economic water use efficiency for maize, cowpeas, onions, sorghum and groundnuts.

Table4. 18: Gross Production Economic Water Use Efficiencies

Main Crops	Total Area – Ha	Total Yield(Mt)	Water delivered (m^3)	Water delivered (ML)	Total cost of consumption ($)	Gross economic water use ($/ML)
Maize	101.090	216.130	59365.760	59.366	12699.620	213.922

Cowpeas	20.550	5.400	12068.360	12.068	2581.680	213.921
Onions	3.630	41.850	2128.850	2.129	455.410	213.923
Sorghum	10.200	30.000	5990.130	5.990	1281.420	213.922
Groundnuts	5.000	2.420	2936.340	2.936	628.150	213.923
Total	140.470	295.800	82489.440	82.489	17646.280	1069.611
Average	28.094	59.160	16497.888	16.498	3529.256	213.922

(Source: Own Field work, 2023)

4.12.2 Irrigation Economic Water Use

The cost involved in pumping certain volume of water after planting to crop maturity and or harvesting. Approximately 56.60, 11.50, 2.03, 5.71 and 2.80 Mega liter of water were equivalent to 12473.40, 2535.64, 447.90, 1258.57 and 619.95 US dollars ($). Approximately 56.60, 11.50, 2.03, 5.71 and 2.80 Mega liter was used to irrigate 101.09, 20.55, 3.63, 10.20 and 5.00 ha of irrigable area for maize, Cowpeas, onions, Sorghum and Groundnuts cultivation respectively. Table4.19 shows irrigation economic water use efficiency for maize, Cowpeas, onions, Sorghum and Groundnuts

Table4. 19: Irrigation Economic Water Use

Main Crops	Total Area – Ha	Total Yield (Mt)	Water delivered (m^3)	water delivered (ML)	Total cost of consumption ($)	Irrigation economic water use ($/ ML)
Maize	101.09	216.13	56595.37	56.60	12473.40	220.40
Cowpeas	20.55	5.40	11504.95	11.50	2535.64	220.40
Onions	3.63	41.85	2032.26	2.03	447.90	220.40
Sorghum	10.20	30.00	5710.48	5.71	1258.57	220.40
Groundnuts	5.00	2.42	2799.26	2.80	616.95	220.40
Total	140.47	295.80	78642.32	78.64	17332.45	1101.98
Average	28.09	59.16	15728.46	15.73	3466.49	220.40

(Source: Own Field work, 2023)

4.12.3 Crop Economic Water Use

Crop economic water use efficiency refers to the ratio of the cost of pumping a specific amount of water to the losses caused by evapotranspiration during the irrigation of crops. One millimeter (1 mm) of water loss to evapotranspiration cost 0.002, 0.010, 0.058, 0.021 and 0.042 ($) at center pivot for cultivation of maize, Cowpeas, onions, Sorghum and Groundnuts respectively. Total water of 113150.037, 8824.170, 875.556, 4364.580 and 2139.500 mm were lost due to evapotranspiration from 101.09, 20.55, 3.63, 10.20 and 5.00 ha for cultivated area. Kamel, (2008) recorded crop evapotranspiration rate of 7.59 ML/ha for cotton production Table 4.20 shows economic water use efficiency.

Table4. 20: Crop Economic Water Use Efficiency

Main Crops	Total Area – Ha	Total cost of Consumption ($)	Evapotranspiration Rate (mm)	Crop economic water use Efficiency($/mm)
maize	101.090	235.050	113150.037	0.002
Cowpeas	20.550	90.170	8824.170	0.010
Onions	3.630	50.650	875.556	0.058
Sorghum	10.200	89.860	4364.580	0.021
Groundnuts	5.000	89.860	2139.500	0.042
Total	140.470	555.590	129353.843	0.133
Average	28.094	111.118	25870.769	0.027

(Source: Own Field work, 2023)

4.12.4 Economic Water Productivity

Economic water productivity relates the quantity of the actual yield and local price per kilogram of the crop to the volume of water consumed (water loss due to ET) by the crop during the period of crop irrigation. It is the gross value of production per unit water consumed. One millimeter of water consumed by maize, Cowpeas, onions, Sorghum and Groundnuts were approximately equivalent to 3.284, 4.048, 48.414, 13.320, 11.926 GH¢/respectively in terms of energy used. Abdul-Ganiyu et al.,(2015) recorded water productivity of 0.311kg/ m^3 and economic water productivity of 0.084$/ m^3 for rice production under surface irrigation in northern region of Ghana. Bruce et al., (2019) recoded the economic water productivity for rice and pepper in the Savelugu municipality in Ghana is 0.38 GH¢/m^3 and 1.23 GH¢/m^3 at Libga, and 0.41 GH¢/m^3 and 1.07 GH¢/m^3 at Bunglung, respectively.

Table4. 21: Economic Water Productivities.

Main Crops	Total Area – Ha	Total Yield(Mt)	Total yield kg	Total Production Cost- GH¢/	Price per kg (GH¢)	Evapotranspiration Rate (mm)	Economic water productivity (GH¢//mm)
Maize	101.088	216.132	216132.000	371627.868	1.719	113147.798	3.284
Cowpeas	20.550	5.400	5400.000	35721.660	6.615	8824.170	4.048
Onions	3.625	41.853	41853.000	42330.630	1.011	874.350	48.414
Sorghum	10.200	30.000	30000.000	58135.510	1.938	4364.580	13.320
Groundnuts	5.000	2.420	2420.000	25516.030	10.544	2139.500	11.926
Total	140.463	295.805	295805.000	533331.698	21.827	129350.398	80.992
Average	28.093	59.161	59161.000	106666.340	4.365	25870.080	16.198

(Source: Own Field work, 2023)

4.13 Agronomic Performance of Center Pivot Irrigation System.

Different agronomic indicators including gross production water use index, irrigation water use index, crop water use index, and crop water productivity were evaluated.

