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FACULTY OF ENGINEERING

DEPARTMENT OF ENVIRONMENTAL AND BIOSYSTEMS ENGINEERING

PERFORMANCE COMPARISON BETWEEN OPEN DRIP AND SUB-SURFACE SYSTEM

A CASE STUDY MWEA IRRIGATION AGRICULTURAL DEVELOPMENT CENTER

Research Thesis submitted in partial fulfilment for the Degree of Master of Science in Environmental and Biosystems Engineering in the Department of Environmental and Biosystems Engineering at the University of Nairobi.

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DECLARATION

This thesis is my original work and has not been submitted for any other degree or qualification at any other institution of higher education.

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DEDICATION

I dedicate this MSc thesis to my cherished family, whose unwavering moral support and tremendous encouragement have been instrumental throughout my studies. They have been my constant pillar of strength in both academic pursuits and career endeavors.

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Finally, I respectfully acknowledge the Almighty God, from whom all knowledge, wisdom, and understanding originate. I grant Him all the glory and praise, for with Him, anything is possible.

Amen

LIST OF ACRONYMS

AMREF- African Medical and Research Foundation.

ETc - Crop evapotranspiration

ETo - Evapotranspiration

FAO - Food and Agricultural Organisation, Rome

KARI - Kenya Agricultural Research Institute

IFPRI - International Food Policy Research Institute

ISBN - International Standard Book Number

MIAD (Mwea Irrigated Agriculture Development) Centre

NIR - Net Irrigation Requirement

GIR - Gross Irrigation Requirement

PERC- Percolation

UM - Upper Middle level

SAT - Saturation

SWR - Scheme Water Requirement.

WL - Water layer

ABSTRACT

Around 75% of Kenya's population relies on agriculture for both sustenance and income. About Kenya's two-thirds of the land is semi-arid to arid. Conventional irrigation systems like furrow and has been largely adopted in Kenya due to low investment costs despite having demerits that include soil salinity, water logging, amongst others. From literature, it has been established that water storage, could be an ultimate solution to some of the aforementioned challenges. This therefore calls for investment in modern irrigation technologies like drip (both surface and sub-surface systems).

A study on the performance comparison on stable sustenance of sub/surface soil moisture between buried and surface drip system was carried out in Mwea Irrigation Agricultural Development (MIAD) Centre and whose objectives were to investigate the wetting patterns in open and sub-surface systems and determine and recommend the better option of the two systems. The EC-5 Soil Moisture Sensor technique, along with the portable soil moisture monitoring system (TRIME FM), was employed to measure soil volumetric moisture. Water quantity changes (%) were determined through the emitters at 0 cm, 5 cm, and 20 cm depths for all experimental setups. Both irrigation systems underwent similar treatments, with the same water quality 2meters standardized head and 2 liters per hour discharge in all three cases. Frictional and other conveyance losses were assumed to be same in all scenarios.

The findings indicated that soil water content increased following an irrigation regime, but gradually decreased over time. Comparatively, the results demonstrated that the moisture in soil was more stable for T2 (5 cm depth placement) in subsurface drip irrigation compared to T1 (open/surface placement) and T3 (20 cm depth dripper placement). Over the same irrigation duration, 20 cm placement had stable water profile than open drip. Mean moisture content for T1, T2 and T3 were 25.98%, 30.09% and 28.45% respectively. The study concluded that subsurface drip irrigation at 5 cm depth (T2) outperforms open drip (T1) and 20 cm depth (T3) in maintaining stable soil moisture. With a mean content of 30.09%, T2 proves superior, indicating its effectiveness for efficient water management in irrigation practices.

It is recommended that future research may delve into analysis of performance of open drip vs sub-surface based on specific crop water requirements.

The study's results are expected to serve as a valuable guide for water managers and farmers in selecting appropriate irrigation systems for sustainable production practices.

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1.0 INTRODUCTION

1.1 Background Information

The advancing of irrigation development is a crucial agricultural policy in Kenya, with the aim of increasing food and horticultural crop production, thereby boosting the nation's economic growth and improving the quality of life for its people. The National Water Master Plan 2030 (NWMP, 2030) states that outside of the Lake Victoria North Catchment Area (LVNCA) and the Lake Victoria South Catchment Area (LVSCA), Kenya has few available water sources for irrigation.

The National Water Master Plan 2030 (NWMP, 2030) outlines a general strategy for agricultural and irrigation research that takes into account the challenges faced by declining water supplies for agriculture. Taking into account the Kenya Vision 2030's development goal of achieving new irrigation development of 1.2 million acres by 2030, we must maximise irrigation areas in each catchment, Enhancing water productivity by introducing and promoting water-saving irrigation methods to expand irrigation areas within the constraints of available water resources, By working together, government agencies and active water users associations made up of farmers, we can improve water management by bolstering the O&M of irrigation systems.

These strategies aim to optimize irrigation utilization while managing the limited water resources effectively, fostering sustainable agricultural development and contributing to Kenya's long-term vision for economic growth and improved living standards.

Meanwhile, on the global platform, irrigation has been largely adopted to curb food insecurity effectively. Conventional irrigation systems like farrow and flooding have been largely adopted due to low investment costs. However, such irrigation systems come with many challenges, with the key issue being the wastage of fresh water. Scientists have predicted global water shortage, severely impacting most nations by 2025 (Kenya included) and globally, affecting nearly "4 billion people by 2050".

In developing nations like Kenya, where groundwater levels are experiencing alarming declines, increasing water production has become an absolute necessity. Kenya is practising irrigation on a medium scale, with 670,000 acres having been developed for irrigation against 1,350,000 acreage potential (National Irrigation Authority Database, July 2013-June, 2022). A significant portion (over 70%) of irrigated agriculture in Kenya is under conventional irrigation systems, which include Basin, furrow and border strip systems. Such conventional systems are associated with several factors undermining irrigated agriculture production and environmental sustainability. The main associated demerits include; heavy water wastage, soil salinity, water logging, irrigation water wastage, deep drainage, and raised water tables (Walker, 2003). According to AIRC *(*2015), the Kenyan Government has demonstrated a willingness to invest in modern irrigation technologies by investing in advanced, more efficient irrigation systems, including Centre pivots (CP), sprinklers and drip systems, as demonstrated in Bura, Hola, Galana and Kulalu and various parts of the country.

Though on a small scale, such an initiative will go a long way in addressing perennial challenges experienced in conventional systems. The ineffective irrigation water utilization is more easily addressable by average irrigated agriculture consumers. Through National Irrigation Authority, the Kenyan government and private consumers have embraced drip irrigation, which has been considered more effective in water conservation, soil management and increased yields. Open (surface) trickle irrigation is widely considered as the most effective irrigation method. However, there are demerits associated with open drip systems. These disadvantages are contributed by, among others, water quality and systems maintenance and management challenges. Clogging of the emitters contributes significantly to reduced drip efficiency. Installation costs are also, at times, significantly high.

Subsurface drip systems have been introduced and practised in various parts of the world to address irrigation shortcomings of open drip. These sub-sub surface systems are relatively new and hence require further enhanced research. Buried Diffuser technology, for example, has been introduced in various parts of Africa, especially in Tunisia.

This irrigation system is suitable for irrigating varied tree species, including ornamental shrubs, vegetables, flower gardens, greenhouse applications, and plants in containers, pots and boxes. The buried diffuser efficiency has been demonstrated elsewhere (Chahbani, 2012) with recorded success. Among the pre-established advantages include; Minimal (almost zero) water wastage by evaporation, 2 to 3 times water utilization efficiency than surface drip, increased yields, simplicity to install, less maintenance, and relatively cheap and highly commercial potential, amongst others. Sub-surface drip technology is new in Kenya. Both Drip (surface and sub- surface) and buried diffuser irrigation systems are a bargain as they save enormous quantities of water.

In order to effectively make an informed choice of the most effective irrigation system of the two, a comparative performance efficiency study of both open drip and sub-surface systems was undertaken on a pilot demonstration plot in MWEA Irrigation Agriculture Development Centre (MIAD) Centre in Kirinyaga County, Kenya, where water emitted by the two systems was measured in terms of available soil water content at various depths (vertical and horizontal).

1.2 Problem Statement

Water scarcity already affects every continent (UNDESA, 2014). Kenya has a human population of over 45 million, out of which an estimated 20 million (over 43 percent) have no direct access to clean and fresh water. Historically, inadequate water (for human, animal and plant utility) has been main undoing for Kenya. This shortage (inadequacy) has largely been facilitated mainly by enhanced durations of droughts, weak management of systems and supply, pollution of present meagre water resources, increased conventional irrigation water use and abnormal upsurge in domestic water demands as an effect of expanding population. Minimal state‟s investment in water resource and management sectors has only but amplified the problems (Marshall, 2011).

Kenya is practicing conventional irrigation systems. Over 60% of the irrigated land is under surface irrigation, which includes Basin, furrow and border strip systems. This puts more pressure on the already existing water scarcity among other competing uses. Conventional surface irrigation systems account for massive wastage of freshwater resource with efficiencies being below 30% in most cases. There is hence need to adopt water storage mechanisms which may be costly or invest in modern irrigation technologies like drip.

It's important to note that every irrigation system performance varies from one place to another. In order to enhance adoption of drip system, there must be supporting scientific research facts on the more efficient drip application system (surface versus sub-surface).

Building on the required scientifically proven data supporting better of the two drip systems, a "comparative efficiency performance study" of both open drip and sub-surface drip systems on pilot demonstration plot in MWEA Irrigation Agriculture Development Centre (MIAD) were undertaken. It is believed that the findings detailed in this thesis will go a long way in contributing towards informed decision making on "better drip system", irrigation water saving and enhanced food production.

1.3 Objectives

1.3.1 Overall Objective

To compare performance between Open Drip and Buried/sub-sub surface Irrigation Systems under similar circumstances.

1.3.2 Specific Objectives

i. To investigate the moisture contents in open drip and buried/sub-surface systems.

ii. To compare moisture content stability of the two irrigation systems

1.3.3 Research Questions

i. What are irrigation efficiencies for open and sub-surface systems in terms of water moisture contents?

ii. Which system has higher and more stable moisture content over two weeks' irrigation regime?

1.3.4 Null and Alternative Hypotheses

i. There is a significant similarity between wetting patterns in open drip and sub- sub surface system.

ii. There is a significant difference between irrigation efficiencies based on wetting patterns of (i) (one) in relation to soil depth.

1.4 Scope

This research entailed engineering analysis of performance of open drip and sub-surface system by varying the depth of sub-surface drip against convectional drip irrigation system. Both systems were subjected to uniform two (2) meters head and quaranteed discharge of 2 liters per hour. The water content percentage (moisture) was measured with tension meters placed at 0cm, 20cm and 40cm respectively for emitters at each experimental block. For data validity, every treatment was replicated twice. The readings in moisture content (%) were noted and recorded after every 2hrs, 4hrs, 6hrs and 8hrs, 2 weeks of data collection. Experimental pairing was done by establishing six plots measuring (two plots per treatment) each measuring sixteen meters square, with clay loam soils, canopied, and initial moisture content of 18% in all cases.

1.5 Relevance of the Study

The thesis, "Performance Comparison Between Open Drip and Sub-Surface (Buried) System: A Case Study Mwea Irrigation Agricultural Development Center," is highly relevant as it delves into the practicalities of agricultural irrigation, offering valuable insights with direct applications to Mwea Irrigation Agricultural Development Center and potentially beyond. By comparing the performance of open drip and sub-surface (buried) systems, the research addresses critical issues related to water efficiency, resource management, and sustainability in agriculture. The findings may guide farmers, agricultural managers, and policymakers in making informed decisions about the most effective and environmentally friendly irrigation methods. Additionally, the study contributes to the broader discourse on technological advancements in irrigation systems and their implications for local and regional agricultural development, aligning with global concerns about water conservation and the environmental impact of farming practices.

2.0 LITERATURE REVIEW

2.1 Irrigation in Africa

Irrigation is essential for increased food production and improving human livelihoods, especially in rural setups. Africa has had a reasonable investment in irrigation development with notable success. According to "Future Agricultures" (WP119, June 2015), there were 18.0 million irrigated acres of land in use for crop production in Africa during the 1960s. Despite the fact that this area had almost doubled to 34 million acres after 50 years, Africa only irrigated 5.4% of its agricultural land by 2006v (Li et al., 2020). This is in comparison to a global average of roughly 20% and almost 40% in Asia.

However, these investments in irrigated agriculture have had a fair share of challenges leading to production targets needing to be met (FAO Aquastat, 2010). Development costs were considered extremely high concerning returns, and substantial techno-management encounters still needed to be solved besides freshwater shortages. Africa's population growth stands at over 30 million people per year. This increases the demand for sustained food production and fresh water.

Many sub–Saharan African countries are continually embracing irrigated agriculture as a way of feeding their ever-increasing population. Irrigated agriculture, however, comes with increased demand for freshwater, a main component in agricultural productivity (Guy, 2015). As a result, international stakeholders are now expressing interest in Sub-Saharan Africa with funding for innovative and sustainable irrigation technologies.

There are now many irrigation success stories, including those funded by donors, the governments and farmers. Such reported success incentivises enhanced research in irrigation and subsequent adoption of researched irrigation systems.

2.2 Irrigation in Kenya

Kenya is a predominantly agriculturally based economy, with agricultural production largely subsistence and dependent on rain. The National government has, however, been putting in measures to expand irrigated agriculture within the country since the inception of Economic Stimulus packages in 2003. The development of Medium-Term Plans has irrigation expansion as one of the strategies under the economic pillar. The efforts have since resulted in the development of a cumulative 670,000acreage under irrigation infrastructure against a national potential of 1,350,000 acres based on available surface water (NIA Projects database 2013- 2022).

Irrigation is the heaviest consumer of freshwater, taking up to 80% of the available resource. Kenya is a water stress country with 617 cubic meters available per capita per year, far less than 1,700cumecs per capita per year according to Falkenmark Water Stress Index (Afzal et al., 2020). The five water basins within the country account for over 90% of the renewable supply. Lake Victoria Basin contributes 54%, Tana River 19%, Rift Valley 14%, Athi River 6%, and Ewaso Ngiro, which covers 36% of the land area, contributes a meagre 2% of the available surface freshwater.

Irrigation constitutes more than 50% of the total fresh surface water demand in Tana and Athi Basins, while the remaining demand is attributed to industrial and domestic abstraction. As the government implements irrigation programs in these basins, it is projected that freshwater usage will increase tenfold, resulting in added strain on this valuable resource. To artificially apply water to the soil's surface or subsurface is known as irrigation (Punmia, 1992).

Various irrigation systems have been developed and adapted based on their intended application and suitability for users. Although plants receive water naturally through rainfall, in certain areas, the total rainfall may be insufficient or poorly timed.

The necessity for irrigation can be succinctly outlined as follows: regions characterized by low precipitation, areas with uneven rainfall distribution, cultivation of cash crops demanding supplementary water, and scenarios where precise water regulation is indispensable (Punmia, 1992). Over time, extensive research efforts have been dedicated to the field of irrigation, leading to the exploration of diverse techniques including surface irrigation, sprinkler systems, localized irrigation systems, as well as open and sub-surface drip systems.

A multitude of factors demand careful consideration prior to the selection of a specific irrigation system. These factors encompass the accessibility and quality of water resources, the lay of the land, soil conditions, prevailing climatic conditions, the types of crops intended for cultivation, availability and cost implications of both capital and labor, appropriateness of the irrigation technology for local farmers, the energy prerequisites associated with the chosen system, water utilization efficiency (Andreas, 2001).

When determining the most suitable irrigation system, a judicious approach involves the utilization of a range of criteria. Nevertheless, there are circumstances where a single criterion might carry substantial influence, tilting the balance in favor of a particular irrigation method. For the selection of an irrigation project with long-term sustainability, an all-encompassing assessment of technical, socio-economic, health, and environmental information becomes imperative. This ensures that the chosen system possesses not only technical feasibility and

economic viability but also social acceptability and environmental integrity (Andreas, 2001).

Many scholars have since conducted studies in the field of irrigation.

Irrigation expansion means increased freshwater stress since 80% of the country is ASAL. Bura, Hola, Mwea, Perkerra, Ahero, Bunyala and West Kano are traditional irrigation Schemes in the country. All the aforementioned schemes employ surface irrigation (flood, basin and furrow) as a method for water application. Conventional irrigation methods are synonymous with less efficiency and water wastage.

The Kenyan government has for a long time been attempting to find amicable solutions towards meeting irrigation water demand geared towards food security while at the same time maintaining an internationally acceptable level of equitable water distribution and access while maintaining environmentally sound for sustained agricultural production (Ngige, 2002). On the evaluation of Kenya's irrigation development, (Ngige, 2002) outlined the following recommendations:

The government needed to adopt reasonable policy changes while creating accessible platforms to inform all critical stakeholders about policy shifts timely. Commercial farming needed to be also embraced by adopting "water stress-resistant" crops in ASAL regions. The state should also strengthen the capacity of bodies to solve "water-based" conflicts due to competition created due to water inadequacy.

