UNIVERSITY FOR DEVELOPMENT STUDIES

EFFECT OF SUPPLEMENTARY IRRIGATION ON CROP WATER STRESS AND SOIL MOISTURE CONTENT UNDER DIFFERENT CONSERVATION METHODS AT NYANKPALA

BY

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DECLARATION

I certify that this work was carried out by me at the University for Development Studies and that it is not to be found anywhere else in the context of scientific work.

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ABSTRACT

In agriculture, the optimization of water uses while guaranteeing crop production is a key issue, especially in areas where water is scarce. This study investigated the influence of Supplementary irrigation on crop water stress within diverse soil conservation methods at Nyankpala. Focusing on amaranth as a model crop, the study elucidated the effects of irrigation and conservation techniques on the plant performance. Using a split-plot design, the research assessed the impact of Supplementary irrigation regimes on crop water stress, growth and yield. Notably, the findings highlight the positive influence of Supplementary irrigation in conjunction with three specific soil conservation methods: "Raised beds", "Ridge tillage" and “Flats lands". Our findings reveal that Supplementary irrigation at a rate of 70% of Evapotranspiration (ETC), when combined with "Raised beds" and "Ridge tillage" soil preparation methods, has proven highly effective in optimizing water utilization These methods exhibited a noteworthy improvement in soil moisture content, plant water stress, and crop yield. The study also highlighted the importance of better understanding the relationship between irrigation and soil conservation practices. The results offer a practical perspective on maximizing water use efficiency and mitigating water stress in agriculture. In a context of water scarcity, these results have practical implications for more sustainable agricultural practices, enhancing the efficient management of water resources while increasing agricultural productivity. This study underscores the feasibility of combining Supplementary irrigation with targeted soil conservation techniques to enhance crop resilience and optimize water utilization. The principles established in our research can be extended to a variety of crops, promoting agricultural diversification. Furthermore, the implementation of these results can contribute to environmental conservation, healthier soils and economic benefits at both individual and regional levels.

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DEDICATION

In memory of my late father

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ABBREVIATIONS

RR - Rainfed and Ridge

RB - Rainfed and Bed

RF - Rainfed and Flat

SR - Supplementary and Ridge

SB - Supplementary and Bed

SF - Supplementary and Flat

RR: Refers to the rainfed agricultural treatment involving ridge soil preparation.

RB: Refers to the rainfed agricultural treatment involving bed soil preparation.

RF: Refers to the rainfed agricultural treatment involving flat soil preparation.

SR: Refers to the Supplementary irrigation treatment with ridge soil preparation.

SB: Refers to the Supplementary irrigation treatment with bed soil preparation.

SF: Refers to the Supplementary irrigation treatment with flat soil preparation.

SWC: Soil Water Content

CWS: Crop Water Stress

SCM : Soil Conservation Method

SI : Supplementary Irrigation

ETC : Crop Evapotranspiration

MDGs: Millennium Development Goals

SDGs: Sustainable Development Goals

PE: Effective precipitation

WUE: Water Use Efficiency

RLWC: Relative Leaf Water Contents

CHAPTER ONE

INTRODUCTION

1.1 Background

Climate change recognized as a major global challenge, goes beyond geographical boundaries affecting ecosystems, economies and livelihoods all over the world. The West African region is widely identified as one of the most sensitive to the effects of climate change (Callo-Concha et al., 2013). It is subject to insufficient water availability due to high variability in rainfall and frequent droughts (Challinor et al., 2007). The region is a key focal point in the global debate on agricultural development and its deep implications for poverty reduction. Agriculture in west Africa region holds significant potential for job creation and reducing poverty. Effective policies covering social protection, sustainable land, water management, market access and food security are widely recognized as essential components of any comprehensive agricultural development plan aimed at improving poverty levels. The adoption of modern agricultural techniques and measures appears to be a powerful force capable of boosting agricultural production, thus, increasing farmers' incomes and, ultimately, reducing the scourge of poverty. Despite the vast promise of agriculture, especially in regions such as northern Ghana where it forms the basis of livelihoods and plays an essential role in the daily lives of its inhabitants, the challenges persist (Kadyampakeni et al., 2017). Among these is low agricultural productivity, a consequence of unpredictable rainfall and poor resource allocation, which has led to growing dependence on food imports and a decline in the competitiveness of domestic producers (Osabohien et al., 2019). The harsh situation of small-scale farmers in northern Ghana, accentuated by food insecurity and seasonal variations in food prices, highlights the difficulties involved in solving the wide-ranging problems faced by these communities (Denisova, 2018). It is paramount to recognize that while Ghana has made good progress in achieving the poverty reduction and hunger eradication-related Millennium Development Goals (MDGs), the transition to the Sustainable Development Goals (SDGs) requires a more careful and holistic approach. In this respect, the agriculture sector's central role in resolving food security issues and promoting sustainable agricultural practices is becoming increasingly evident. The persistence of food insecurity in various regions of Ghana points to the importance of targeted policy measures and strategic planning to sustain national food production and reduce the challenges posed by limited growth in the agricultural sector and lack of investment (Denisova, 2018).