4.13.1 Gross Production Water Use Index

Gross Production Water Use Index is a gross estimation of the total volume of water applied to irrigable land from planting to crop maturity for producing a certain weight of crop yield. Approximately one (1) Mega liter of water was required to produce 3640.684 kg of maize grain, 447.451 kg of cow peas, 19659.910 kg of onion, 5008.239 kg of sorghum and 824.155 kg of groundnuts. According to Kamel, (2008) recorded average gross production water use index of 2.75 bales/ML of irrigation used both rain and irrigation for cotton under center pivot irrigation system. North, (2016b) reported that average gross production water uses index of 2 tons/ha per ML of water through rainfall and supplement irrigation through center pivot system for wheat and 2 to 5 tones /ha per mega liter of Lucerne under subsurface drip irrigation.

Table4. 22: Gross Estimation of the Total Volume of Water Applied

Main Crops	Total Area – Ha	Total Yield(Mt)	Total yield (kg)	Water delivered (m^3)	Water delivered (ML)	Gross water use index (Kg/ML)
Maize	101.088	216.132	216132.000	59365.760	59.366	3640.684
Cowpeas	20.550	5.400	5400.000	12068.360	12.068	447.451
Onions	3.625	41.853	41853.000	2128.850	2.129	19659.910
Sorghum	10.200	30.000	30000.000	5990.130	5.990	5008.239
Groundnuts	5.000	2.420	2420.000	2936.340	2.936	824.155
total	140.463	295.805	295805.000	82489.440	82.489	3585.974
Average	28.093	59.161	59161.000	16497.888	16.498	3585.974

(Source: Own Field work, 2023)

4.13.2 Irrigation Water Use Index

Irrigation Water Use Index is the total volume of water applied after planting to crop maturity for producing yield (kg) under a given area of production. 1ML mega liter of water released was required to produce 3640.64kg of maize, 477.46 kg of cowpeas, 19657.12 kg of onions, 5008.35 kg of sorghum and 824.25 kg of groundnuts per one hectare of irrigable area. A total of 82.49 ML of water released was used to produce 216.13, 5.40, 41.85, 30.00 and 2.42 Mt of maize, cowpeas, onions, sorghum, and groundnut respectively. Kamel, (2008) reported that for cotton production using center pivots and lateral moves irrigation systems, the average and range irrigation water use index values were 1.9 bales/ ML of irrigation and 1.35 to 2.6 bales/ML.

Table4. 23: Total Volume of Water Applied after Planting to Crop Maturity

Main Crops	Total Area – Ha	Total Yield(Mt)	Total Yield (Kg)	Water delivered (ML)	Irrigation Water Use Index
Maize	101.09	216.13	216130.00	59.37	3640.64
Cowpeas	20.55	5.40	5400.00	12.07	447.46
Onions	3.63	41.85	41850.00	2.13	19657.12
Sorghum	10.20	30.00	30000.00	5.99	5008.35
Groundnuts	5.00	2.42	2420.00	2.94	824.25
Total	140.47	295.80	295800.00	82.49	29577.81
Average	28.09	59.16	59160.00	16.50	5915.56

(Source: Own Field work, 2023)

4.13.3 Crop Water Use Index

Crop water use index for each crop cultivated was related to the yield obtained to water losses due to evapotranspiration over the periods of crop irrigation. Crop water use index were 1.910 kg/mm of maize, 0.612 kg/mm of cow peas, 47.868 kg/ mm of onions, 6.874 kg/ mm of sorghum, and 1.131 kg/ mm of groundnuts. The highest crop water use index was obtained for onions followed by sorghum and the lowest values for maize, cowpeas and groundnuts. Kamel, (2008) reported 1.41 bales/ ML of cotton production. North, (2016) recorded crop water index of

22 kg/ha/mm for both rainfall and irrigation of wheat grown and 20 kg/ha/mm of lucerne under center pivot irrigation system in southern Riverina. (Table 4.24) shown crop water use index

Table4. 24: Crop Water Use Index

Main Crops	Total Area – Ha	Total Yield(Kg)	Evapotranspiration Rate (mm)	Crop water index (kg/mm)
Maize	101.088	216132.000	113147.798	1.910
Cowpeas	20.550	5400.000	8824.170	0.612
Onions	3.625	41853.000	874.350	47.868
Sorghum	10.200	30000.000	4364.580	6.874
Groundnuts	5.000	2420.000	2139.500	1.131
Total	140.463	295805.000	129350.398	58.394
Average	28.093	59161.000	25870.080	11.679

(Source: Own Field work, 2023).

4.13.4 Crop Water Productivity

Crop water productivity was calculated using relationship between crop yield and total volume of irrigation water consumed by the crop. 1 m^3 consumed lead to the production of 2.759 kg of maize grain, 0.18 kg of cow peas, 2.478 kg of onions, and 1.002 kg of sorghum and 0.081 kg of ground nuts. Maize was the best crop tolerant to drought and was used lower water required followed by onions. The income will be increased and reduces poverty when the farmers are carefully conscious about the crop water productivity. Crop water productivities of maize in subs-Saharan Africa was below 0.3 kg /m^3 compare to 1.9 kg/ m^3 in united stated (Boadjo and Culas, 2021). And according to Yiran *et al.*,(2018) recorded crop water productivity of 3.94 kg grain of sorghum at Kukobila Nasia Farms Limited. Bruce et al., (2019) recorded the crop water productivity at Libga in Ghana's Northern region is 0.50 kg/m³ for rice and 0.74 kg/m³ for pepper.