Ngige further noted that there was a need to enhance on-farm water management, adopt new irrigation technologies and ensure there is growth in operational knowledge of better and more precise irrigation systems. Farmers also needed to be encouraged to adopt and improve on on- farm innovations and technologies by conducting water application trials. Officers responsible for implementing irrigation programs should also examine developing water irrigation demands

in existing water sheds development in consultation with Farmer Organizations (FOs), Irrigation Water User Associations (IWUAs) and Water Resource User Organizations (WRUOs)

Apart from using a highly efficient irrigation system, planning and organisation of smallholder irrigation and drainage was found to be another critical requirement. National Irrigation Authority has been implementing a smallholder irrigation expansion program where improved water conveyance and application efficiency have been adopted on some projects. The result has been improved yields and reduced abstraction water quantities, maintaining environmental flows for downstream users.

2.2.1. Irrigation and Development

In 2013, National Water Master Plan took effect and estimated that Kenya has irrigation potential of 2,000,000 acres. The Irrigation Strategy (2021-2030) has since revised the figure to 1,350,000 acres which can be irrigated by available surface water.

Kenya is an acute fresh water country, hence relying on limited surface run offs leads to insufficient water supply for irrigation. Coupling this with conventional irrigation systems like flooding increases stress on available fresh water .

Investing in new irrigation methods like drip, adopting on-farm water-saving practises, and expanding research and development in the irrigation sector can all help with the current problem of water sustainability and prudence. Water conservation and increased efficiency in the use of fertiliser, labour, energy, and electricity are two key benefits of drip irrigation. The literature on this topic is extensive (Kumara & Palanisami 2010; Kaushal et al. 2012; Kumari et al. 2014; Sharma & Kaushal 2015; Rao et al. 2017; Rao et al. 2018).

Kenya has been able to sustainably produce annually over 150,000tons of rice, 500tons of seed rice, 6,000 tons of seed maize amongst other crops for over five years period. Irrigation expansion efforts and water storage since 2013 to 2022 have seen Kenya Shillings 51billion generated as gross income benefitting 258,766 Kenyans (NIA Projects Database June 2022 PP 11).

The acceptance and incorporation of highly efficient irrigation systems carry the potential to not only amplify agricultural output and significantly contribute to socioeconomic progress, but also to conserve substantial quantities of essential freshwater resources. Drip irrigation, a prime exemplar of such a system, entails the precise discharge of water onto the soil at remarkably low rates (as little as 1.8 liters per hour) through a network of narrow-diameter pipes outfitted with outlets known as emitters (Li et al., 2020). This method ensures that water is applied in close proximity to the plants, thereby moistening solely the portion of soil where their roots are actively developing.

Unlike alternative irrigation methodologies, drip irrigation employs more frequent watering intervals, typically occurring every 1 to 3 days. This distinctive approach engenders an optimal moisture balance within the soil, which fosters an environment conducive to robust plant growth. In essence, this practice nurtures a favorable habitat where plants can thrive, leading to enhanced productivity and agricultural yield. Furthermore, this method of irrigation exhibits an inherent capacity to conserve water resources, aligning with broader efforts to address the growing scarcity of freshwater.

2.2.1.1 Conventional technologies

Bulk of the 670,000 acres under irrigation in Kenya is under conventional systems mostly furrow and basin. Basin irrigation is practised in rice growing schemes like Mwea, Ahero, Bunyala, Lower Kuja and of late Bura and Hola Schemes where Komboka rice variety has been recently introduced. Perkerra, Hola, Bura, Katilu and Lokubae are some of schemes/projects where furrow is practised. Pump fed systems like Bura and Hola have recorded huge conveyance losses in addition to “wasteful” furrows.

2.2.1.2 Modern Technologies

There is every growing need to convey and apply water artificially for crop production. However, one of the biggest challenges has been initial investment costs. There has been however increased uptake of modern technologies by key players in the industry. Adoption of sprinkler, centre pivot system and drip are on the rise, with National Irrigation Authority having 10,000 acres under centre pivots and drip in Galana and Kulalu Food Security Project (GKFSP) (Muhammad et al., 2022). Such systems have recorded higher efficiencies hence reduced water wastage. All these technologies are reported to have improved production, water utilization efficiency and reduced labour costs.

2.2.1.3. Technology Uptake

Modern and affordable technologies may help smallholder irrigators to sustainably produce crops that can meet demand. These technologies could facilitate farmers to transit to commercial farming from subsistence. Some of the factors that could influence technology uptake include; a) Availability of market for the expected produce; b) affordable and appropriate technologies that are easy to acquire, implement and operate; c) ease of accessibility to manufacture and repair; d) efficient distribution networks for required and up to date inputs including and not limited to transportation, infrastructure development and local dealers (Kay, 2001). All these coupled with ever growing need of saving water could work together in improving productivity.

2.3. The Need for Irrigation

Irrigation is of great importance in stabilizing food production in many countries by supplementing, precipitation or replacing the natural precipitation process in crop production.

Irrigation enables many nations and farmers to feed themselves and provision of good living standards. Irrigation does not only protect against drought but has other benefits as well as problems. Civilization in most Mesopotamia, 4000 years ago, depended on irrigated agriculture. Waterlogging and salinization, erosion and deposition from irrigation have rendered most farms no longer key in terms of agricultural production. (Fethi, 2016).

2.4. Types of Irrigation Systems

A good knowledge on the types of irrigation systems is essential for an Irrigation Engineer, Operator, Researcher or farmer who wants to venture into irrigated agriculture since it makes him/her make wise decisions pertaining the choice of a system that is suitable for his/her farm. There are five irrigation methods which include; Surface, Sprinkler, Sub-surface, Micro and Hybrid irrigation systems.

2.4.1. Surface Irrigation Systems

In surface irrigation, water is pumped to the highest point on the property and then allowed to flow across the field by gravity. Consequently, as the water travels across the field, it infiltrates or pools. The energy gradient that causes water flow in the farm depends on the soil surface slope and the water surface gradient of the moving stream. In this system, the coefficient of uniformity is dependent on the homogeneity of the soil's infiltration characteristics and the intake opportunity time, which is the time required for a unit area of soil to be inundated. Once irrigation water has reached the lower portions of the farm, runoff occurs. Basett et al. (1987).

Surface irrigation is composed of four phases which are; the advance (initial) phase where the water is introduced into the field by intake and main canal and flows to the lower side of the field where runoff takes place. The second phase is the water storage or ponding phase, in this phase, the water has just been introduced into the high elevated fields. The ponded water continues to flow down with reduced velocities, hence high infiltration and wetting of the soil. The third phase is the depletion phase where the water inflow is stopped and depth of stored water starts to decrease. In this phase, the water would also be redistributing itself to other points of the field (Muhammad et al., 2022). The last phase is the recession phase where water disappears upstream and the recession front travels across the field up to when the surface is no longer inundated.

Surface irrigation is a simple form of irrigation system because only a river dyke and canal are required to transport water to adjacent lands. The other advantage is that the cost incurred to set up the system is quite low compared to the pressurized systems unless the farm to be irrigated is far from the river. The disadvantage with this kind of a system is the inefficiency in the application of water compared to sprinkler and drip irrigation systems. Additionally, the cost of land leveling for conveyance and distribution is expensive in areas whose slopes are uneven.

2.4.2. Surface Irrigation Methods

The various types of surface irrigation are:

i. Flooding and contour ditches

In this system, canals are dug at the highest point of the field and water is allowed to flow downwards in an erratic manner.

ii. Border Dike

This technique involves constructing earthen dikes parallel to the direction of the steepest land slope. Border strips are level in a direction perpendicular to the dikes. Water introduced at the upstream end of such a strip tends to spread across the full width as it advances to the lower parts of the field. In this system, vegetation may be planted perpendicular to the slope to encourage the flow of water to distribute itself across the width of the strip.

iii. Graded Furrow

This method is mainly applied for annual crops and some trees and vine crops. Furrows are formed between the crop rows and water is introduced into each furrow at the upper end of the field by siphon tubes or cutouts in a ditch or gated pipe outlets.

iv. Corrugation

This system is similar to graded furrow irrigation only that small and shallow furrows or corrugates are used for close growing crops. These corrugates have small flow rates to minimize soil erosion in erosive soils.

v. Level Basin

This is an irrigation method done to a level soil surface where the field doesn’t slope in any direction. Close growing crops such as grass, rice and hay are grown on the basin surface. Water is introduced from one or two turnouts along one edge of the basin. The basin is surrounded by dikes ensuring that once the water has advance is complete the water starts to pond and no runoff occurs. The amount of water required to infiltrate to a certain depth can thus be determined accurately in this system.

2.4.3. Sprinkler Irrigation

This is the process of applying water to the soil using a device that directs a stream of water through the air and into the soil via a pressurised conduit. This form of irrigation system attempts to simulate natural precipitation. The system's design determines the size of the drops, the uniformity with which they descend, and the system's overall effectiveness.

When sizing of nozzles is precisely done together with spacing of sprinklers and right pressure, the water quantities needed for crop root zone is applied with uniformity at rates that suit particular soil infiltration capacity. The merits of sprinkler irrigation system include; doing away with cumbersome conveyance systems hence conveyance losses are eliminated. The system suites most soil types apart from heavy clay, high intensity cropping, higher water utilization and application efficiency, increased productivity, mobility (flexibility), can be utilized at undulating areas, land saving ie no bunds, amongst others. Sprinklers are generally classified as Rotating head and perforated pipe systems. Rotating head has laterals running on ground surface with small nozzles placed on riser pipes which tend to be fixed at equal intervals. Rotating heads are able to irrigate circular and wider areas than fixed types. Perforated system has holes drilled or nozzles longitudinally where water is emitted by spraying under designed pressures. This system has low pressure application requirements (usually 1 kg/cm2).

In terms of portability, sprinklers can be classified as portable, semi portable, semi-permanent, solid set and permanent systems. A portable system is composed of movable mains, laterals and pumping mechanism. Semi portable has pumping mechanisms and water source are fixed. The other components are movable. Semi-permanent has portable laterals with fixed mains and sub-mains with fixed water source and pumping mechanism (Muhammad et al., 2022). Solid set comes with several laterals that are placed in the farm for entire irrigating duration hence movement is eliminated.

Permanent system has all components fixed. Most installed sprinkler systems have 90% conveyance efficiency and 70% field application efficiencies (Atef. Hamdy, 2012).

2.4.4. Drip Irrigation

Drip/trickle irrigation system encompasses emitting water on and into soils at low but precise rates usually between 2 to 20 litres/hour. Irrigation water gets to targeted crops at root zones hence wetting only important soils unlike conventional and sprinkler systems, which wet entire soil profiles. Depending with a number of factors, frequency for drip irrigation is between 1 to 3 days, thus providing favourable optimum moisture levels for growth of crops and hence increased yields.

Drip components include water source, filtration mechanism, pumping, laterals and emitters. The types of emitters are characterized by their mode of operation, such as laminar, turbulent, orifice, or compensating emitter. Compensating emitters are suitable for undulating fields while the other types are suitable for flat or gently sloping fields. The operating pressures along the lateral lines range between 35 kPa and 140 kPa (5-20 psi) (Junejo et al., 2023). The pressures at the water control station should be between 245 and 310 kPa (35-45 psi) i.e. 3.2 m to overcome losses through filtration and other regulating equipment (Bernuth and Solomon, 1986).

2.5. Performance of surface drip irrigation: Case Study: South Africa

This section delves into the performance of surface drip irrigation, focusing on a case study in South Africa. Examining practical implications and outcomes, it contributes valuable insights to optimize irrigation strategies for sustainable water management in diverse agricultural settings, addressing the critical issue of water scarcity and resource efficiency.F.H. Koegelenberg, 2012 conducted research on performance of surface drip. Observations were made on performance of various drippers based on water quality, soil types and systems maintenance. The findings indicated variation of discharge coefficients in new drippers (CVq) ranged from 2, 1% (Excellent) to 4, 2% (Good) averaging at 3, 12%. The CVq of drippers that were pressure compensated averaged 3.45%, while normal drippers had a better 2.63%.

Emission Uniformity (EU) was noted to deteriorate as calculated in the field of all kinds of drippers over time from 87.1% during the first evaluation to EU of 82,4% in the fourth and final measurement. This was a possible indicator of drippers' performance being affected by clogging resulting from water quality, soil profiles, and temperatures amongst other concerns. From the study, deductions were made on need of improved designs and manufacturing of anti-clogging emitters and/or further development and adoption of sub-surface systems to address clogging and other environmental related challenges facing surface drip.

Ahmed et al. (2012) initiated the exploration into surface and subsurface irrigation systems, using pipes with varying flexibility. Our study expands upon their research, revealing that low flexible drip pipes, particularly in subsurface conditions, exhibit superior water use efficiency. This results in increased fruit yield per tree during peak periods. Despite higher upfront costs, subsurface drip irrigation proves economically advantageous, yielding higher revenue and gross margin per hectare per season in US dollars. This underscores the potential of subsurface systems, especially with low flexible pipes, in optimizing agricultural productivity.

2.6. Understanding Sub-Surface Drip Irrigation

Irrigation is the process by which water is artificially supplied to agricultural crops. The amount of rain that can be used to grow food crops would be the limiting factor in a world without irrigation.

Emitter homogeneity, water efficiency, and greater efficiency are just few of the reasons why subsurface drip irrigation is widely regarded as the most effective method of watering crops.

Placement depth of laterals, emitter spacing, lateral spacing, discharge rate of emitters, and system pressure are all important aspects of the Sub-Surface Drip Irrigation (SSDI) system. According to numerous studies (Assouline et al., 2002; Lamm & Trooien, 2005; Elmaloglou & Diamantopoulos, 2008; Bozkurt & Mansuroglu, 2011; Badr & Abuara, 2013), these variables have a major effect on the soil moisture distribution pattern and the efficiency with which water is delivered to the plants. With SSDI, water is applied below the soil's surface and seeps down via the emitters to the root zone. According to research conducted by Njovu (2018), the amount of water retained in the root zone is proportional to the soil volume that has been wetted.

With SSDI, the root zone of a crop is continuously sprayed with tiny droplets of water, soaking it from above via gravity and from the sides via capillary action. Bainbridge (2001) and Wei Wei et al. (2010) found that this method helps conserve water by reducing the amount of water lost to evaporation in agricultural systems.

2.6.1 Overview of drip irrigation Components

There are many components of drip system, which each playing a pivotal role. These components are clustered in water source, pumping system and in-field distribution network

2.6.1.1 Source of Water

The main water sources include surface and ground water sources. Surface water could be tapped from natural flowing rivers, streams and artificial storage systems that include dams and water pans. Most surface water sources have less salt levels, hence being the most preferred for drip systems. However, there is need to improve water quality in some cases where sediments are reasonably high and could encourage clogging in drippers. (M. Pandit, 2013)

In such cases, small sedimentation basins are constructed to facilitate settlement of silt loads. These are some of the biological hazards that need to be handled when the available water source is surface. Where wastewater could be considered as the only potential water source, there will be need to factor in water treatment to improve on water quality and reduce potential clogging effect, enhance palatability and acceptable biochemical levels (Junejo et al., 2023).

Groundwater is mostly fresher and of high quality. This water source has also less turbidity. There is however a general tendency of this water source having higher mineral contents mostly manganese and iron (depending on the host rock). These levels should be determined through measurement and necessary chemical treatment done if the levels are very high to reduce clogging in drippers. (M. Pandit, 2013)

2.6.1.2 Pumping

Pumping is important to create adequate pressure to ensure stable water supply through pipes and emitters. This of course works in a situation where other water supply entities like Municipalities that could be cheaper don"t exist. Pumps and pumping are mostly an integral part of drip systems. Pumping and water storage go hand in hand. (FAO.org).

Hydrostatic/Gravitational Pressure

This is the pressure created by fluid in reference at rest as a result to the force being exerted on it by fluid above it. Where the water is at higher elevation than field conveyance system, then the elevation difference determines the Hydrostatic Pressure level in the irrigation system. (I.e. assuming that the storage tank water level is 10 meters measured above pump axis elevation, then the Hydrostatic Pressure is 10 meters = 1.0 bar).

Such a system calls for careful pump selection by considering optimally required head, fuel consumption, type of fuel, durability, serviceability and ergonomics. Water quality, water source, environmental conditions and crop selection play pivotal roles in determining which pump is suitable for the intended purpose.

2.6.1.3. Infield Distribution Network

In designing and laying field conveyancing; costing, efficiency and need are primary factors considered. Drip irrigation systems handbook outlines mains pipe selection (polyethylene, PE) as shown in table below;

Pipe diameter/class*	Outside Diameter (OD) (mm)	Wall Thickness (WT) (mm)	Inside Diameter (ID) (mm)
63/12	63	4.70	53.60
75/12	75	5.60	63.80
90/12	90	6.70	76.60
110/12	110	8.10	93.80
125/12	125	9.20	106.60
140/12	140	10.30	119.40
160/12	160	11.80	136.40
200/12	200	14.70	170.60
225/12	225	16.60	191.80
250/12	250	18.40	213.20

*By international standard ISO 4427/07.

Laterals

The ultimate of drip irrigation system are dripper lines also known as laterals. Spacings between emitters and lines, flow rate, thickness of dripper walls are key considerations factored when designing dripper lines. The depth of insertion is also considered in sub-surface irrigation regimes.

Drippers are either non pressure compensated (NPC) or pressure compensated (PC). NPC emit water based on design working pressure. PC system is preferred for both open and SDI systems since pressure difference is continuously created by labyrinths which activate diaphragms resulting in stable flows and discharge in wider pressure ranges (Junejo et al., 2023). Working pressure fluctuations doesn’t affect targeted emitter discharge.