Table4. 25: Crop Water Productivity

Main Crops	Total Area – Ha	Actual yield kg/ha	Evapotranspiration Rate (mm)	Crop water productivity (Kg/ m³)
maize	101.088	2138.058	7835.000	2.759
Cowpeas	20.550	262.774	3006.000	0.180
Onions	3.625	11545.655	1689.000	2.478
Sorghum	10.200	2941.176	2995.000	1.002
Groundnuts	5.000	484.000	2995.000	0.081
Total	140.463	17371.663	18520.000	6.499
Average	28.093	3474.333	3704.000	1.300

(Source: Own Field work, 2023)

CHAP FIVE: CONCLUSIONS AND RECOMMENDATIONS

The chapter summarizes the study's results and offers recommendations for further research in this area. The study can be used to draw the following conclusions and recommendations:

5.1 Conclusions

The studies showed that:

- Average water depth in catch cans increased to (6.50 mm, 10.01 mm, 12.87 mm, 19.63 mm) for decreasing of running speed of system (100%, 80%, 60%, 40%) respectively
- Coefficient uniformity was below recommended value due to wrong nozzles under water application and leakage.
- Distribution uniformity and irrigation efficiency were below recommended value due to the sprinkler size, type of nozzle, pressure variation, sprinkler spacing, and the main uncontrollable variable, the wind speed.
- The average value of scheduling coefficient for twelve irrigations in the dry season cultivation was 1.35% which was above recommended value of 1.3%
- Soil moisture content before irrigation and after irrigation was correlated significantly at 0.01 levels which mean there was no deficit irrigation to affect available water for the crop. However, there was over irrigation, which resulted in lower yield and wasted water and energy
- Average value of percentage of water losses of center pivot of twelve irrigations in growing season was 7.20 % corresponding to 7.3 m^3 per hectare could be due to wind drift, droplet evaporation and leaking pipe.

- Average application rate found on the field was lower than hydraulic conductivity of the soil at irrigable area, this means no soil erosion and fertilizer losses were taken place during field experiment.
- Approximately 213.922 US Dollars ($) was used for pumping 1 mega liter (ML) of water to 1ha of irrigable land. Approximately one (1) Mega liter of water was required to produce 3640.684 kg of maize grain, 447.451 kg of cow peas, 19659.910 kg of onion, 5008.239 kg of sorghum and 824.155 kg of groundnuts.

5.2 Recommendations

5.2.1 Recommendation for Improvement of System Efficiency to Obtain Low Water Losses

Based on the findings of the study, the following recommendations were made for policy:

- To improve efficiency of the system there is needed to use flow meter to apply water need to meet with crop water requirement
- Soil sensors are necessary to measure soil moisture levels before and after irrigation. This helps determine the most efficient way to replenish water in the field.
- Computer Technologies are needed to automate the system so as to bring out greater efficiency in water and input use.
- Operating pressure regulator like pressure gouge for all system should be checked and replaced where needed.
- The system should be used at 80 % speed which was more efficient and effective at peak water demand of maize, cow peas, onions, sorghum and ground nuts to avoid wasted water, energy and yield.
- Regular evaluation of center pivot irrigation system should be done every two years

5.2.2 Recommendations for Future Research

Based on the findings of the study, the following are the recommendations for future research:

- Further research should be conducted to evaluate the economic performance of center pivot irrigation systems using additional indicators such as cost benefit ratio, net present value, internal rate of return, and payback period. This evaluation should also consider the costs of using solar and diesel energy sources, as well as taxes and insurance.
- Other field water losses and irrigation water quality should be evaluated

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APPENDICES

Appendix (A): Climatic Data

Appendix (A_1): Environmental Conditions during Field Measurements (SKIS)

Days	Max temp	Min temp	Mean Temp	Max Hum%	Min Hum%	Mean Hum%	Rain(mm)
1	35.00	16.40	25.70	54.00	11.00	32.50	0.00
2	35.40	13.20	24.30	80.00	10.00	45.00	0.00
3	37.10	13.30	25.20	78.00	10.00	44.00	0.00
4	36.20	15.80	26.00	67.00	11.00	39.00	0.00
5	35.70	15.30	25.50	71.00	13.00	42.00	0.00
6	35.90	16.00	25.95	70.00	13.00	41.50	0.00
7	35.90	18.00	26.95	84.00	13.00	48.50	0.00
8	37.00	18.40	27.70	70.00	11.00	40.50	0.00
9	38.20	18.30	28.25	68.00	11.00	39.50	0.00
10	39.00	16.40	27.70	76.00	10.00	43.00	0.00
11	39.60	16.50	28.05	63.00	11.00	37.00	0.00
12	38.50	15.90	27.20	68.00	18.00	43.00	0.00
13	38.50	21.20	29.85	65.00	15.00	40.00	0.00
14	38.60	20.90	29.75	64.00	13.00	38.50	0.00
15	39.00	18.40	28.70	72.00	11.00	41.50	0.00
16	41.20	18.70	29.95	60.00	11.00	35.50	0.00
17	39.70	18.10	28.90	72.00	11.00	41.50	0.00
18	40.80	19.50	30.15	66.00	11.00	38.50	0.00
19	40.60	18.20	29.40	69.00	17.00	43.00	0.00
20	39.30	23.50	31.40	48.00	11.00	29.50	0.00
21	37.60	18.10	27.85	57.00	11.00	34.00	0.00
22	38.90	18.20	28.55	71.00	12.00	41.50	0.00
23	39.40	18.90	29.15	69.00	11.00	40.00	0.00
24	40.20	19.00	29.60	65.00	13.00	39.00	0.00
25	40.50	18.90	29.70	76.00	15.00	45.50	0.00
26	40.30	18.50	29.40	69.00	12.00	40.50	0.00
27	40.00	21.40	30.70	64.00	25.00	44.50	0.00
28	40.00	26.60	33.30	70.00	29.00	49.50	0.00
29	35.60	22.60	29.10	76.00	52.00	64.00	0.00
30	38.50	26.00	32.25	82.00	32.00	57.00	0.00
Total	1152.20	560.20	856.20	2064.00	454.00	1259.00	0.00
Average	38.41	18.67	28.54	68.80	15.13	41.97	0.00

Appendix (A_2): Uniform Environment condition during field work

Days	Eto (mm)	Sunshine(Hrs)	Radiation W/m2	Wind (Km/hr)	Wind (Km/hr) Gust	Mean Wind speed (km/h)
1	5.14	2.90	661.00	11.00	28.80	19.90
2	4.67	3.40	696.00	6.60	18.90	12.75
3	3.83	2.40	667.00	5.70	17.30	11.50
4	4.29	1.30	634.00	9.60	17.40	13.50
5	4.14	0.80	618.00	6.30	16.60	11.45
6	3.80	0.10	580.00	8.10	16.60	12.35
7	3.98	0.00	547.00	9.00	15.50	12.25
8	4.47	0.30	590.00	9.00	28.50	18.75
9	4.38	0.40	602.00	6.00	25.40	15.70
10	4.78	1.20	641.00	11.60	20.40	16.00
11	4.03	1.90	664.00	7.30	16.40	11.85
12	3.63	1.00	623.00	5.90	17.50	11.70
13	3.56	0.00	566.00	5.00	14.50	9.75
14	4.70	0.20	580.00	14.90	30.70	22.80
15	4.56	0.70	630.00	10.00	23.30	16.65
16	4.38	1.30	663.00	12.70	26.20	19.45
17	4.96	1.50	665.00	12.40	23.40	17.90
18	5.05	1.40	660.00	10.70	23.80	17.25
19	4.48	0.70	638.00	7.20	21.40	14.30
20	5.46	0.70	633.00	8.80	21.40	15.10
21	4.94	0.10	583.00	11.30	24.70	18.00
22	4.01	0.20	598.00	11.00	18.60	14.80
23	4.76	0.70	640.00	13.20	24.00	18.60
24	4.10	0.50	625.00	9.90	22.00	15.95
25	4.28	0.80	645.00	8.90	21.50	15.20
26	4.61	0.40	610.00	8.40	21.40	14.90
27	3.68	0.30	613.00	6.30	12.90	9.60
28	3.58	0.10	597.00	6.30	18.50	12.40
29	3.36	0.10	451.00	10.80	22.80	16.80
30	3.85	0.20	513.00	6.20	16.90	11.55
Total	129.46	25.60	18433.00	270.10	627.30	448.70
Average	4.32	0.85	614.43	9.00	20.91	14.96

Appendix (A_3): Climatic Data Annual Summary (Year 2022)

Days	Eto (mm)	Sunshine(Hrs)	Radiation W/m2	Wind (Km/hr)	Wind (Km/hr) Gust	Mean Wind speed (km/h)
1	5.14	2.90	661.00	11.00	28.80	19.90
2	4.67	3.40	696.00	6.60	18.90	12.75
3	3.83	2.40	667.00	5.70	17.30	11.50
4	4.29	1.30	634.00	9.60	17.40	13.50
5	4.14	0.80	618.00	6.30	16.60	11.45
6	3.80	0.10	580.00	8.10	16.60	12.35
7	3.98	0.00	547.00	9.00	15.50	12.25
8	4.47	0.30	590.00	9.00	28.50	18.75
9	4.38	0.40	602.00	6.00	25.40	15.70
10	4.78	1.20	641.00	11.60	20.40	16.00
11	4.03	1.90	664.00	7.30	16.40	11.85
12	3.63	1.00	623.00	5.90	17.50	11.70
13	3.56	0.00	566.00	5.00	14.50	9.75
14	4.70	0.20	580.00	14.90	30.70	22.80
15	4.56	0.70	630.00	10.00	23.30	16.65
16	4.38	1.30	663.00	12.70	26.20	19.45
17	4.96	1.50	665.00	12.40	23.40	17.90
18	5.05	1.40	660.00	10.70	23.80	17.25
19	4.48	0.70	638.00	7.20	21.40	14.30
20	5.46	0.70	633.00	8.80	21.40	15.10
21	4.94	0.10	583.00	11.30	24.70	18.00
22	4.01	0.20	598.00	11.00	18.60	14.80
23	4.76	0.70	640.00	13.20	24.00	18.60
24	4.10	0.50	625.00	9.90	22.00	15.95
25	4.28	0.80	645.00	8.90	21.50	15.20
26	4.61	0.40	610.00	8.40	21.40	14.90
27	3.68	0.30	613.00	6.30	12.90	9.60
28	3.58	0.10	597.00	6.30	18.50	12.40
29	3.36	0.10	451.00	10.80	22.80	16.80
30	3.85	0.20	513.00	6.20	16.90	11.55
Total	129.46	25.60	18433.00	270.10	627.30	448.70
Average	4.32	0.85	614.43	9.00	20.91	14.96