The PC system that comes with free floating diaphragm enables dripperlines to be constantly self-flushing, hence eliminating particles that could cause clogging. This overriding advantage makes such system good for SDI (sub-surface drip irrigation). Drip systems manufacturers like Netafim have since designed suitable brands that come with Anti-Siphon mechanisms which prevent dirt being sucked into dripperlines. The anti-siphon mechanism closes drippers when it's not pressurized hence pollutants don't enter the system (Junejo et al., 2023). No pressure cases are common when irrigation regime is not active ie during rain seasons and when the soils are saturated, or when the field capacity is attained. PC drippers are highly recommended to ensure sustained uniform water distribution, longer dripperlines and where there is enhanced topographic variations.

The profiles of irrigation water movement vary according to soil textures. Coarser textures like sandy soils require shorter dripper spacings due to less water movement laterally than finer soil textures like clay.

The table below details medium sized dripper selection based on available flow pressures.

Dripperline model	Pipe's inside diameter(ID)(mm)*	Wall thickness		Max. working pressure (bar)	Max. flushing pressure (bar)
		(mm)	(mil)		
12200	12	0.50	20.0	3.0	3.5
12250	12	0.63	25.0	3.5	4.6
16200	16	0.50	20.0	2.5	3.3
16250	16	0.63	25.0	2.8	3.6
16007	16	0.70	27.0	2.9	3.8
16008	16	0.80	32.0	3.0	3.9
22250	22	0.63	25.0	2.5	2.9

Netafim specifications: Source drip Irrigation Handbook

Modern dripperlines come with flushing manifolds. The manifolds flush particles that can cause clogging by opening flush valves when flow rates and water velocity through the lines is greater than usual operating modes. The settled solids are hence removed (flushed) and precipitants, hence preventing clogging.

The flow velocity of at least 0.5 m/sec is designed for manifolds ensuring effective sediments removal.

Many systems of drip irrigation have been in use. The most common types are as outlines below;

1. ***Bucket systems***

The Bucket-like storage is used to store and release water into drip lines. The reservoir is usually placed at 0.5m to 1m above the drippers on ground, hence providing required pressure. This system is labour intensive due to small storage capabilities of buckets due to requirement to be filled regularly in short intervals. The system is efficiently utilized in situations where irrigation water requirement varies between 30 to 60 litres daily (Afzal et al., 2020). Such small systems are suitable for small scale vegetable growing. (Blank et al, 2002).

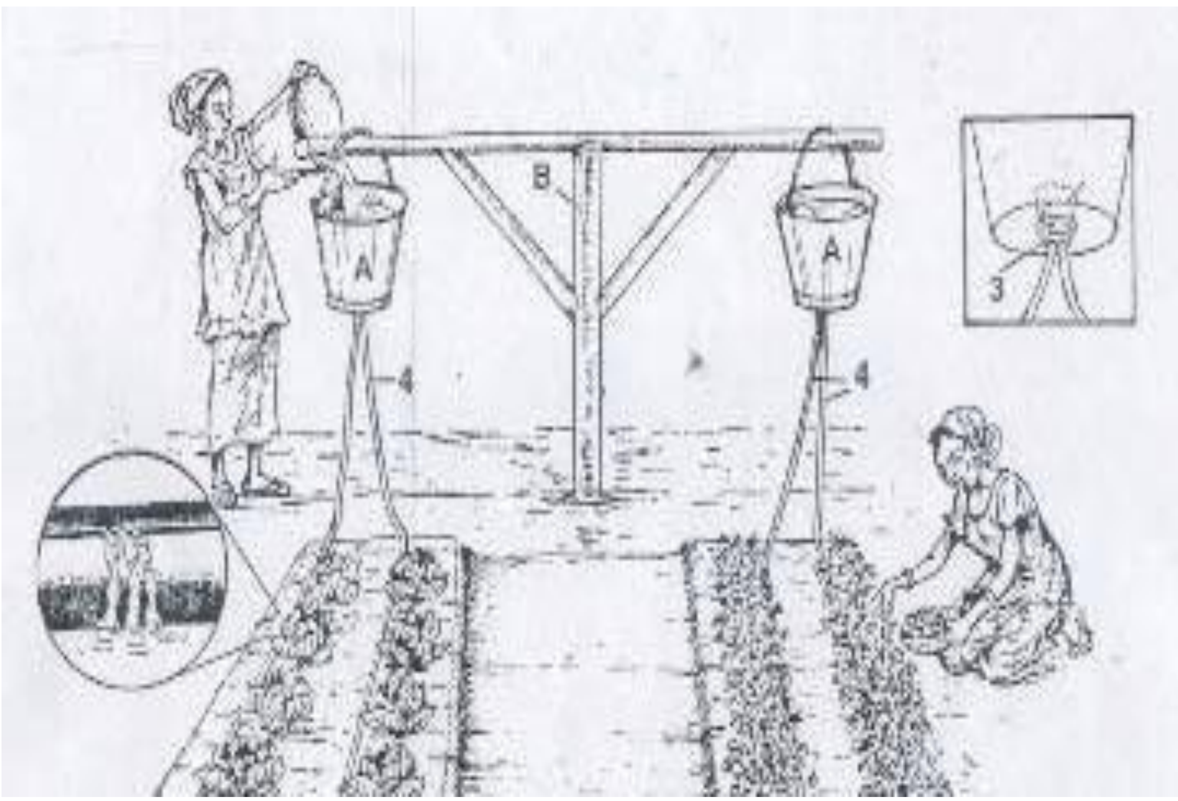


Figure 2 : Bucket system (Source: Blank et al, 2002)

2. ***Drum systems***

This is a low-pressure operating system, requiring a head variation of between 0.5m to 5m. This is one of the commonest drip systems in application today. A drum (storage) is usually hoisted at 1m above the dripper level. This system can achieve a bigger area (up to 1,000m2) than bucket system. The increased irrigable area coverage has more production benefits and lesser maintenance needs than bucket system. Farmers can hence have a wider crop selection criterion here.

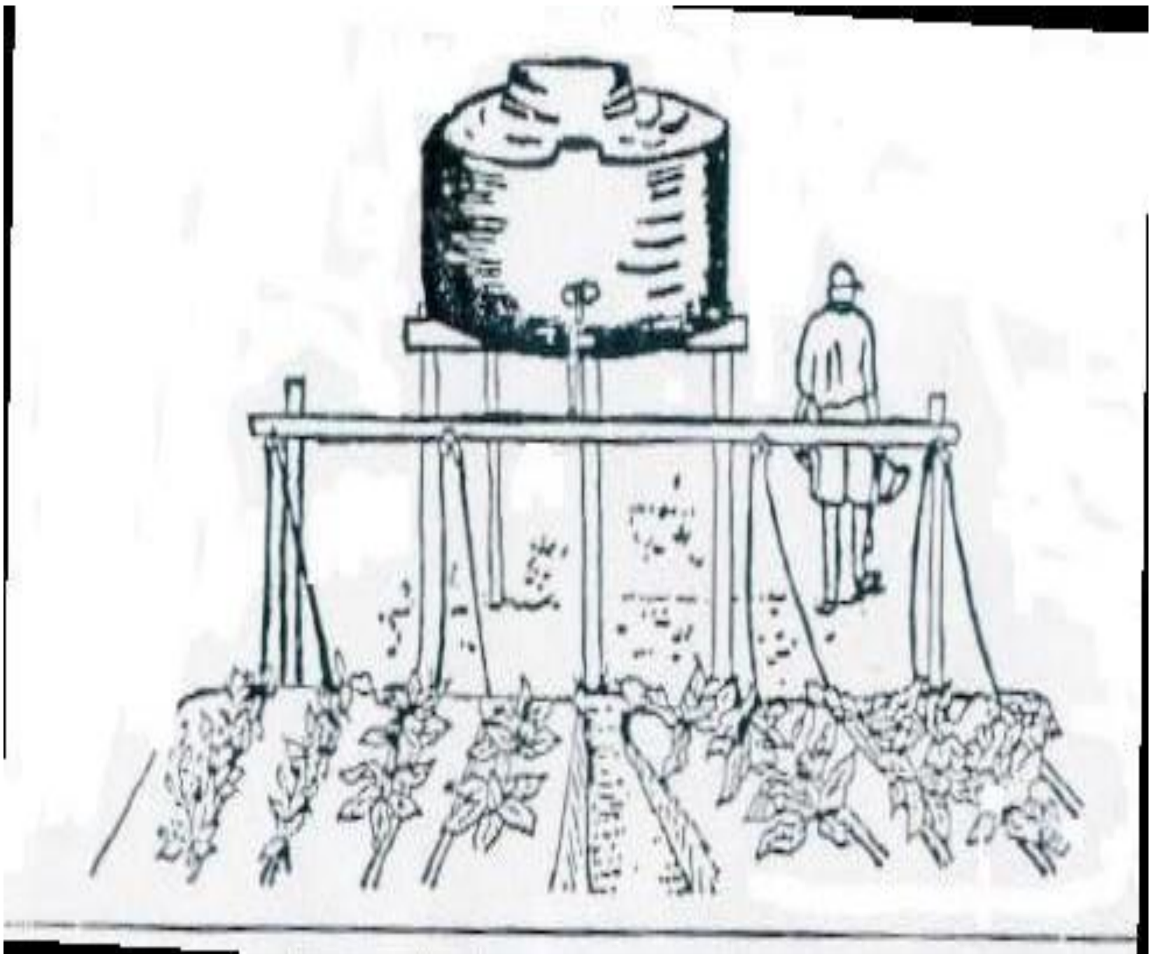


Figure 3: Drum system (Source: Blank et al, 2002)

3. *Eighth-acre systems*

This is the latest technology introduced to most Kenyan farmers. As the name says, the complete drip kit covers an eighth (0.05ha) of acre and is suitable for small scale vegetable production or it can be rolled out in large scale for commercial production.

Because of increased efficiency, this system can increase plant holding capacity 20 times that of bucket kit. This system is pre-packaged, and has drip lateral lines (usually 20 in number) which are hooked to the vinyl hose that is flat. This system has full self-installation and maintenance instructions.

The system components include;

a. Head unit: It comprises of pressure regulator and water filter

b. A PV hose that is 15m in length,

c. Drip tube (600m rolled out to set 20 drip lines of 30m each)

As discussed earlier, conditions necessary for setting up successful drip include availability of good quality water, optimum water flow (minimum of 1m3/hr) and adequate pressure (minimum of 0.5bar or 5m).

System management: For sustained functioning of the drip system, it’s important to clean filters on regular basis to remove dirt. Flushing for end of drip is also vital as well as unblocking of outlets.

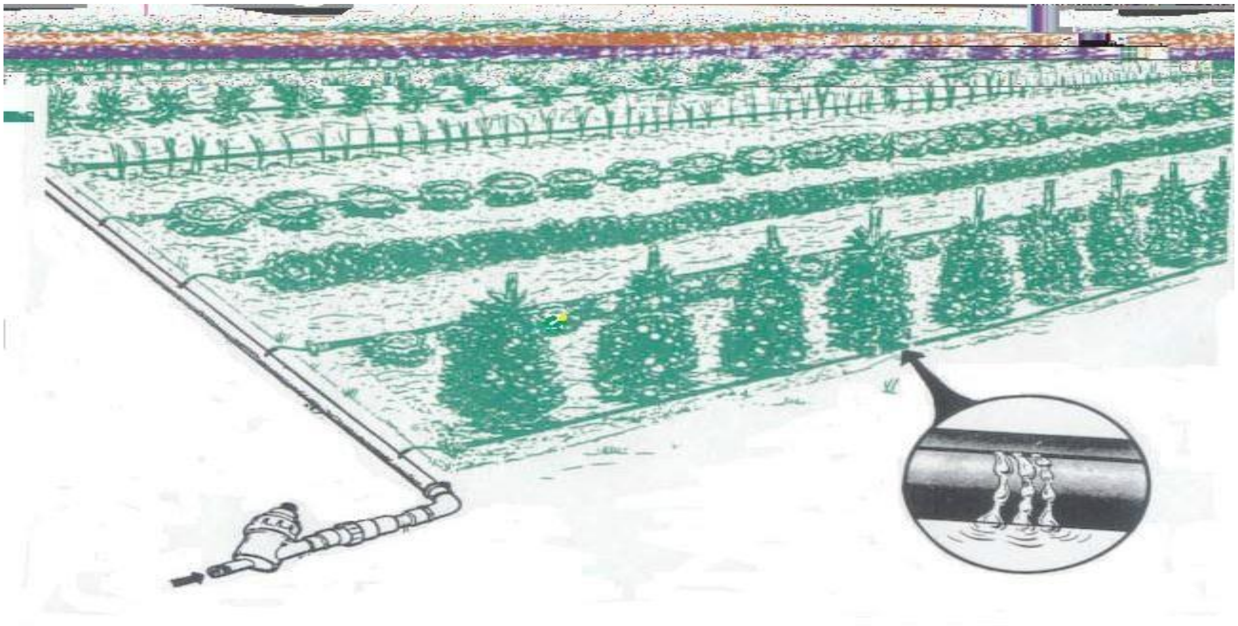


Figure 4: Eighth-acre system (Source (Blank et al, 2002))

2.7. Sub-Surface System

Subsurface drip irrigation employs hidden diffusers and drip tubes or tape to irrigate plants at low pressure and with great efficiency.

Because of sub-surface water application, the disadvantages of open drip including crusting, ponding water saturated conditions, drip lines physical disturbance and potential soil erosion are eliminated. Smart sizing and scheduled maintenance ensure that crop water application is in high uniformity and efficient. The reported wetting pattern is well distributed.

Sub surface irrigation has improved water savings and better yields are also recorded by elimination of surface water evaporation, weeds challenges and crop diseases.

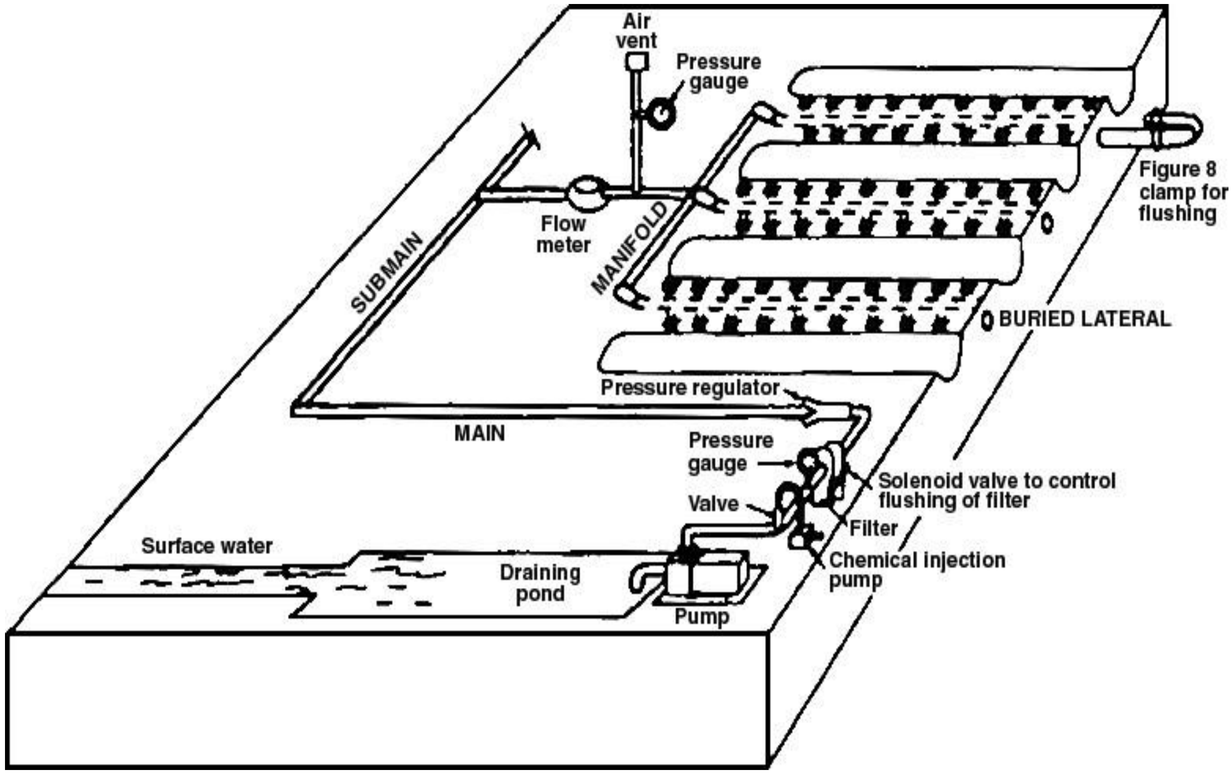


Figure 5: Design layout of sub surface drip system components. Source: (Blank et al, 2002)

2. 7.1 Buried Diffuser

The diffuser can be made from a range of locally available materials including but not limited to plastic, metal, rubber, ceramics etc. however, the most common and affordable material is plastic or PV group.

Diffusers can be designed or moulded in various shapes to suite intended use. Unlike the normal drip, diffuser irrigation is localized. Water drips directly to the crop's root zone hence minimizing transportation and evaporation losses (Afzal et al., 2020).

The diffuser has a bottom part connecting the water emitter that is made of a selected porous material that allows enhanced infiltration of water to the root zone.

Trial Results

Diffuser application trials have been done in Tunisia and other parts of the world with recorded success. While the systems are easy to manufacture and adopt, the technology has not spread much, with no recorded trials in Kenya and East Africa. The major findings in Tunisia trials were documented as follows;

Water savings: The research (Dr. Chabhani, 2013) found out that the diffuser prototype performance at both field and controlled environment outwitted open drip system. The 2 months long experiment was conducted in 2013. After 61 days of trials, diffuser saved up to 34% of irrigation water while open drip saved 8%.

Reduced irrigation frequency: This is a measure of water saved hence prolonging two irrigation intervals period. The experiment compared irrigation of crops in containers irrigated by both surface and sub-surface emitters.

The resulting findings were as tabulated below;

After 2 months' duration, buried diffusers containers had 89 and 91% water content whereas surface drip had 51% and 54% water contents respectively.

After double the period, it was recorded that the available irrigation water for surface system was 22.6% and 20.6% while the diffuser had 81% and 84%.

The deduction in the programmed irrigation is that if 50% of field capacity is attained by water content, then surface drip can only attain a 2 months' irrigation periodicity while diffusers attain 6 months. This implies that with a same water amount, diffusers can produce three times the surface drip.

Literature gathered from previous research regimes have shown that adoption of drip technology (both surface and sub-surface) has tremendously saved irrigation water. However, it's paramount to note that there exist notable gaps in previous studies that require further research. Further quantification of emitter efficiencies, in varied fields and location, for both surface and sub- surface systems is hence necessary to contribute towards more informed decision making on best drip option is hence necessary.

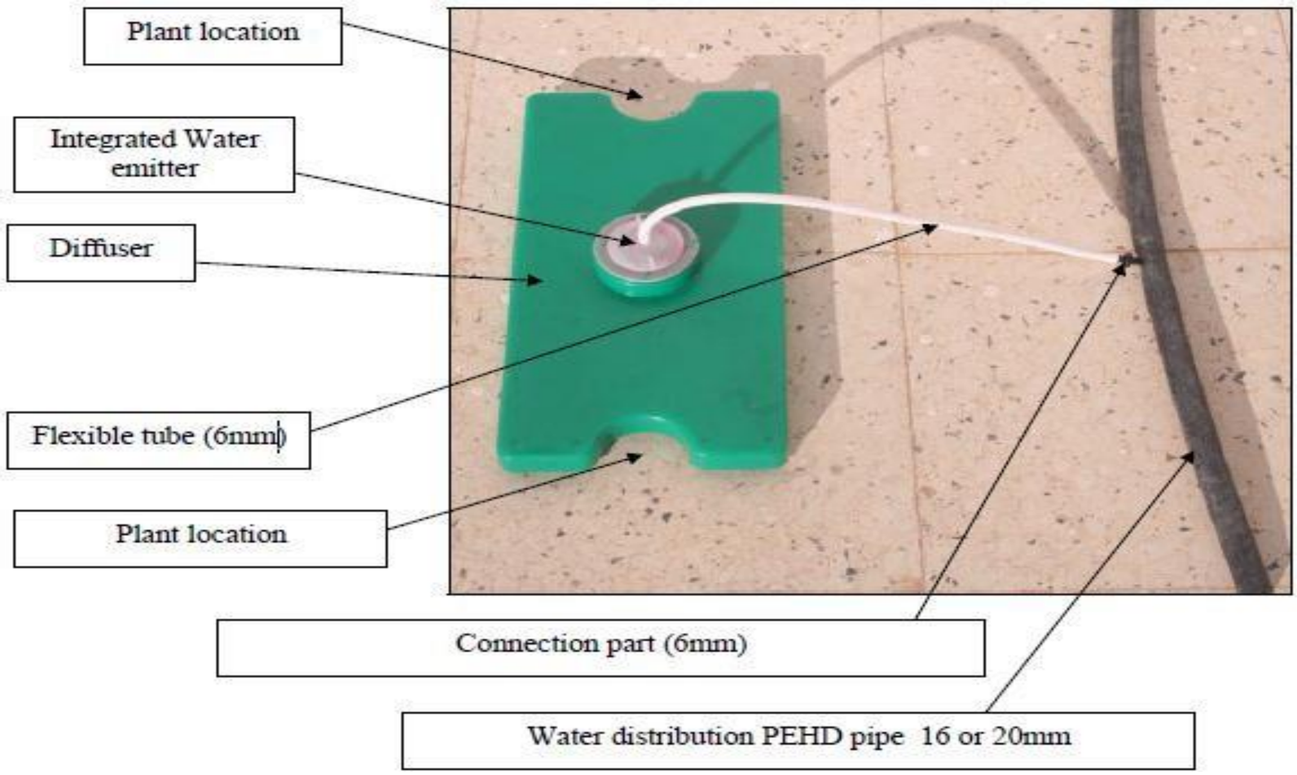


Figure 6: Components of Buried Diffuser System (Source: www.chahtech.com)

2.8. Theoretical Framework

The first step in the irrigation process is calculating how much water the crop needs to replace what is lost via evaporation and transpiration. The Evapotranspiration Rate (ETo) must be determined for this purpose, and several methods for doing so have already been covered. The crop water need and irrigation requirement for this scenario were calculated using the CROPWAT model analysis and the crop coefficient.

When comparing two irrigation systems that use the same pressure, the average emitter discharge can be calculated by dividing the supply flow-rate by the total number of emitters being evaluated. According to the description given by Burt and Styles in 1994, the outcomes of these tests are displayed in the form of a table, a discharge curve, and a mathematical equation.

2.8.1 Emitter Discharge

1.1.1 $Q = kP^x$..Equation 1

Where: Q = emitter discharge (l/h)

k = emitter constant

P = emitter operating pressure (kPa)

x = discharge exponent.

Theoretically, the Q in Equation 1 above should be equal to water retained in the wetted area, over specified time. Movement of water in the soil creating wetted area is determined by soil conductivity (K) and estimation of the wetting front.

Darcy developed an equation estimating flow of water (q) through the media as;

1.1.2 $q = KA (h_1-h_2)/L$.. Equation 2

or q = Q/A = -K dh/dl, h: *hydraulic head*, $h = p/\rho g + z$

where;

Q = volumetric flow rate (L^3/T)

K = hydraulic conductivity (varies according to the media texture and uniformity)

Δ*h* = difference in hydraulic head between two measuring points (h2-h1). Since h2, h3, h4 will always be less that h1, Q is hence negative).

ΔL = length along flow paths of measurement (L2-L1)

A = cross-sectional area of flow perpendicular to the direction of flow (L^2)

Under ideal conditions, q (Equation 1= Q) at h1.

Now, to determine h2, the suction head must be available as a positive value, whose negative value must be taken for energy head fluid flow.

Therefore h1= h0

1.1.3 H2= -(Hs)-L .... Equation 3

Where Hs is the suction head.

The volume of each calibrated container for collecting samples is divided by the time and goal volume to determine the discharge of individual emitters at a given pressure. All of the selected emitters have their CVq values, minimum and maximum discharge, and discharge variation determined. Here's how you get the CVq, which is the standard deviation as a fraction of the mean discharge:

$$V = \frac{1}{n}\sum_{i=1}^{n} q_i \qquad \textbf{Equation 4}$$

$$\mathbf{CV\ q} = \frac{sq}{V} \times 100 \qquad \textbf{Equation 5}$$

Where: Qi = Emitter Discharge Rate (L/H)

N = Number Of Emitters Of The Sample

V = Mean Of All The Measured Discharge Rates (L/H)

Sq = Standard Deviation Of The Discharge Rate Of The Emitter.

Cvq = Coefficient Of Variation Of Discharge Rate Of The Emitters (%).

The Emitter variation will be hence measured against available water content for the crop over a time period (t).

2.8.2 Wetting Pattern

The size of the wetting pattern is influenced by a number of factors including;

a. Soil initial conditions
b. The emitter discharge as determined in equations 2-1, 2-2 and 2-4 above
c. Irrigation application management
d. Evapotranspiration
e. Crop root characteristics and
f. Types of soils

Wetted volumes of soils have been shown to be influenced by varying design parameters (laterals and emitter spacing, pressure of the drip system, flow rate amongst others). (Lubana and Narda, 2001) review presentation indicated that there is inadequate publications and research on design parameters to effectively choose between surface and sub-surface drip systems.

2.6.3 Empirical Models for Wetted Area

Since then, empirical models based on regression/dimensional analysis and field data have been created to aid in predicting drip wetted area (for both surface and sub-surface systems).

Wetted area (Aw) was first estimated using a table created by Keller and Bliesner in 1990.

A universal semi-empirical model for calculating the depth(Y) and width(X) of the wetted soil volume at the emitter point was developed by Zir and Schwartzman (1986).

1.1.4 $X = 1.82V^{0.22} (Ks/Q)^{-0.17}$ ……………………………………………………………… **Equation 6**

$$\mathbf{Y = 2.54V^{0.63} (Ks/Q)^{0.45}} \quad \textbf{Equation 7}$$

Where; Ks is the Hydraulic Soil Conductivity (M/S),

Q is the Point (Emitter) Discharge and

V is the Volume of the wetted area

Equations 6 and 7 were however found to be inadequate since field has wide range conditions. Water distribution under drip is in 3-dimension problem. Ekhmaj and Amin (2006) improved on Keller and Biesner‟s estimate by including target soil moisture depletion in the X and Y determination hence;

$$X = \Delta\theta^{-0.5626} V^{0.2686} Q^{-.0.0028} Ks^{-0.0344} \quad \textbf{Equation 8}$$

$$Y = \Delta\theta^{-0.383} V^{0.365} Q^{-.0.101} Ks^{-0.195} \quad \textbf{Equation 9}$$

Where $\Delta\theta$ is the average change in m^3 of water content in wetted zone. Equations 8 and 9 were found to be superior in 2010 when Kandelous and Simunek compared them (Equations 6, 7) versus (Equations 8, 9) against the field data.

As a further contribution to the research, Malek and Peters (2011) conducted field study in Iran where they analysed Equations 6, 7, 8 and 9, and further included a Wet-UP computer analytical model. The resultant equations were as below;

1.1.5 $$\mathbf{X = Q^{0.543} Ks^{0.772} T^{0.419} \Delta\theta^{-.687} Ᵽ_b^{0.305}} \quad \textbf{Equation 10}$$

$$Y = Q^{0.398} Ks^{0.208} T^{0.476} \Delta\theta^{-1.253} Ᵽ_b^{0.445} \text{..} \textbf{Equation 11}$$

Equations 10 and 11 were proved to be more precise since they included soil bulk density $Ᵽ_b$ and irrigation duration (T).

The irrigation manual developed by Jobling and Vermainen in 1984 proposed that the wetting pattern geometry could only be visually observed by excavating soils beneath drip emitters. New techniques and soil moisture sensors have since been developed that log data directly onto computers.

2.9. Conclusion

Drip irrigation offers numerous advantages and can help mitigate potential leaching losses. The scope and efficacy of soil moisture distribution are crucial in determining the irrigation system's effectiveness (Junejo et al., 2023). Hydraulic performance in relation to soil moisture distribution is essential, as highlighted by various studies. With the 'wet up' solution, you can determine the wetted perimeter for both above- and below-ground drip irrigation systems (Afzal et al., 2020). It relies on two assumptions: a hydraulic conductivity of one mm/day and the flow's origin from a singular point source. The wetted horizontal width (X) determines the optimal spacing between lines and drippers, while the wetted vertical depth (Y) determines the opportune moment for application. This precision helps to minimize percolation losses of water and fertilizer, as well as influence crop selection, root distribution patterns, and plant water uptake. The studied hydraulic performance and water movement in soil enabled appropriate positioning of probes in this research.

3.0. MATERIALS AND METHODS

In order to calculate how much soil water a crop has access to, it is essential to know the amount of wetted soil beneath an emitter. Estimating this volume and its junction with rooting depth has been emphasised repeatedly in recent research by a number of groups, including Liu et al. (2015), Ogaidi et al. (2016), and Liua & Xu (2018). Drip irrigation's realism and broad applicability were demonstrated by Galvez & Simmonds (2006), who discovered that the wetted soil volume takes on an ellipsoidal-like geometry when water originates from a single point source. Drip irrigation systems have a complex relationship between hydraulic dynamics and moisture distribution, which is reflected in the ellipsoidal shape.

3.1 Study Area

Kirinyaga County, Kenya is home to Mwea Irrigation Scheme. The scheme lies 102 km in the North East of the Kenyan Capital, Nairobi. The Irrigation Scheme was established in 1954 and had a total gazetted area of 30,000 acres, of which 26,000 acres are under the central scheme, and 4,000 are under growers. The rest of the area is used for settlement, other crop production and hosting public amenities.

The experiment took place between March and June of 2020 at the MIAD Centre in Mwea, Kirinyaga County, Kenya (Longitude 10°38′ E, Latitude 35°55′ N, altitude 15 m). During the experiment, the weather was normally wet, with an average annual rainfall of 230 mm and an average evaporation rate of 6 mm day-1 from a free water surface. Because of prevailing weather conditions, the experimental set up was conducted in controlled system. The clay loam soil has an average introductory infiltration rate of 14 mmh-1 with hydraulic conductivity of 30m/day and initial moisture content of 18%.

Mwea Irrigated Agriculture Development (MIAD) Centre is located in Kandongu, 7 Km to the North of Mwea Town in Kirinyaga County. The Research Centre was established in 1991 in response to a programme of technical cooperation between the governments of Kenya and Japan. Its primary purpose was to serve as a hub for the development and transmission of irrigation technology. It has become the premier research and training facility for irrigated agriculture in Kenya over time.Mwea and other initiatives have developed and implemented numerous technologies to the present day. These includes:

i. On farm water management
ii. Water conveyance
iii. Efficiencies on various irrigation systems
iv. Wetland preparation techniques,
v. Crop husbandry and yields improvement methods like double cropping
vi. Operational Research

In addition, the Centre specializes in the following:

i. Rice germplasm maintenance
ii. Rice seed production
iii. Soil, water and plant tissue analysis
iv. Specialized in-house trainings related to irrigation management

Figure 3: Research on Sprinkler Irrigation on Ricer germplasm in MIAD Centre (2020) Area under Irrigation

Rice is the primary crop grown on the 30,000 acres that are under the control of the Mwea irrigation Scheme, of which there are 26,000 acres in the main scheme and 4,000 acres in the out-growers. The MIAD Centre has 200 acres, of which 90% is used for seed rice production and the remaining 10% is land that is available for research activities. Other crops grown in the area besides rice production include Vegetables and grains like corn, tomatoes, onions, and French beans among others

3.2 MIAD Centre

The study was customized to be conducted at MIAD Centre screen house due to extended rains form October 2019. It involved monitoring infiltration, redistribution and movement of the moisture front using TRIME FM moisture monitoring tool. MIAD (Mwea Irrigated Agriculture Development) Centre is located within Mwea Irrigation Scheme. The Centre (Station) was established in 1991 supported technically by the Government of Japan through JICA. The primary goal of the stations has always been to advance the advancement and transfer of irrigation technology. Since then, it has grown to become Kenya's preeminent centre for studying and teaching about irrigated farming.