Appendix (B): Measuring Water Depth

Appendix (B_1): Running Speed 100%

Span 1	Cans	Water depth in Ml	Water depth in Ml	water depth in Ml
	1	19	22	20
	2	20	21	19
	3	26	19	25
	4	23	18	22
	5	18	23	19
	6	41	14	36
	7	28	18	24
	8	40	36	38
	9	20	26	25
	10	24	22	23
Span 2	Cans			
	11	54	50	53
	12	60	53	56
	13	24	21	25
	14	20	15	19
	15	23	20	22
	16	26	26	25
	17	36	44	38
	18	32	31	30
	19	26	38	29
	20	33	41	37
Span 3	Cans			
	21	40	38	39
	22	21	37	36
	23	18	23	24
	24	22	25	23
	25	26	49	27
	26	20	20	19
	27	24	29	25
	28	22	26	24
	29	28	32	31
	30	20	18	23
Span 4	Cans			
	31	28	29	27
	32	16	27	24
	33	36	37	35
	34	31	31	30
	35	30	27	29
	36	38	38	37
	37	37	36	38
	38	31	30	30

	39	26	26	27
	40	33	28	31
Span 5	Cans			
	41	30	33	32
	42	24	30	27
	43	38	42	36
	44	22	28	26
	45	50	66	48
	46	17	20	19
	47	40	25	37
	48	28	26	25
	49	40	34	35
	50	42	38	40
Span 6	Cans			
	51	26	26	24
	52	18	18	19
	52	20	26	23
	54	30	24	21
	55	28	26	27
	56	34	52	48
	57	36	36	36
	58	29	31	30
	59	36	38	30
	60	31	32	28
span 7	Cans			
	61	25	26	27
	62	34	33	34
	63	28	26	29
	64	30	31	30
	65	17	17	18
	66	34	29	31
	67	29	28	29
	68	38	41	39
	69	30	26	28
	70	50	50	48
Span 8	Cans			
	71	50	28	40
	72	50	50	47
	73	55	50	54
	74	50	35	37
	75	66	50	58
	76	50	50	54
	77	52	54	58

	78	50	50	47
	79	24	25	31
	80	50	27	36
Overhang	Cans			
	81	28	50	34
	82	65	66	61
	83	64	65	65
	84	13	19	25

Appendix (B_2): Running speed 80%

Span 1	**Cans**	**Water depth in Ml**	**Water depth in Ml**	**Water Depth In Ml**
	1	42	40	41
	2	60	42	56
	3	46	40	48
	4	42	56	54
	5	38	40	45
	6	67	27	67
	7	67	37	56
	8	47	34	48
	9	33	34	37
	10	44	54	48
Span 2	Cans			
	11	81	40	70
	12	41	50	60
	13	41	54	50
	14	47	83	76
	15	52	66	60
	16	57	92	69
	17	62	64	66
	18	56	52	58
	19	70	47	72
	20	67	46	74
Span 3	Cans			
	21	50	47	55
	22	47	54	58
	23	55	41	58
	24	40	54	55
	25	62	36	65

	26	41	42	48
	27	54	72	68
	28	36	92	87
	29	29	58	57
	30	65	57	58
Span 4	Cans			
	31	33	63	62
	32	82	78	80
	33	62	63	60
	34	58	63	59
	35	52	49	54
	36	48	56	59
	37	48	57	54
	38	54	53	58
	39	42	61	48
	40	47	69	57
Span 5	Cans			
	41	45	38	43
	42	46	67	46
	43	47	37	48
	44	75	55	55
	45	41	43	41
	46	52	57	45
	47	49	45	49
	48	38	41	46
	49	46	39	37
	50	48	51	48
Span 6	Cans			
	51	48	50	48
	52	36	51	45
	52	39	42	37
	54	53	71	58
	55	36	66	56
	56	48	58	70
	57	56	54	66
	58	98	69	85
	59	52	54	56
	60	41	53	54
Span 7	Cans			
	61	39	53	54
	62	33	52	46
	63	52	86	87
	64	59	73	60

	65	64	31	64
	66	40	58	59
	67	20	50	36
	68	33	80	69
	69	51	42	53
	70	60	66	64
Span 8	Cans			
	71	50	66	59
	72	50	56	56
	73	51	54	58
	74	51	64	63
	75	49	69	65
	76	48	64	49
	77	47	55	61
	78	40	42	40
	79	30	53	56
	80	43	39	62
Overhang	Cans			
	81	43	45	60
	82	60	43	43
	83	67	35	58
	84	53	47	49

Appendix (B_3): Running speed 60%

Span 1	**Cans**	**Water depth in Ml**	**Water depth in Ml**	**water depth in Ml**
	1	48	100	50
	2	85	80	83
	3	64	100	70
	4	78	90	87
	5	90	76	85
	6	102	64	78
	7	109	58	86
	8	63	100	93
	9	68	100	89
	10	68	64	66
Span 2	Cans			
	11	60	90	88

	12	76	98	78
	13	89	90	86
	14	64	78	74
	15	92	69	86
	16	78	65	72
	17	57	76	68
	18	65	78	75
	19	66	84	69
	20	69	90	80
Span 3	Cans			
	21	73	68	70
	22	62	116	89
	23	74	100	78
	24	94	84	90
	25	50	76	80
	26	120	54	88
	27	74	67	76
	28	100	68	88
	29	63	69	82
	30	105	69	70
Span 4	Cans			
	31	96	52	93
	32	98	59	88
	33	79	82	81
	34	78	92	78
	35	69	74	72
	36	70	76	70
	37	93	79	90
	38	74	82	84
	39	82	67	78
	40	100	72	83
Span 5	Cans			
	41	104	72	80
	42	76	72	71
	43	80	69	78
	44	77	65	69
	45	110	60	80
	46	64	103	68
	47	64	77	72
	48	90	89	87
	49	54	100	68
	50	64	78	74
Span 6	Cans			