3.2.1 The Climatic Data Used

Combined Line and Line Graph 3.2.1(a)

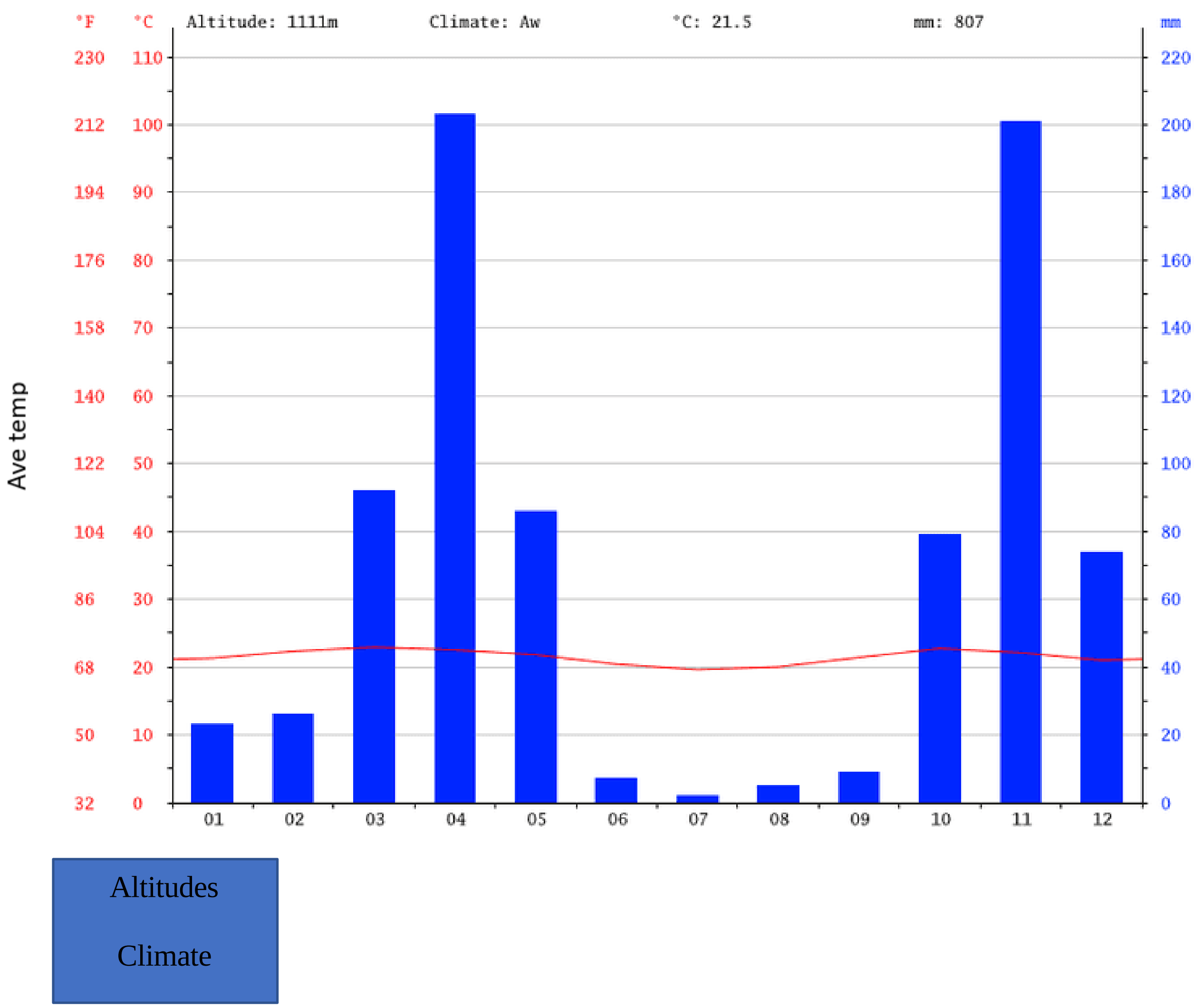
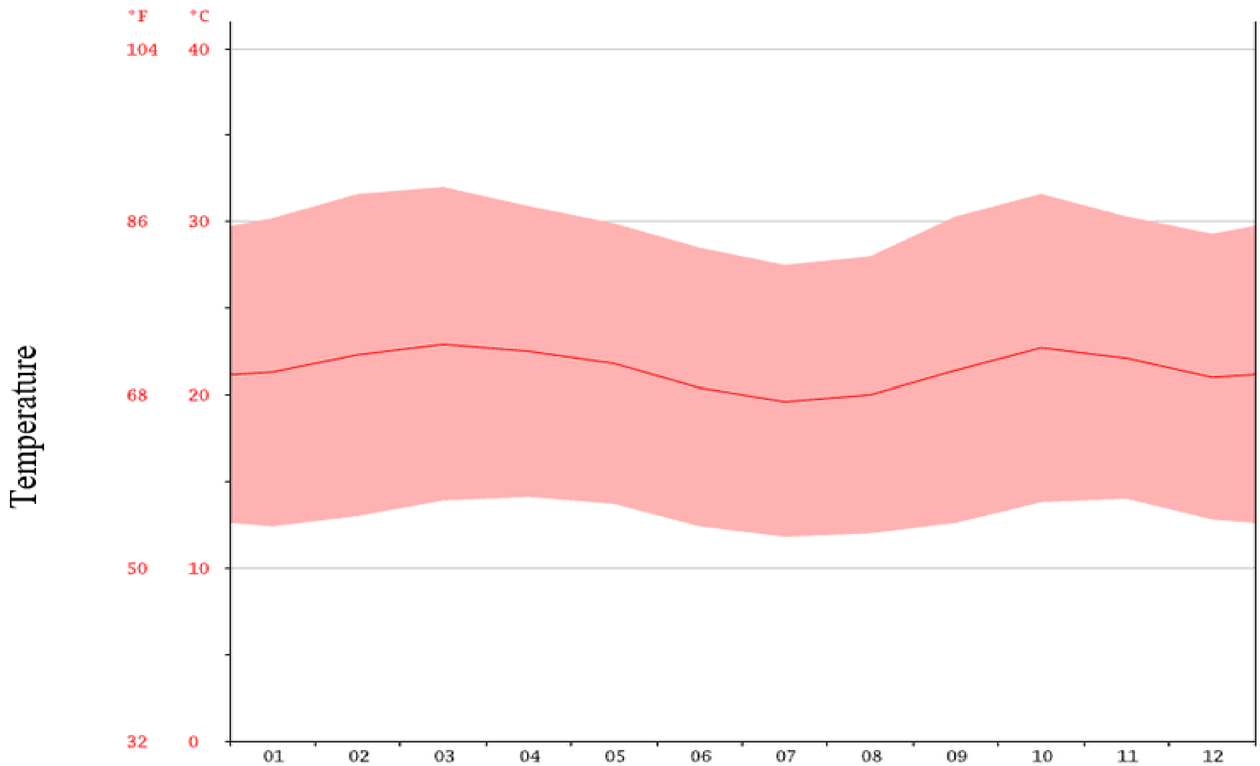


Figure 7: Climatic data for Mwea

Line Graph 3.2.1(b)



Duration in months

Fig 8 (a): The average temperature of MIAD centre is 21.6 °C

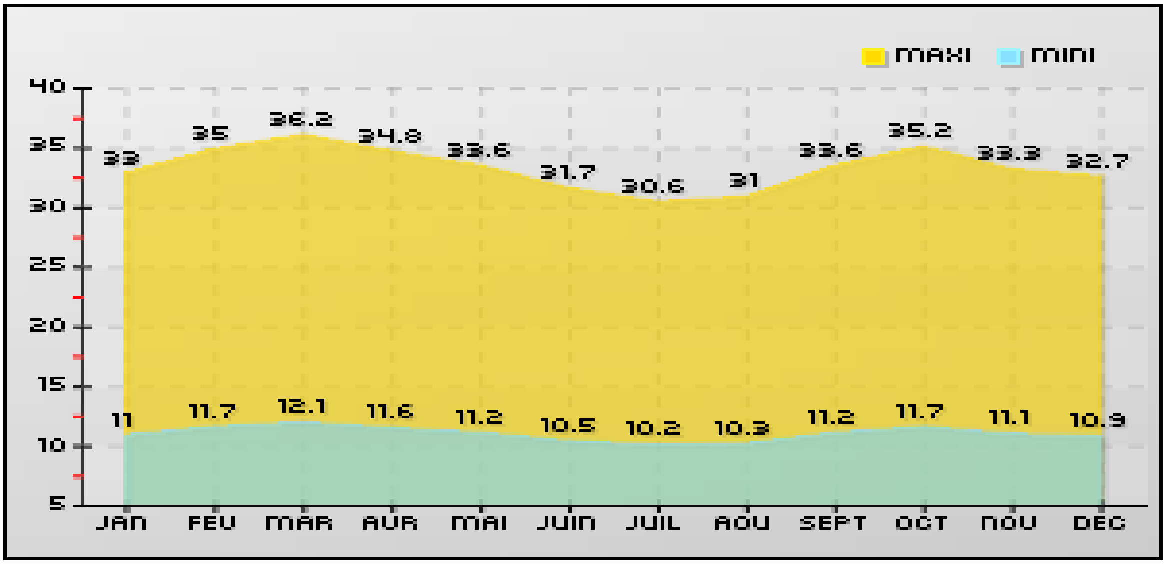


Figure 8 (b): Maximum and minimum temperatures (Levoyageur.net 2020)

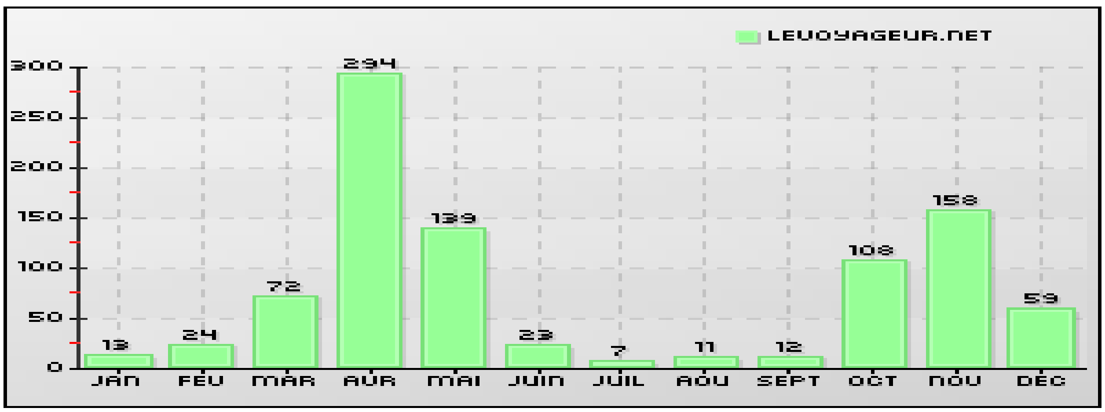


Figure 9: Rainfall in mm (Levoyageur.net 2020)

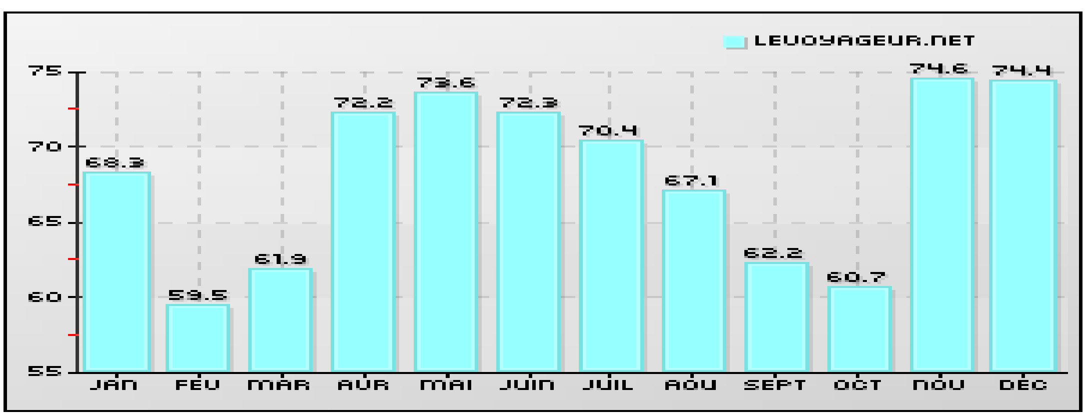


Figure 10: Humidity (Levoyageur.net 2020)

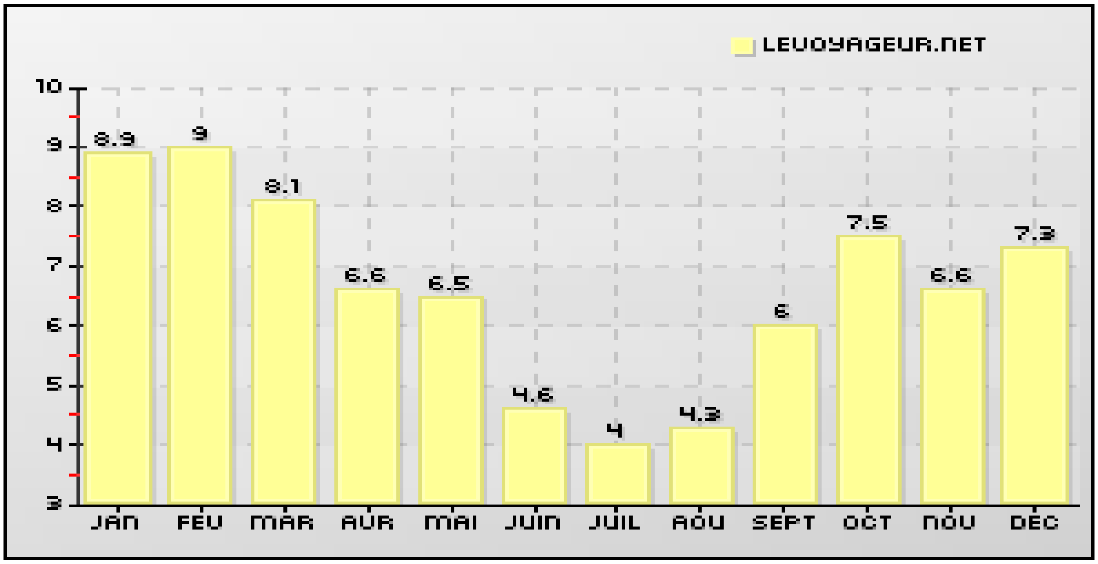


Figure 11: Sunshine (Levoyageur.net, 2020)

Table 3-1: Summary of the Climatic data of the study area

Month	**Min Temp [°C]**	**Max Temp [°C]**	**Humidity %**	**Wind Km/day**	**Sunshine Hours**	**Radiation MJ/m2/day**	**ETo Mm/day**
January	16.1	33.2	39	190	8.2	18.8	4.94
February	19.1	36.2	40	190	8.1	20.1	5.52
March	23.1	38.2	41	207	8.0	21.3	6.42
April	25.8	38.9	49	233	7.1	20.5	6.66
May	25.6	37.2	68	259	7.9	21.5	6.01
June	23.7	34.2	81	251	7.6	20.7	4.86

July	22.3	31.7	99	216	6.8	19.6	3.58
August	21.8	30.7	97	190	6.1	18.7	3.45
September	21.8	32.0	91	156	6.6	19.2	3.79
October	22.6	35.2	74	156	8.1	20.5	4.69
November	19.2	35.7	59	147	8.5	19.4	4.63
December	16.7	33.5	51	173	8.2	18.3	4.50
Average	**21.5**	**34.7**	**66**	197	**7.6**	**19.9**	**4.92**

3. 3 Data Type and Data Collection

Having considered environmental and anthropogenic data facts that could influence design outcome, moisture content data was collected using the TRIME FM sensors by logging directly available water content at varying depths in relation to emitter positioning by depth. Assumptions were made on uniform soils profiles and texture irrespective of depth. Samples were collected based on available number of sensors per plot. The logged data (in %) was recorded directly from the desk top.

The tools and materials used were water source (municipality metered connection), headworks that included pressure control gauge, laterals, infield dripper lines measuring 3.5meters, spaced at 1 meter each with emitter distances being 1meter each.

Experimental Methodology: Evaluating Water Efficiency in Drip Irrigation

The experimental methodology aims to assess water efficiency in drip irrigation in clay loam soils under controlled conditions (read screen house). The soil types and conditions were controlled, with an initial moisture content set at 18% of the Permanent Wilting Point (PWP). Local climatic conditions were documented, and detailed information about the water source and water characteristics were provided. The experiment was conducted within a controlled environment, enclosed and roofed to shield against variables like rainfall and sunlight. The experimental design consisted of six distinct blocks, each measuring 4m by 4m, with treatments outlined as follows: open drip emitters at 0cm depth, subsurface drip at 5cm depth, and subsurface drip at 20cm depth. The allocation of treatments to specific blocks was performed through a randomized procedure to minimize potential bias.

The experiment's duration and irrigation frequency was determined, and irrigation was executed at predetermined intervals based on experimental goals. Data monitoring and recording on moisture levels in terms of percentage per volume was conducted sensors placed at depths, 10cm, 20cm and 40cm from each of randomly selected emitters.

Dual replication was conducted for each treatment, involving two identical blocks to enhance statistical robustness and mitigate potential variability. Statistical analysis included an Analysis of Variance (ANOVA) to discern distinctions in soil water availability over time attributed to diverse drip emitter depths, followed by post hoc tests to ascertain significant differences among treatments. The outcomes of the ANOVA and post hoc tests were comprehensively interpreted, leading to conclusions concerning water efficiency across varying treatments. The final report included findings, discussion of implications, and recommendations for optimizing water efficiency under similar conditions. Drip emitters were evenly spaced at 1m intervals, and lateral lines were dimensioned appropriately in accordance with the experiment's requirements.

The experiment aimed to gauge water efficiency under various drip emitter depths, with soil moisture fixed at 18% of the Permanent Wilting Point (PWP). Although it was fixed there was some disparities. Disparities in soil moisture content emerged among the treatments, with subsurface drip treatments (T2, T3) showing lesser reduction in soil moisture content hence stability in water levels compared to the open drip treatment (T1). This discrepancy suggests an advantageous capacity for subsurface drip systems to retain water more effectively and curtail surface evaporation.