	51	92	50	86
	52	60	50	61
	52	54	66	58
	54	76	68	70
	55	73	74	72
	56	50	80	80
	57	50	88	78
	58	50	60	58
	59	64	79	69
	60	58	58	59
Span 7	Cans			
	61	53	78	70
	62	52	70	68
	63	58	62	61
	64	67	50	67
	65	66	100	89
	66	54	69	70
	67	50	78	68
	68	52	70	69
	69	52	66	60
	70	64	58	63
	Cans			
Span 8	71	50	57	58
	72	64	50	63
	73	70	64	68
	74	50	67	66
	75	60	71	70
	76	64	73	74
	77	56	73	68
	78	62	63	60
	79	72	57	76
	80	69	50	65
Overhang	Cans			
	81	69	68	70
	82	75	50	77
	83	50	75	72
	84	52	50	56

Appendix (B_4): Running Speed 40%

Span 1	**Cans**	**Water depth in Ml**	**Water depth in Ml**	**Water depth in Ml**
	1	100	100	98

	2	98	68	97
	3	58	119	90
	4	102	100	96
	5	79	100	87
	6	102	100	98
	7	100	86	86
	8	100	100	90
	9	143	64	110
	10	68	150	120
Span 2	Cans			
	11	90	113	98
	12	105	84	88
	13	142	63	120
	14	140	50	110
	15	130	70	89
	16	120	110	100
	17	110	116	98
	18	134	105	103
	19	110	70	87
	20	100	100	95
Span 3	Cans			
	21	100	100	100
	22	100	125	96
	23	114	125	102
	24	50	192	120
	25	100	100	98
	26	100	123	110
	27	110	125	106
	28	146	90	98
	29	100	110	102
	30	100	110	97
Span 4	Cans			
	31	100	112	106
	32	100	86	98
	33	144	60	120
	34	100	100	100
	35	110	90	97
	36	100	150	112
	37	100	105	108
	38	100	111	96
	39	48	200	140
	40	100	129	110
Span 5	Cans			

	41	100	102	95
	42	100	160	134
	43	100	145	121
	44	128	120	112
	45	100	150	130
	46	100	100	124
	47	100	136	115
	48	102	95	99
	49	100	76	78
	50	100	100	89
Span 6	Cans			
	51	56	150	130
	52	114	81	86
	52	109	78	79
	54	116	55	105
	55	100	106	98
	56	100	107	103
	57	50	150	120
	58	100	129	112
	59	100	95	78
	60	122	115	116
span 7	Cans			
	61	150	96	121
	62	79	77	80
	63	100	100	102
	64	100	79	79
	65	100	72	87
	66	100	72	75
	67	114	56	105
	68	90	80	88
	69	100	72	97
	70	66	174	63
Span 8	Cans			
	71	100	143	132
	72	66	112	110
	73	100	104	106
	74	97	111	98
	75	100	116	112
	76	66	129	87
	77	100	112	108
	78	100	124	115
	79	67	100	98
	80	78	157	132

Overhang	Cans			
	81	100	130	125
	82	78	100	106
	83	100	76	105
	84	131	64	132

Appendix (C): **Soil Moisture Measurement**

Appendix (C_1): Measuring of soil moisture content before irrigation at 100%

Sample	**Soil depth in Cm**	**wet weight (g)**	**Dray weight in (g)**	**Moisture content in (%)**
1	0 – 5	100	93.01	8%
2	5 – 10	100	93.12	7%
3	10 - 15	100	95.93	4%
4	15 - 20	100	97.22	3%
5	0 – 5	100	92.61	8%
6	5 – 10	100	93.37	7%
7	10 - 15	100	96.94	3%
8	15 - 20	100	98.73	1%
9	0 – 5	100	90.55	10%
10	5 – 10	100	94.05	6%
11	10 - 15	100	95.88	4%
12	15 - 20	100	97.88	2%
13	0 – 5	100	93.24	7%
14	5 – 10	100	94.91	5%
15	10 - 15	100	95.75	4%
16	15 - 20	100	98.43	2%
17	0 – 5	100	92.72	8%
18	5 – 10	100	93.4	7%
19	10 - 15	100	93.98	6%
20	15 - 20	100	97.42	3%
21	0 – 5	100	90.58	10%
22	5 – 10	100	94.67	6%
23	10 - 15	100	95.08	5%
24	15 - 20	100	96.94	3%
25	0 – 5	100	95.61	5%
26	5 – 10	100	95.7	4%
27	10 - 15	100	97.03	3%
28	15 - 20	100	97.37	3%
29	0 – 5	100	95.24	5%
30	5 -10	100	95.67	5%

31	10 -15	100	95.72	4%
32	15 - 20	100	96.49	4%
33	0 – 5	100	94.6	6%
34	5 – 10	100	95.14	5%
35	10 - 15	100	95.44	5%
36	15 - 20	100	95.82	4%