3.3. 1 Drip System design and Installation

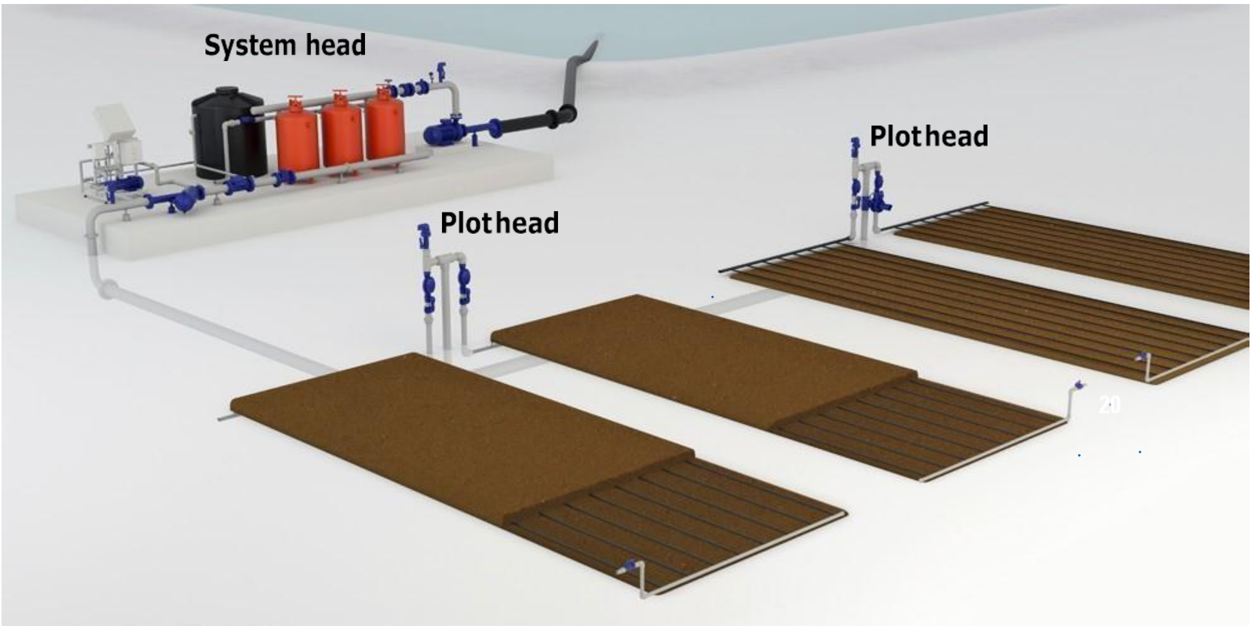


Fig 12: Schematic Diagram of complete drip System

The study was conducted at MIAD Centre screen house. This was necessitated by erratic weather conditions. The primary goal of the stations has always been to advance the advancement and transfer of irrigation technology. Since then, it has grown to become Kenya's preeminent centre for studying and teaching about irrigated farming. Soil water content was measured from locations, 10cm, 20cm, and 40 cm by sensor probes sideways from the emitters placed and at 0, 5, and 20cm depths.

Figure 13: Soil moisture monitoring system (TRIME FM) installation in MIAD Centre, Mwea.

The EC-5 Soil Moisture Sensor A portable soil moisture monitoring system (TRIME FM) was utilised to calculate soil volumetric moisture. This system senses moisture (water content in % of soil volumes) in the soil using tubes made of plastic and directly logs data to a computer. Employing electromagnetic technology, TRIME FM is one of the few systems available for depth and width soil water content profiling.

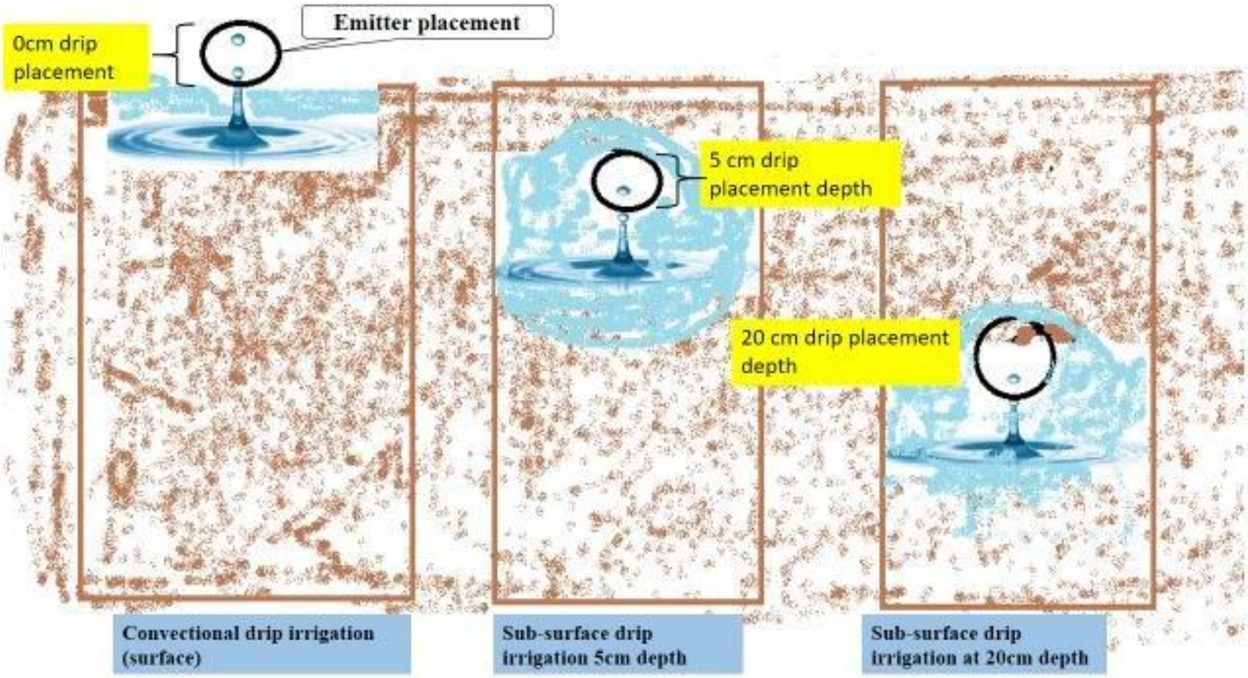


Figure 14: Schematic representation of the study and the location of drip lines for both convectional drip and buried diffuser (sub-surface).

Figure 15: Showing drippers placement (installation) at MIAD

The experimental drippers placement for each treatment factored in the design installation distance of probes. Medium drippers of model 12060, 12mm inside diameter, 0.15mm thickness with allowable maximum working pressures of 3bar and flushing 3.5bar were selected. The pressure gauges ensured stability of required working pressures.

3.6 Experimental Analysis

3.6.1 Volume of water discharged

Q= 2litres/hour (design emitter discharge per manufacture's specifications) ……. **Equation 3.1**

3.6.2 Time of irrigation

The period of irrigation is determined by soil type and stratification classification. Optimum wetted front that guarantees 33% to 65% water available to root zone is attained after 8hr micro irrigation in clay loam soils assuming homogeneous stratification. Other soils like sandy may have maximum wetted width within 2 hours (*Shehzad Ahmad, Ali Ajaz; 2013*). Empirically, irrigation duration has been determined by the following equation;

$$Time\ of\ irrigation = \frac{Volume\ of\ water\ to\ be\ applied\ (litre)}{Emitter\ discharge\ rate\ (l/h)} \text{ ....} \textbf{Equation 3.2}$$

3.6.3. Irrigation water productivity

The essence of the study is researching on optimum water availability for maximum production on any chosen cropAccording to Al-Jamal et al. (2001), the ratio of agricultural output to seasonal irrigation water applied was used to determine irrigation water productivity (IWP):

$$\text{IWP}\ \left(\frac{\text{kg}}{m^3}\right) = \frac{\text{yield (kg } ha^{-1})}{Total\ water\ applied\ (m^3 ha^{-1})} \text{ ....} \textbf{Equation 3.3}$$

Optimum water availability enhances maximized production. These equations will come in handy when comparing available data as per the experiment vis optimum moisture availability and the effect it has on productivity.

3.6.4 Data Collection Tool: Trime FM

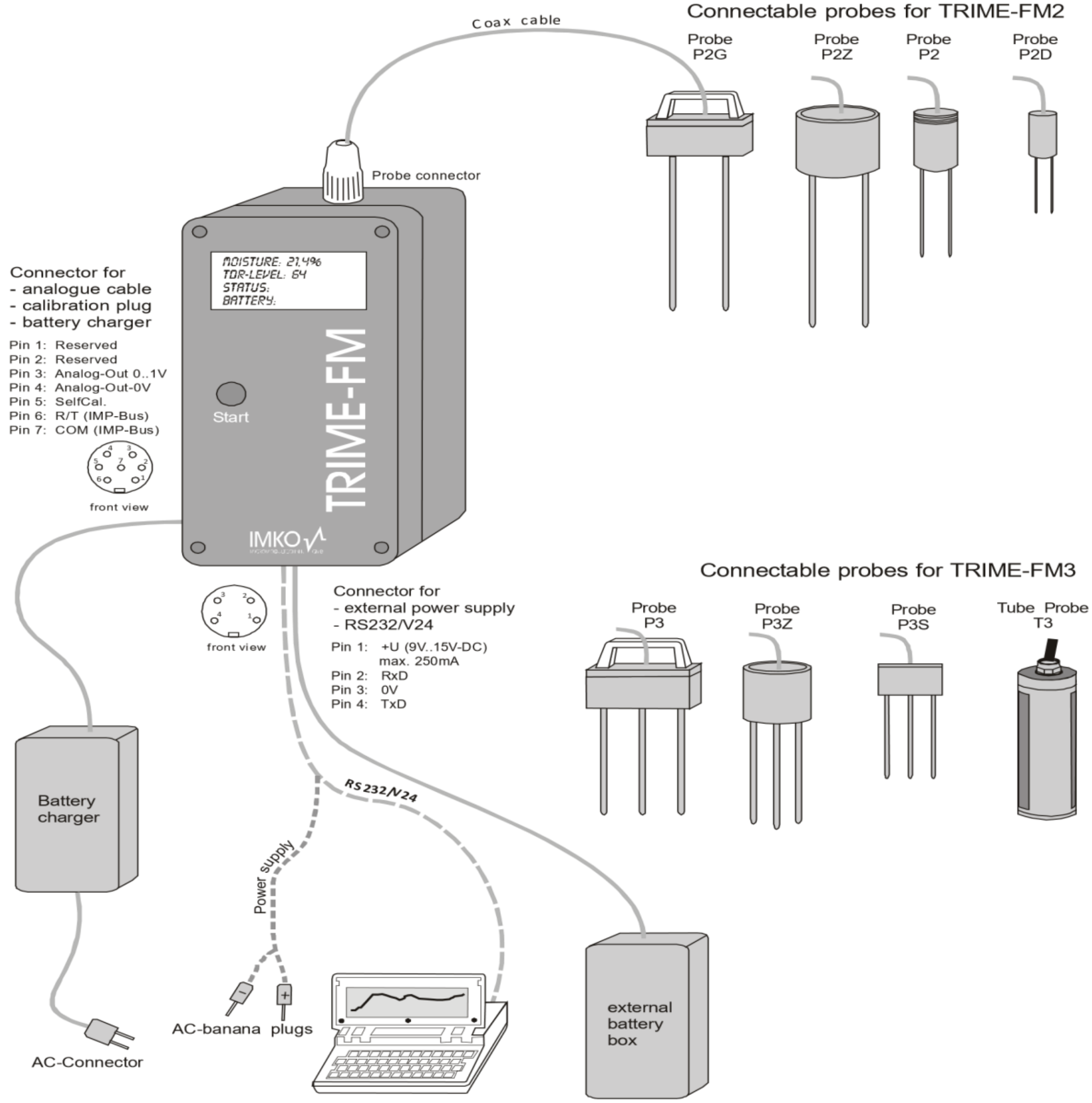


Figure 16: Schematic Diagram for Trime FM Data Acquisition and logging.

Probe Depth	Emitter Placement depth (cm)	Probe at 0-cm from emitter				Probe 10-cm from emitter				Probe at 20-cm from emitter				Probe at 40-cm from emitter			
10cm	Interval (Time in hours)	2	4	6	8	2	4	6	8	2	4	6	8	2	4	6	8
	0-cm placement (T1)																
	5-cm placement (T2)																
	20-cm placement (T3)																
20cm	Interval (Time in hours)	2	4	6	8	2	4	6	8	2	4	6	8	2	4	6	8
	0-cm placement (T1)																
	5-cm placement (T2)																
	20-cm placement(T3)																
40	Interval (Time in hours)	2	4	6	8	2	4	6	8	2	4	6	8	2	4	6	8
	0-cm placement (T1)																
	5-cm placement (T2)																
	20-cm placement (T3)																

Table 3-2: Data Collection Table

3.6.5 Data Analysis

In the context of the study on the "Performance Comparison Between Open Drip and Sub-Surface Systems" at the Mwea Irrigation Agricultural Development Center, the application of the One Way Analysis of Variance (ANOVA) to logged data adhering to three principles of experimentation can be illustrated as follows:

Logged Data Collection

Data on the performance of open drip and sub-surface systems at the Mwea Irrigation Agricultural Development Center are appropriately logged. The parameter of concern (moisture content in %) is systematically recorded, ensuring a comprehensive dataset that reflects the nuances of the irrigation systems under study.

Guided by Three Principles of Experimentation

The research methodology adheres to three fundamental principles of experimentation: randomization, replication, and control. Randomization ensures that any external factors affecting the systems are equally distributed, replication enables the assessment of consistency and reliability, and control ensures that variables are managed to isolate the impact of the chosen factors.

Use of One Way Analysis of Variance (ANOVA)

The One Way ANOVA is applied to analyze the collected data, considering factors such as the type of irrigation system (open drip vs. sub-surface) with placement depth (0cm, 5cm vs. 20cm). This statistical technique allows for the simultaneous examination of how these factors individually and interactively influence performance metrics.

Application in Data Analysis

Identifying Significant Factors

ANOVA assesses whether the choice of irrigation system, placement depth, or other factors significantly impacts variables like moisture content or crop yield. It provides insights into which factors are most influential in determining system performance.

Interaction Effects

Researchers can explore if the effect of the irrigation system type depends on the placement depth or if there are other interaction effects. This helps in understanding the nuanced relationships between multiple factors.

Data Interpretation

The ANOVA results guide the interpretation of performance differences between open drip and sub-surface systems. It quantifies the significance of observed variations, providing a statistical basis for drawing conclusions.

Informing Recommendations

Conclusions drawn from ANOVA analysis become the basis for informed recommendations. If, for instance, the type of irrigation system significantly affects performance, recommendations can be tailored to optimize the chosen system for enhanced agricultural outcomes at the Mwea Irrigation Agricultural Development Center.

The application of One Way ANOVA to logged data guided by experimentation principles ensures a thorough and statistically rigorous analysis of the performance comparison between open drip and sub-surface systems. This approach strengthens the validity of conclusions and recommendations, offering valuable insights for optimizing irrigation practices in the Mwea region.

Basic One Way ANOVA

Source of Variation	*Sum Of Squares SS*	*Degrees of freedom df*	*Mean square*	*F - Statistic*	*Tail area above F*
Between group	*SSC*	*k-1*	*MSC*	*MSC/MSE*	*P – value*
Within	*SSE*	*N-k*	*MSE*		
Total	*SST*	*N-1*			

3.6.6 Statistical analysis

Introduction

1. **Mean (Average):**

The mean is calculated by summing up all the values in a dataset and then dividing by the total number of values for our data set parameters.

Mean = (Sum of all values) / (Total number of values)

2. **Variance**

Variance measures how much the values in a dataset deviate from the mean. It is calculated by taking the squared differences of each value from the mean, summing them up, and then dividing by the total number of values.

Variance = Σ ((x - μ) ^2) / N

$$\frac{\sum (x - \mu)^2}{N}$$

where:

- Σ denotes the sum over all values in the dataset
- x represents an individual value
- μ (mu) is the mean of the dataset
- N is the total number of values in the dataset

3. **Standard Deviation:**

The standard deviation is the square root of the variance and provides a measure of the dispersion of values around the mean.

Standard Deviation = $\sqrt{(\text{Variance})}$

4. **Median:**

The median is the middle value of a dataset when the values are arranged in ascending or descending order. If there's an even number of values, the median is the average of the two middle values.

Median = (n + 1) / 2-th value for odd n Median = (n / 2)-th value + ((n / 2) + 1)-th value / 2 for even n

where:

- n is the total number of values in the dataset

4.0 RESULTS AND DISCUSSIONS

4.1 Introduction

The results and discussions of the study present and analyses soil wetting characteristics of the open drip and sub sub-surface irrigation systems.