Appendix (C_2): Measuring of soil moisture content after irrigation at 100%

Sample	Soil depth in Cm	wet weight (g)	Dray weight in (g)	Moisture content in (%)
1	0 – 5	100	90.82	10%
2	5 – 10	100	92.35	8%
3	10 - 15	100	95.27	5%
4	15 - 20	100	97.08	3%
5	0 – 5	100	90.02	11%
6	5 – 10	100	90.98	10%
7	10 - 15	100	95.43	5%
8	15 - 20	100	96.12	4%
9	0 – 5	100	89.76	11%
10	5 – 10	100	96.02	4%
11	10 - 15	100	96.7	3%
12	15 - 20	100	96.8	3%
13	0 – 5	100	94.12	6%
14	5 – 10	100	94.56	6%
15	10 - 15	100	96.78	3%
16	15 - 20	100	96.98	3%
17	0 – 5	100	91.38	9%
18	5 – 10	100	95.06	5%
19	10 - 15	100	95.72	4%
20	15 - 20	100	96.82	3%
21	0 – 5	100	93.05	7%
22	5 – 10	100	95.1	5%
23	10 - 15	100	94.84	5%
24	15 - 20	100	96.51	4%
25	0 – 5	100	94.64	6%
26	5 – 10	100	95.4	5%
27	10-15	100	95.51	5%
28	15 - 20	100	95.64	5%
29	0 – 5	100	93.53	7%
30	5 – 10	100	94.2	6%
31	10 - 15	100	95	5%
32	15 - 20	100	95.76	4%

33	0 – 5	100	91.12	10%
34	5 – 10	100	93.32	7%
35	10 - 15	100	94.88	5%
36	15 - 20	100	95.51	5%

Appendix (C_3): Measuring of soil moisture content before irrigation at 80%

Sample	Soil depth in Cm	wet weight (g)	Dray weight	Moisture content in (%)
1	0 – 5	100	91.26	10%
2	5 – 10	100	91.40	9%
3	10 - 15	100	94.91	5%
4	15 - 20	100	96.53	4%
5	0 – 5	100	90.76	10%
6	5 – 10	100	91.71	9%
7	10 - 15	100	96.18	4%
8	15 - 20	100	98.41	2%
9	0 – 5	100	88.19	13%
10	5 – 10	100	92.56	8%
11	10 - 15	100	94.85	5%
12	15 - 20	100	97.35	3%
13	0 – 5	100	91.55	9%
14	5 – 10	100	93.64	7%
15	10 - 15	100	94.69	6%
16	15 - 20	100	98.04	2%
17	0 – 5	100	90.90	10%
18	5 – 10	100	91.75	9%
19	10 - 15	100	92.48	8%
20	15 - 20	100	96.78	3%
21	0 – 5	100	88.23	13%
22	5 – 10	100	93.34	7%
23	10 - 15	100	93.85	7%
24	15 - 20	100	96.18	4%
25	0 – 5	100	94.51	6%
26	5 – 10	100	94.63	6%
27	10 - 15	100	96.29	4%
28	15 - 20	100	96.71	3%
29	0 – 5	100	94.05	6%
30	5 – 10	100	94.59	6%
31	10 - 15	100	94.65	6%
32	15 - 20	100	95.61	5%
33	0 – 5	100	93.25	7%
34	5 – 10	100	93.93	6%

35	10 - 15	100	94.30	6%
36	15 - 20	100	94.78	6%

Appendix (C_4): Measuring of soil moisture content after irrigation at 80%

Sample	Soil depth in Cm	wet weight (g)	Dray weight (g)	Moisture content in (%)
1	0 – 5	100	88.53	13%
2	5 – 10	100	90.44	11%
3	10 - 15	100	94.09	6%
4	15 - 20	100	96.35	4%
5	0 – 5	100	87.53	14%
6	5 – 10	100	88.73	13%
7	10 - 15	100	94.29	6%
8	15 - 20	100	95.15	5%
9	0 – 5	100	87.20	15%
10	5 – 10	100	95.03	5%
11	10 - 15	100	95.88	4%
12	15 - 20	100	96.00	4%
13	0 – 5	100	92.65	8%
14	5 – 10	100	93.20	7%
15	10 - 15	100	95.98	4%
16	15 - 20	100	96.23	4%
17	0 – 5	100	89.23	12%
18	5 – 10	100	93.83	7%
19	10 - 15	100	94.65	6%
20	15 - 20	100	96.03	4%
21	0 – 5	100	91.31	10%
22	5 – 10	100	93.88	7%
23	10 - 15	100	93.55	7%
24	15 - 20	100	95.64	5%
25	0 – 5	100	93.30	7%
26	5 – 10	100	94.25	6%
27	10 - 15	100	94.39	6%
28	15 - 20	100	94.55	6%
29	0 – 5	100	91.91	9%
30	5 – 10	100	92.75	8%
31	10 - 15	100	93.75	7%
32	15 - 20	100	94.70	6%
33	0 – 5	100	88.90	12%
34	5 – 10	100	91.65	9%
35	10 - 15	100	93.60	7%
36	15 - 20	100	94.39	6%

Appendix (C_5): Measuring of soil moisture content before irrigation at 60%

Sample	Soil depth in Cm	wet weight (g)	Dray weight (g)	Moisture content in (%)
1	0 – 5	100	85.44	17%
2	5 – 10	100	85.67	17%
3	10 - 15	100	91.52	9%
4	15 - 20	100	94.21	6%
5	0 – 5	100	84.60	18%
6	5 – 10	100	86.19	16%
7	10 - 15	100	93.63	7%
8	15 - 20	100	97.35	3%
9	0 – 5	100	80.31	25%
10	5 – 10	100	87.60	14%
11	10 - 15	100	91.42	9%
12	15 - 20	100	95.58	5%
13	0 – 5	100	85.92	16%
14	5 – 10	100	89.40	12%
15	10 - 15	100	91.15	10%
16	15 - 20	100	96.73	3%
17	0 – 5	100	84.83	18%
18	5 – 10	100	86.25	16%
19	10 - 15	100	87.46	14%
20	15 - 20	100	94.63	6%
21	0 – 5	100	80.38	24%
22	5 – 10	100	88.90	12%
23	10 - 15	100	89.75	11%
24	15 - 20	100	93.63	7%
25	0 – 5	100	90.85	10%
26	5 – 10	100	91.04	10%
27	10 - 15	100	93.81	7%
28	15 - 20	100	94.52	6%
29	0 – 5	100	90.08	11%
30	5 – 10	100	90.98	10%
31	10 - 15	100	91.08	10%
32	15 - 20	100	92.69	8%
33	0 – 5	100	88.75	13%
34	5 – 10	100	89.88	11%
35	10 - 15	100	90.50	10%
36	15 - 20	100	91.29	10%