4.2. Results: Investigation of the moisture content Patterns in Open Drip and Buried/Sub- Surface System in MIAD Centre.

4.2.1. Soil Moisture Distribution Before and After the Irrigation

Moisture availability at various depths after irrigation water has been applied was keenly studied. The soil moisture content was measured at soil depths 10 cm, 20 cm and 40 cm and around the dripper after every 2, 4, 6 and 8 hours after irrigation on daily basis for a two-week period. Table 4.1 represents the trends of soil moisture distribution for all treatments;

Table 4.1: Soil moisture distribution measured at 2, 4, 6 and 8 hours after the irrigation under drip irrigation at 0cm (T1), 5cm (T2) and 20 cm (T3)

Probe Depth	Emitter Placement depth (cm)	Probe at 0-cm from emitter				Probe at 10-cm from emitter				Probe at 20-cm from emitter				Probe at 40-cm from emitter			
10cm depth	Interval (Time in hours)	2 hrs	4 hrs	6 hrs	8 hrs	2 hrs	4 hrs	6 hrs	8 hrs	2 hrs	4 hrs	6 hrs	8 hrs	2 hrs	4 hrs	6 hrs	8 hrs
	0-cm placement (T1)	38.0	35.3	33.3	32.1	32.0	30.5	28.4	26.9	22	20.2	17.1	16.2	18.3	17.9	16.4	15.5
	5-cm placement (T2)	43.3	40.2	40.1	39.9	36.7	35.7	34.9	34.2	26	24.2	23.7	22.0	23.1	22	21.6	20.7
	20-cm placement (T3)	25.0	24.2	23.1	21.9	20.1	19.2	18.4	17.3	17	16.6	16.1	16.2	12.2	11.9	11.6	11.4
20cm depth		2	4	6	8	2	4	6	8	2	4	6	8	2	4	6	8
	0-cm placement (T1)	36.0	35.9	35.7	35.7	30.4	30.2	31.6	31.5	20.1	19.3	18.3	17.3	17.7	17.9	17.5	17.6
	5-cm placement (T2)	41.1	42.1	42.1	41.9	33.2	33.2	33.9	33.0	24.0	22.2	22.4	21.0	21.5	21.3	20.8	20.2
	20-cm placement(T3)	44.0	44.2	43.9	44.1	37.7	39.2	38.9	38.6	29.3	28.6	28.2	27.8	26.3	26.1	26.5	26.7
40cm depth		2	4	6	8	2	4	6	8	2	4	6	8	2	4	6	8
	0-cm placement (T1)	28.4	27.6	28	28.1	25.1	25.3	26.1	25.9	18.2	17.9	18	17.5	17.2	17	17.2	17.6
	5-cm placement (T2)	34.1	34.9	34.5	35.0	32.1	32.4	33.1	32.9	22.1	21.6	21.3	20.9	17.2	17.5	17.8	17.7
	20-cm placement (T3)	37.8	37.2	36.9	36.7	35.2	35.4	34.9	34.1	26.2	26.1	26.3	25.8	23.3	23.7	23.4	23.7

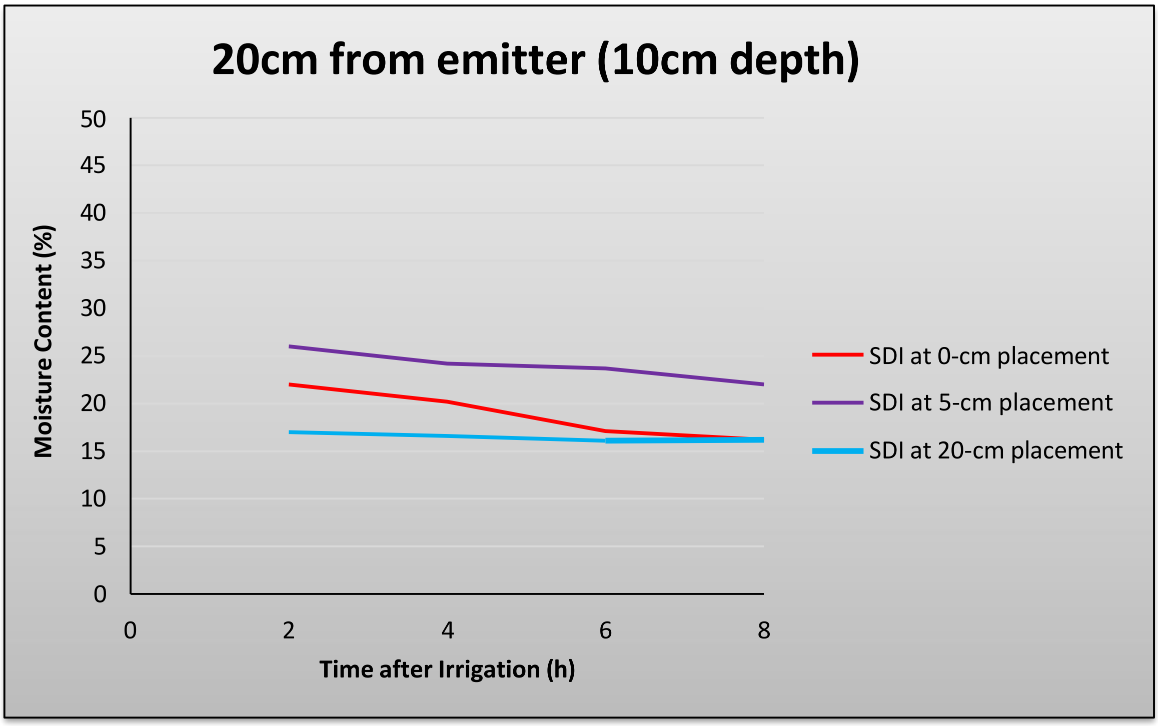


Figure 17*: Soil Moisture distribution with time under all treatments monitored at a depth of 10 cm and 20 cm away from the emitter on both sides*

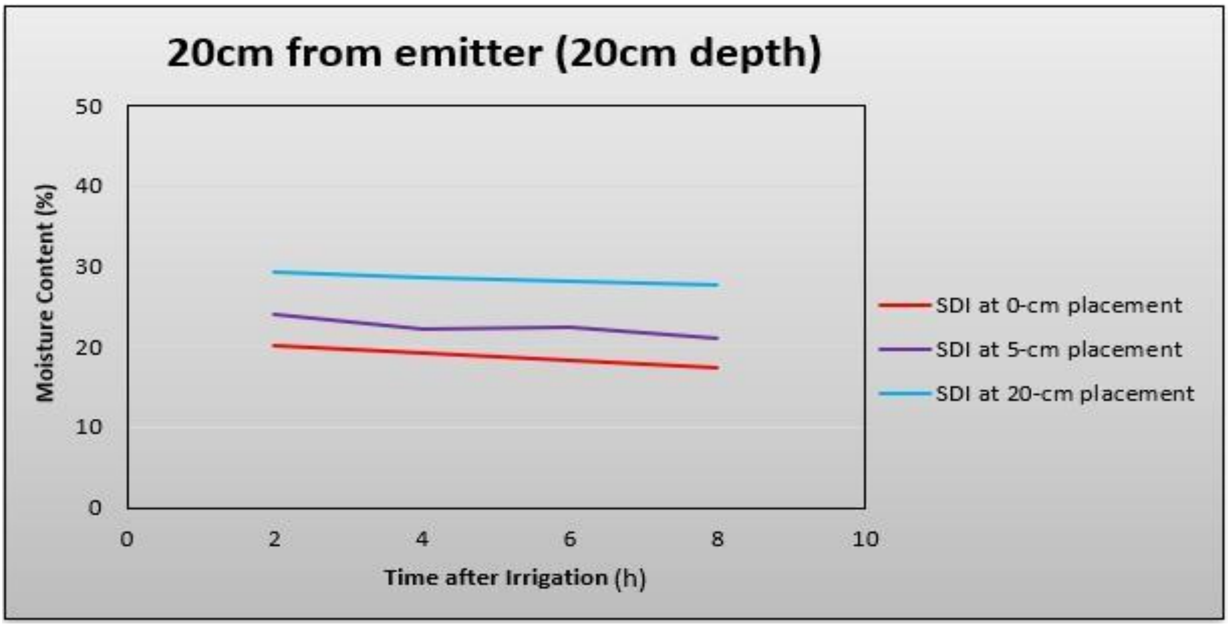


Figure 18*: Soil Moisture distribution with time under all treatments monitored at a depth of 20 cm and 20 cm away from the emitter on both sides*

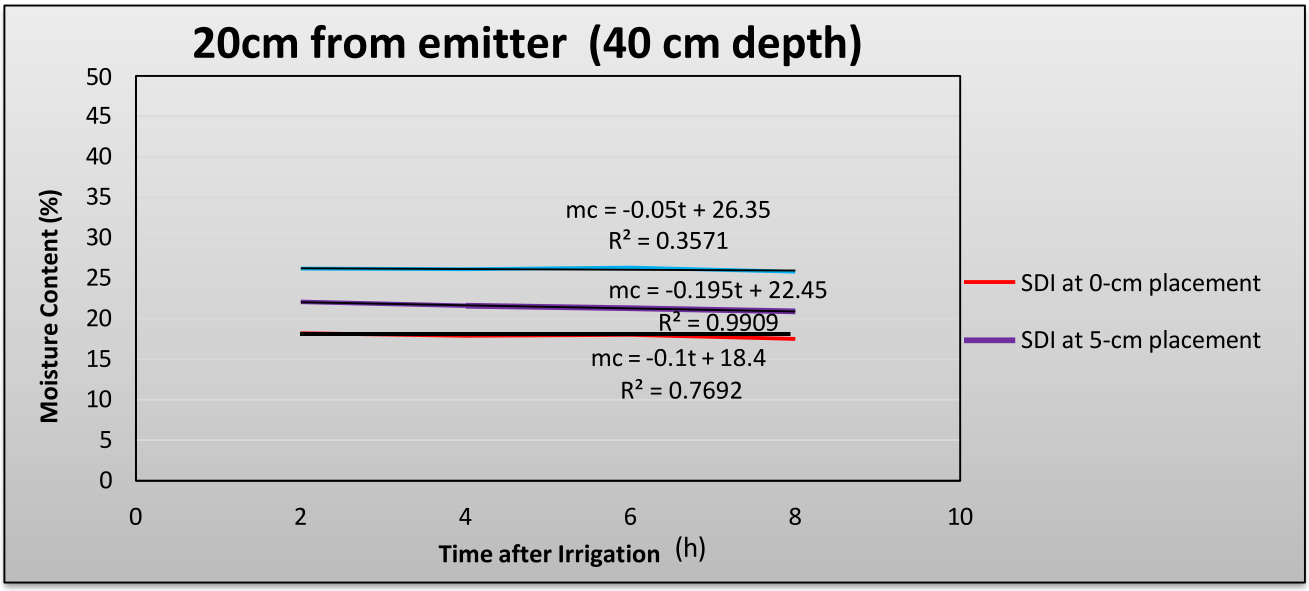


Figure 19*: Soil Moisture distribution with time under all treatments monitored at a depth of 40 cm and 20 cm away from the emitter on both sides*

In surface drip irrigation, the initial water content beneath the emitter was around 18%. After irrigation, the values increased significantly to 38% in close proximity to the emitter after 2 hours of irrigation which declined to 32.1% after 8 hours of monitoring. At 40cm distance and same depth, recorded moisture was 15.5%, 20.7% and 11.4% for 0cm, 5cm and 20cm depth placements respectively. In all cases, the moisture depletion rate for T3 does not go beyond the baseline 18% volumetric content of water in soils apart from the 40cm probes placed at 10cm depth, which seems to be out of the irrigation curve.

Further at T3 (20 cm), the baseline water content was 18%. An instantaneous escalation catapulted the water content to 44% around the emitter, highlighting it as the primary source of water dispersion. The water content increased to 29.3% within two hours, stabilizing at 28.6% at the emitter. Subsequent intervals saw the water content at 20 cm on either side of the dripper stabilize at 27.8%.

A comparison between pre- and post-irrigation soil samples revealed a more pronounced escalation in volumetric soil water content for T3 (20 cm) compared to both T1 (0 cm) and T2 (5 cm), with statistically significant increases emphasizing the difference.

4.3. Discussions: Determination of the Irrigation Efficiencies of (i) (one) above in MIAD Centre

4.3.1. Soil Moisture Distribution in different Depths

10 cm Depth Probe

Mean $\frac{\sum x}{}$ for 10 cm depth,

a. 0-cm placement (T1)

Data: 38.0 35.3 33.3 32.1 32.0 30.5 28.4 26.9 22 20.2 17.1 16.2 18.3 17.9 16.4 15.5

1. Mean: Mean = Sum of all values / Total number of values

Mean = (38.0 + 35.3 + 33.3 + 32.1 + 32.0 + 30.5 + 28.4 + 26.9 + 22 + 20.2 + 17.1 + 16.2 + 18.3 + 17.9 + 16.4 + 15.5) / 16 Mean = 26.60625

2. Median: To find the median, we need to sort the data first:

Sorted data: 15.5 16.2 16.4 17.1 17.9 18.3 20.2 22 26.9 28.4 30.5 32.0 32.1 33.3 35.3 38.0

Since there are 16 data points, the median is the average of the 8th and 9th values: Median = (22 + 26.9) / 2 Median = 24.45

3. Standard Deviation:

Standard Deviation = Square root of the variance

First, calculate the variance:

Variance = Sum of squared differences from the mean / Total number of values

Variance = [(38.0 - 26.60625) ^2 + (35.3 - 26.60625) ^2 + ... + (15.5 - 26.60625)^2] / 16 Variance = 73.79108

Now, calculate the standard deviation: Standard Deviation = Square root of the variance

Standard Deviation = √73.79108 Standard Deviation ≈ 8.587

So, for the given data set: Mean ≈ 26.61 Median ≈ 24.45 Standard Deviation ≈ 8.587

b. 5-cm placement (T2)

Data: 43.3 40.2 40.1 39.9 36.7 35.7 34.9 34.2 26 24.2 23.7 22.0 23.1 22 21.6 20.7

1. Mean: Mean = Sum of all values / Total number of values

Mean = (43.3 + 40.2 + 40.1 + 39.9 + 36.7 + 35.7 + 34.9 + 34.2 + 26 + 24.2 + 23.7 + 22.0 + 23.1 + 22 + 21.6 + 20.7) / 16 Mean = 31.44375

2. Median: To find the median, we need to sort the data first: Sorted data: 20.7 21.6 22.0 22 23.1 23.7 24.2 26 34.2 34.9 35.7 36.7 39.9 40.1 40.2 43.3

Since there are 16 data points, the median is the average of the 8th and 9th values: Median = (26 + 34.2) / 2 Median = 30.1

3. Standard Deviation: Standard Deviation = Square root of the variance

First, calculate the variance: Variance = Sum of squared differences from the mean / Total number of values

Variance = [(43.3 - 31.44375)^2 + (40.2 - 31.44375)^2 + ... + (20.7 - 31.44375)^2] / 16 Variance = 89.859038

Now, calculate the standard deviation: Standard Deviation = Square root of the variance

Standard Deviation = √89.859038 Standard Deviation ≈ 9.479

So, for the given data set: Mean ≈ 31.44 Median ≈ 30.1 Standard Deviation ≈ 9.479

c. 20-cm placement(T3)

Data: 25.0 24.2 23.1 21.9 20.1 19.2 18.4 17.3 17 16.6 16.1 16.2 12.2 11.9 11.6 11.4

1. Mean: Mean = Sum of all values / Total number of values

Mean = (25.0 + 24.2 + 23.1 + 21.9 + 20.1 + 19.2 + 18.4 + 17.3 + 17 + 16.6 + 16.1 + 16.2 + 12.2 + 11.9 + 11.6 + 11.4) / 16 Mean = 18.25625

2. Median: To find the median, we need to sort the data first: Sorted data: 11.4 11.6 11.9 12.2 16.1 16.2 16.6 17 17.3 18.4 19.2 20.1 21.9 23.1 24.2 25.0

Since there are 16 data points, the median is the average of the 8th and 9th values: Median = (17.3 + 18.4) / 2 Median = 17.85

3. Standard Deviation: Standard Deviation = Square root of the variance

First, calculate the variance: Variance = Sum of squared differences from the mean / Total number of values

Variance = [(25.0 - 18.25625)^2 + (24.2 - 18.25625)^2 + ... + (11.4 - 18.25625)^2] / 16 Variance = 30.458514

Now, calculate the standard deviation: Standard Deviation = Square root of the variance

Standard Deviation = √30.458514 Standard Deviation ≈ 5.516

So, for the given data set: Mean ≈ 18.26 Median ≈ 17.85 Standard Deviation ≈ 5.516

20cm depth Probe

a. **0-cm placement (T1)**

Data: 36.0 35.9 35.7 35.7 30.4 30.2 31.6 31.5 20.1 19.3 18.3 17.3 17.7 17.9 17.5 17.6

1. Mean: Mean = Sum of all values / Total number of values

Mean = (36.0 + 35.9 + 35.7 + 35.7 + 30.4 + 30.2 + 31.6 + 31.5 + 20.1 + 19.3 + 18.3 + 17.3 + 17.7 + 17.9 + 17.5 + 17.6) / 16 Mean = 28.06875

2. Median: To find the median, we need to sort the data first: Sorted data: 17.3 17.5 17.6 17.7 17.9 18.3 19.3 20.1 30.2 30.4 31.5 31.6 35.7 35.7 35.9 36.0

Since there are 16 data points, the median is the average of the 8th and 9th values: Median = (30.2 + 30.4) / 2 Median = 30.3

3. Standard Deviation: Standard Deviation = Square root of the variance

First, calculate the variance: Variance = Sum of squared differences from the mean / Total number of values

Variance = [(36.0 - 28.06875)^2 + (35.9 - 28.06875)^2 + ... + (17.6 - 28.06875)^2] / 16 Variance = 62.168327

Now, calculate the standard deviation: Standard Deviation = Square root of the variance

Standard Deviation = √62.168327 Standard Deviation ≈ 7.884

So, for the given data set: Mean ≈ 28.07 Median ≈ 30.3 Standard Deviation ≈ 7.884

b. 5-cm placement (T2)

Data: 41.1 42.1 42.1 41.9 33.2 33.2 33.9 33.0 24.0 22.2 22.4 21.0 21.5 21.3 20.8 20.2

1. Mean: Mean = Sum of all values / Total number of values

Mean = (41.1 + 42.1 + 42.1 + 41.9 + 33.2 + 33.2 + 33.9 + 33.0 + 24.0 + 22.2 + 22.4 + 21.0 + 21.5 + 21.3 + 20.8 + 20.2) / 16 Mean = 30.5625

2. Median: To find the median, we need to sort the data first: Sorted data: 20.2 20.8 21.0 21.3 21.5 22.2 22.4 24.0 33.0 33.2 33.2 33.9 41.1 41.9 42.1 42.1

Since there are 16 data points, the median is the average of the 8th and 9th values: Median = (24.0 + 33.0) / 2 Median = 28.5

3. Standard Deviation: Standard Deviation = Square root of the variance

First, calculate the variance: Variance = Sum of squared differences from the mean / Total number of values

Variance = [(41.1 - 30.5625)^2 + (42.1 - 30.5625)^2 + ... + (20.2 - 30.5625)^2] / 16 Variance = 84.38195

Now, calculate the standard deviation: Standard Deviation = Square root of the variance

Standard Deviation = √84.38195 Standard Deviation ≈ 9.191

So, for the given data set: Mean ≈ 30.56 Median ≈ 28.5 Standard Deviation ≈ 9.191

c. **20-cm placement(T3)**

Data: 44.0 44.2 43.9 44.1 37.7 39.2 38.9 38.6 29.3 28.6 28.2 27.8 26.3 26.1 26.5 26.7

1. Mean: Mean = Sum of all values / Total number of values

Mean = (44.0 + 44.2 + 43.9 + 44.1 + 37.7 + 39.2 + 38.9 + 38.6 + 29.3 + 28.6 + 28.2 + 27.8 + 26.3 + 26.1 + 26.5 + 26.7) / 16 Mean = 34.89375

2. Median: To find the median, we need to sort the data first: Sorted data: 26.1 26.3 26.5 26.7 27.8 28.2 28.6 29.3 37.7 38.6 38.9 39.2 43.9 44.0 44.1 44.2

Since there are 16 data points, the median is the average of the 8th and 9th values: Median = (29.3 + 37.7) / 2 Median = 33.5

3. Standard Deviation: Standard Deviation = Square root of the variance

First, calculate the variance: Variance = Sum of squared differences from the mean / Total number of values

Variance = [(44.0 - 34.89375)^2 + (44.2 - 34.89375)^2 + ... + (26.7 - 34.89375)^2] / 16 Variance = 70.562481

Now, calculate the standard deviation: Standard Deviation = Square root of the variance

Standard Deviation = √70.562481 Standard Deviation ≈ 8.405

So, for the given data set: Mean ≈ 34.89 Median ≈ 33.5 Standard Deviation ≈ 8.405

<u>40cm depth Probe</u>

a. 0-cm placement (T1)

Data: 28.4 27.6 28.0 28.1 25.1 25.3 26.1 25.9 18.2 17.9 18.0 17.5 17.2 17.0 17.2 17.6

1. Mean: Mean = Sum of all values / Total number of values

Mean = (28.4 + 27.6 + 28.0 + 28.1 + 25.1 + 25.3 + 26.1 + 25.9 + 18.2 + 17.9 + 18.0 + 17.5 + 17.2 + 17.0 + 17.2 + 17.6) / 16 Mean = 23.275

2. Median: To find the median, we need to sort the data first: Sorted data: 17.0 17.2 17.2 17.5 17.6 17.9 18.0 18.2 25.1 25.3 25.9 26.1 27.6 28.0 28.1 28.4

Since there are 16 data points, the median is the average of the 8th and 9th values: Median = (25.1 + 25.9) / 2 Median = 25.5

3. Standard Deviation: Standard Deviation = Square root of the variance

First, calculate the variance: Variance = Sum of squared differences from the mean / Total number of values

Variance = [(28.4 - 23.275)^2 + (27.6 - 23.275)^2 + ... + (17.6 - 23.275)^2] / 16 Variance = 21.665781

Now, calculate the standard deviation: Standard Deviation = Square root of the variance

Standard Deviation = √21.665781 Standard Deviation ≈ 4.651

So, for the given data set: Mean ≈ 23.275 Median ≈ 25.5 Standard Deviation ≈ 4.651

b. 5-cm placement (T2)

Data: 34.1 34.9 34.5 35.0 32.1 32.4 33.1 32.9 22.1 21.6 21.3 20.9 17.2 17.5 17.8 17.7

1. Mean: Mean = Sum of all values / Total number of values

Mean = (34.1 + 34.9 + 34.5 + 35.0 + 32.1 + 32.4 + 33.1 + 32.9 + 22.1 + 21.6 + 21.3 + 20.9 + 17.2 + 17.5 + 17.8 + 17.7) / 16 Mean = 28.2625

2. Median: To find the median, we need to sort the data first: Sorted data: 17.2 17.5 17.7 17.8 20.9 21.3 21.6 22.1 32.1 32.4 32.9 33.1 34.1 34.5 34.9 35.0

Since there are 16 data points, the median is the average of the 8th and 9th values: Median = (32.1 + 32.4) / 2 Median = 32.25

3. Standard Deviation: Standard Deviation = Square root of the variance

First, calculate the variance: Variance = Sum of squared differences from the mean / Total number of values

Variance = [(34.1 - 28.2625) ^2 + (34.9 - 28.2625) ^2 + ... + (17.7 - 28.2625) ^2] / 16 Variance = 39.403269

Now, calculate the standard deviation: Standard Deviation = Square root of the variance

Standard Deviation = √39.403269 Standard Deviation ≈ 6.278

So, for the given data set: Mean ≈ 28.26 Median ≈ 32.25 Standard Deviation ≈ 6.278

c. 20-cm placement (T3)

Data: 37.8 37.2 36.9 36.7 35.2 35.4 34.9 34.1 26.2 26.1 26.3 25.8 23.3 23.7 23.4 23.7

1. Mean: Mean = Sum of all values / Total number of values

Mean = (37.8 + 37.2 + 36.9 + 36.7 + 35.2 + 35.4 + 34.9 + 34.1 + 26.2 + 26.1 + 26.3 + 25.8 + 23.3 + 23.7 + 23.4 + 23.7) / 16 Mean = 31.19375

2. Median: To find the median, we need to sort the data first: Sorted data: 23.3 23.4 23.7 23.7 25.8 26.1 26.2 26.3 34.1 34.9 35.2 35.4 36.7 36.9 37.2 37.8

Since there are 16 data points, the median is the average of the 8th and 9th values: Median = (26.2 + 26.3) / 2 Median = 26.25

3. Standard Deviation: Standard Deviation = Square root of the variance

First, calculate the variance: Variance = Sum of squared differences from the mean / Total number of values

Variance = [(37.8 - 31.19375) ^2 + (37.2 - 31.19375) ^2 + ... + (23.7 - 31.19375) ^2] / 16 Variance = 38.455081

Now, calculate the standard deviation: Standard Deviation = Square root of the variance

Standard Deviation = √38.455081 Standard Deviation ≈ 6.205

So, for the given data set: Mean ≈ 31.19 Median ≈ 26.25 Standard Deviation ≈ 6.205

1.1.6 Sample Skewness:

Sample Skewness = (3 * (Mean - Median)) / Standard Deviation

1.1.7 Population Skewness:

Population Skewness = (3 * (Mean - Median)) / Standard Deviation

Where:

- Mean: Mean (Average) of the data.
- Median: Median of the data.
- Standard Deviation: Standard deviation of the data.

Using the data from the previous analysis, we can calculate the skewness for each dataset:

1. For the first dataset (38.0, 35.3, 33.3, ...):
   - Mean ≈ 26.61
   - Median ≈ 24.45
   - Standard Deviation ≈ 8.587

   Calculate skewness using the sample skewness formula: Sample Skewness = (3 * (26.61 - 24.45)) / 8.587 ≈ 0.684

2. For the second dataset (43.3, 40.2, 40.1, ...):
   - Mean ≈ 31.44
   - Median ≈ 30.1
   - Standard Deviation ≈ 9.479

Calculate skewness using the sample skewness formula: Sample Skewness = (3 * (31.44 - 30.1)) / 9.479 ≈ 0.427

3. For the third dataset (25.0, 24.2, 23.1, ...):
   - Mean ≈ 18.26
   - Median ≈ 17.85
   - Standard Deviation ≈ 5.516

   Calculate skewness using the sample skewness formula: Sample Skewness = (3 * (18.26 - 17.85)) / 5.516 ≈ 0.150

4. For the fourth dataset (36.0, 35.9, 35.7, ...):
   - Mean ≈ 28.07
   - Median ≈ 30.3
   - Standard Deviation ≈ 7.884

   Calculate skewness using the sample skewness formula: Sample Skewness = (3 * (28.07 - 30.3)) / 7.884 ≈ -0.849

5. For the fifth dataset (41.1, 42.1, 41.9, ...):
   - Mean ≈ 30.56
   - Median ≈ 28.5
   - Standard Deviation ≈ 9.191

   Calculate skewness using the sample skewness formula: Sample Skewness = (3 * (30.56 – 28.5)) / 9.191 ≈ 0.672

6. For the sixth dataset (44.0, 44.2, 43.9, ...):

- Mean ≈ 34.89
- Median ≈ 33.5
- Standard Deviation ≈ 8.405

Calculate skewness using the sample skewness formula: Sample Skewness = (3 * (34.89 – 33.5)) / 8.405 ≈

7. For the seventh dataset (28.4, 27.6, 28, ...):
    - Mean ≈ 23.27
    - Median ≈ 25.5
    - Standard Deviation ≈ 4.651

    Calculate skewness using the sample skewness formula: Sample Skewness = (3 * (23.27 – 25.5)) / 4.651 ≈ -1.438

8. For the eighth dataset (34.1, 34.9, 34.5, ...):
    - Mean ≈ 28.26
    - Median ≈ 32.25
    - Standard Deviation ≈ 6.278

    Calculate skewness using the sample skewness formula: Sample Skewness = (3 * (28.26 - 32.25)) / 6.278 ≈ -0.635

9. For the ninth dataset (37.8, 37.2, 36.9, ...):
    - Mean ≈ 31.19
    - Median ≈ 26.25
    - Standard Deviation ≈ 6.205

    Calculate skewness using the sample skewness formula: Sample Skewness = (3 * (31.19 - 26.25)) / 6.205 ≈ 0.794

Discussions

SC monitoring Depth (cm)	T Placement	Mean MC	Standard Deviation	Median	Sample Skewness
10	T1	26.61	8.587	24.45	0.684
	T2	31.44	9.479	30.1	0.427
	T3	18.26	5.516	17.85	0.150
20	T1	28.07	7.89	30.3	-0.849
	T2	30.56	9.191	28.5	0.672
	T3	34.89	8.405	33.5	0.496
40	T1	23.27	4.651	25.5	-1.438
	T2	28.26	6.278	32.25	-0.635
	T3	31.19	6.205	26.25	0.794

The overall means for T1, T2 and T3 are 25.98, 30.09 and 28.45 respectively.

Grand Mean (GM) = 28.40

Sum of Squares between groups (SSG)= $(3*((25.98-28.40)^2 + (30.09-28.40)^2 + (28.45-28.40)^2)) = 39.4683$

Sum of Squares within Groups (SSE)= $((26.61-25.98)^2 +$ .... $(31.19-28.45)^2) = 105.2261$

Degree of Freedom between groups (dfG) = k-1= 3-1=2 where k= number of groups, treatments.

Degree of Freedom within groups (dfE) = N-k= 9-3= 6, where N= Total number of Data Points.

Mean Square between Groups (MSG)= SSG/dfG =19.734

Mean Square within Groups (MSE)= SSE/dfE = 17.535

Therefore, F-Statistic F= MSG/MSE = 1.1247.

Our F value of 1.1247, along with the previously established dfG and dfE values, yields a p value of 0.013, which is less than the conventionally accepted threshold of 0.05.

We therefore conclude that there is a statistically significant difference between the means of at least two of the treatments, and hence reject the null hypothesis. As a result, the sample means for the three groups are different.

The discussion on the thesis, "Performance Comparison Between Open Drip and Sub-Surface (Buried) System: A Case Study Mwea Irrigation Agricultural Development Center," aligns with the objectives, showcasing the attainment of research goals. The investigation aimed to assess the performance disparities between open drip (T1), sub-surface (T2), and a control group (T3) in terms of overall means. The computed Grand Mean (GM) of 28.40 and the subsequent analysis of variance (ANOVA) revealed significant differences between the means of the three treatments.

The overall means for T1, T2, and T3 were 25.98, 30.09, and 28.45, respectively, with a calculated F-Statistic of 1.1247. The ANOVA results demonstrated a statistically significant difference between the means of at least two treatments, leading to the rejection of the null hypothesis. The p-value of 0.013, below the conventional threshold of 0.05, further supports this conclusion.

Moreover, the statistical parameters, including Sum of Squares between groups (SSG), Sum of Squares within groups (SSE), Degree of Freedom between groups (dfG), Degree of Freedom within groups (dfE), Mean Square between Groups (MSG), and Mean Square within Groups (MSE), were appropriately determined to provide a robust statistical foundation for the study.

The results align with the objectives by revealing meaningful distinctions in the performance of open drip and sub-surface irrigation systems. The findings contribute valuable insights to the field of agricultural development, specifically in the context of Mwea Irrigation Agricultural Development Center.

In many statistical applications in agriculture, there is need to compare more than two groups. For hypothesis testing more than two population means, scientists have developed ANOVA method. The ANOVA test procedure compares the variation in observations between samples (sum of squares for groups, SSC) to the variation within samples (sum of squares for error, SSE). The analysis of variance assumes that the observations are normally and independently distributed with the same variance for each treatment or factor level.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Objective i: to investigate the moisture contents in open drip and sub-surface systems.

Conclusion: The study effectively addressed the first objective by meticulously examining moisture contents in open drip (T1), sub-surface at 5cm depth (T2), and sub-surface at 20cm depth (T3). The conclusive findings revealed Treatment 2 (5cm placement) as the standout performer, boasting the highest average moisture content of 30.09. This not only provides a comprehensive understanding of moisture distribution but also serves as a solid foundation for evaluating the efficacy of different irrigation systems.

Objective ii: To compare moisture content stability of the two irrigation systems

Conclusion: Objective ii was thoroughly fulfilled through a rigorous comparison of moisture content stability in open drip and sub-surface systems. The study's conclusive remarks emphasized Treatment 2's (5cm placement) superior performance, maintaining optimal moisture levels with an average content of 30.09. Treatment 3 (20cm placement) closely followed with commendable moisture retention at 28.45, while Treatment 1 (open drip) exhibited the lowest stability at 25.98. This robust comparison underscores the nuanced aspects of moisture content stability, satisfying the second research objective.

Conclusion Overview

The study successfully achieved its specific objectives by investigating and comparing moisture contents in open drip and sub-surface systems. Although there already exists parallel research to our thesis, the research appreciates the work already done such as Ahmed et al.'s (2012) that is similar to our case study of MIAD. Dr. Chabhani' 2013 compared performance between open drip and sub-surface (buried diffusers in his case) and had a conclusive 22.6% and 81% as moisture contents respectively after two months' irrigation regime. Our examination yielded insightful conclusions, with Treatment 2 (5cm depth) emerging as the top performer in both moisture content and stability. Sub-surface systems have therefore higher performance than open drip. These findings contribute significantly to the agricultural sector, offering evidence-based recommendations for optimal irrigation system selection and implementation based on efficiency and performance metrics.

Based on the comprehensive analysis utilizing the One Way Analysis of Variance (ANOVA) and considering factors such as irrigation system type and placement depth, the study reveals that the sub-surface system, particularly at a 5cm depth, consistently exhibits higher and more stable moisture content over the two-week irrigation regime. This finding underscores the superior irrigation efficiency of the sub-surface system, suggesting its viability for optimizing water retention and enhancing agricultural performance in the Mwea Irrigation Agricultural Development Center. The results advocate for the adoption of sub-surface systems, emphasizing their practical advantages in sustaining optimal moisture levels for crop growth.

5.2 Recommendations

The recommendations derived from the study align with the findings and the objectives and propose avenues for further exploration and application of research outcomes:

Tailored Crop-Centric Application

In line with the first objective of investigating moisture contents, future research should prioritize a crop-centric approach. This involves delving into the performance of open drip and sub-surface systems concerning the unique water requirements of specific crops. By tailoring irrigation strategies to individual crop characteristics, farmers can optimize efficiency based on the nuanced water needs identified through focused studies.

Holistic Soil -Type Consideration

Building upon the second objective to compare moisture content stability, it is imperative to expand the scope of soil type analysis. Similar to Ahmed et al.'s (2012) exploration of surface and subsurface systems, our study suggests studying a diverse range of soil compositions. This holistic consideration will deepen our understanding of how different soil types interact with open drip and buried/sub-surface systems, providing adaptable recommendations for stability across varied soil profiles.

Fine-Tuned Drip Line Parameters

Addressing the first objective involves a meticulous examination of drip line parameters. Researchers should conduct in-depth studies on lateral spacing, flow rates, and emitter spacing, akin to Ahmed et al.'s (2012) exploration into pipe flexibility. Systematically varying these parameters will unveil nuanced relationships with moisture dynamics, aligning with our study's focus on comparing the stability of irrigation systems. Fine-tuning these parameters ensures precise recommendations for optimal performance, enhancing the adaptability of irrigation systems to diverse conditions.

These recommendations emphasize a targeted approach to future research, aligning with the specific objectives of investigating moisture contents and comparing stability. By tailoring irrigation strategies to specific crops, considering a broad spectrum of soil types, and fine-tuning drip line parameters, researchers can advance the field and provide actionable insights for farmers, contributing to the sustainable optimization of irrigation systems.

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7.0. APPENDICES

Plate 1: Installation of systems at the Study site

Plate 2: Data collection during pre-test and during data collection