Appendix (C_6): Measuring of soil moisture content after irrigation at 60%

Sample	Soil depth in Cm	wet weight (g)	Dray weight (g)	Moisture Content in (%)
1	0 – 5	100	80.88	24%
2	5 - 10	100	84.06	19%
3	10 - 15	100	90.15	11%
4	15 - 20	100	93.92	6%
5	0 – 5	100	79.21	26%
6	5 - 10	100	81.21	23%
7	10 - 15	100	90.48	11%
8	15 - 20	100	91.92	9%
9	0 – 5	100	78.67	27%
10	5 - 10	100	91.71	9%
11	10 - 15	100	93.13	7%
12	15 - 20	100	93.33	7%
13	0 – 5	100	87.75	14%
14	5 - 10	100	88.67	13%
15	10 - 15	100	93.29	7%
16	15 - 20	100	93.71	7%
17	0 – 5	100	82.04	22%
18	5 - 10	100	89.71	11%
19	10 - 15	100	91.08	10%
20	15 - 20	100	93.38	7%
21	0 – 5	100	85.52	17%
22	5 - 10	100	89.79	11%
23	10 - 15	100	89.25	12%
24	15 - 20	100	92.73	8%
25	0 – 5	100	88.83	13%
26	5 - 10	100	90.42	11%
27	10 - 15	100	90.65	10%
28	15 - 20	100	90.92	10%
29	0 – 5	100	86.52	16%
30	5 - 10	100	87.92	14%
31	10 - 15	100	89.58	12%
32	15 - 20	100	91.17	10%
33	0 – 5	100	81.50	23%
34	5 - 10	100	86.08	16%
35	10 - 15	100	89.33	12%
36	15 - 20	100	90.65	10%

Appendix (C_7): Measuring of soil moisture content before irrigation at 40%

Sample	Soil depth in Cm	wet weight (g)	Dray weight in (g)	Moisture Content in (%)
1	0 – 5	100	90.18	11%
2	5 – 10	100	91.02	10%
3	10 - 15	100	91.07	10%
4	15 - 20	100	92.32	8%
5	0 – 5	100	88.51	13%
6	5 – 10	100	91.22	10%
7	10 - 15	100	92.61	8%
8	15 - 20	100	93.17	7%
9	0 – 5	100	90.67	10%
10	5 – 10	100	91.41	9%
11	10 - 15	100	91.99	9%
12	15 - 20	100	94.25	6%
13	0 – 5	100	91.3	10%
14	5 – 10	100	92.18	8%
15	10 - 15	100	92.52	8%
16	15 - 20	100	92.78	8%
17	0 – 5	100	92.09	9%
18	5 – 10	100	92.58	8%
19	10 - 15	100	92.61	8%
20	15 - 20	100	95.82	4%
21	0 – 5	100	91.21	10%
22	5 – 10	100	91.55	9%
23	10 - 15	100	92.54	8%
24	15 - 20	100	93.62	7%
25	0 – 5	100	91.28	10%
26	5 – 10	100	94.16	6%
27	10 - 15	100	94.18	6%
28	15 - 20	100	94.8	5%
29	0 – 5	100	92.25	8%
30	5 – 10	100	93.79	7%
31	10 - 15	100	94.38	6%
32	15 - 20	100	94.92	5%
33	0 – 5	100	92.59	8%
34	5 – 10	100	93.82	7%
35	10 - 15	100	93.84	7%
36	15 - 20	100	94.32	6%

Appendix (C_8): Measuring of soil moisture content after irrigation at 40%

Sample	Soil depth in Cm	wet weight (g)	Dray weight in	Moisture Content in

			(g)	(%)
1	0 – 5	100	86.91	15%
2	5 - 10	100	90.83	10%
3	10 - 15	100	92.1	9%
4	15 - 20	100	92.21	8%
5	0 – 5	100	89.29	12%
6	5 - 10	100	90.43	11%
7	10 - 15	100	90.91	10%
8	15 - 20	100	92.39	8%
9	0 – 5	100	89.32	12%
10	5 - 10	100	89.65	12%
11	10 - 15	100	89.81	11%
12	15 - 20	100	90.13	11%
13	0 – 5	100	86.67	15%
14	5 - 10	100	88.6	13%
15	10 - 15	100	90.46	11%
16	15 - 20	100	92.73	8%
17	0 – 5	100	88.57	13%
18	5 - 10	100	88.95	12%
19	10 - 15	100	91.08	10%
20	15 - 20	100	92.57	8%
21	0 – 5	100	89.4	12%
22	5 - 10	100	89.64	12%
23	10 - 15	100	89.96	11%
24	15 - 20	100	92.33	8%
25	0 – 5	100	88.9	12%
26	5 - 10	100	90.26	11%
27	10 - 15	100	90.3	11%
28	15 - 20	100	92.33	8%
29	0 – 5	100	87.22	15%
30	5 - 10	100	89.89	11%
31	10 - 15	100	91.31	10%
32	15 - 20	100	91.4	9%
33	0 – 5	100	90.02	11%
34	5 - 10	100	90.07	11%
35	10 - 15	100	90.23	11%
36	15 - 20	100	92.61	8%