The case of Nyankpala, a semi-arid region in the Northern Region of Ghana, is still heavily affected by water shortages and consequently limitated in the expansion of agricultural production. This is a crucial challenge for farmers, as the situation is becoming increasingly serious in the context of climate change. Extensive research over the years has highlighted the existence of substantial, but untapped, potential for improving agricultural practices in this region. These in-depth studies constantly confirm the promising prospects for agricultural intensification. The aim is to optimize the productivity of existing arable land and extend cultivation to previously unexplored territories through the strategic deployment of irrigation systems and the introduction of innovative farming strategies across the region. It is therefore important to identify the most suitable irrigation methods and the corresponding production strategies, taking account of the region. This comprehensive approach to agricultural development will not only enhance food security, but will also present a trajectory for economic growth, empowering local community ownership and serving as a powerful force in transforming the agricultural landscape of northern Ghana into a thriving center of sustainable productivity. Supplementary irrigation (SI) remains a promising way of combating this scourge, as it reduces water stress and improves agricultural production in general. It's a simple but very effective technology that allows growers to plant and manage crops at the optimum time, without being at the mercy of unexpected rainfall. SI enables farmers to plant their crops early, increasing yields and preventing exposure to terminal heat and drought stress in hot areas, and frost in cold areas. It can play an important role in the adaptation efforts to climate change in rainfed agroecosystems (Nangia & Oweis, 2016). The use of Supplementary irrigation is a multifaceted agricultural strategy, whose viability depends on factors including regional specificity, climatic attributes, crop varieties, soil type, soil texture, soil preparation method and a range of other determining factors. The interaction of these elements requires in-depth examination to understand the nuanced dynamics of Supplementary irrigation, its potential for improving agricultural productivity and its role as an essential tool for combating the evolving challenges posed by climate change. Given the importance of conserving precious water resources, the crucial aim of this research is to study and evaluate the impact of Supplementary irrigation on crop water stress in the context of implementing different soil conservation methods. Focusing on amaranth cultivation, this study seeks to determine how different soil conservation approaches interact with irrigation practices.

This study not only examined the problem of water scarcity and its adverse effects on agricultural productivity, but also provided valuable information on sustainable land management strategies that can be implemented in semi-arid regions to maximize water use and crop yields. The research investigated the relationship between supplementary irrigation and soil conservation practices in the Nyankpala agricultural landscape, in order to provide information for policy-makers, experts and farmers to improve food production, security, resilience in harsh climates and sustainable agricultural practices worldwide. To this end, soil water content was measured a crucial variable, to highlight its dynamic interaction with Supplementary irrigation and conservation methods. This in-depth analysis of soil moisture content allows the better understanding of how these practices collectively influence crop water stress and, consequently, agricultural outcomes in semi-arid regions.

1.2 Problem Statement and Justification

Water remains an indispensable and precious resource, and particularly so in regions where agriculture plays a central role in a country's economic landscape. Nevertheless, the availability of this vital resource is constantly limited, due to factors such as geographical location and the growing influence of climate change. Such is the case in northern Ghana, which, as the findings of Jeil et al. show in their 2020 study, still faces severe water shortages. The shortage of water precisely in the Tamale Metropolis of Ghana's northern region underscores a critical societal issue. Its pervasive impact resonates through the community, highlighting the pressing need for a solution (Musah, 2013). It has led to low productivity and inefficient water use in the agricultural sector, posing a threat to the livelihoods of the rural population (Aidam, 2015). This permanent problem of water scarcity takes a heavy toll on agricultural production, especially in semi-arid areas such as Nyankpala. In recent years, in light of the challenges posed by water availability in the region, it has become increasingly clear that agriculture cannot rely exclusively on rain-fed systems to maintain and improve crop production. It is therefore imperative to adopt innovative strategies and water management approaches to secure and strengthen agricultural efforts in these regions subject to water stress.

In addition, it is essential to point out that discussions on the impact of water scarcity on agriculture have also been addressed by other researchers. Konishi et al. (2004) have highlighted the pressing challenges facing irrigated agriculture and water resource management in agriculture with regard to sustainable development in a context of water scarcity. In response to the challenge posed by water scarcity, the introduction of Supplementary irrigation has experienced an ascending trajectory as a means of sustaining agricultural production. Supplementary irrigation refers to providing crops with water in addition to that which they naturally obtain from rainfall, particularly at specific growth stages. This helps to alleviate water stress and, ultimately, improve crop yields. It is important to note that the effectiveness of

Supplementary irrigation can depend on a variety of factors, including soil preparation techniques such as bed and ridge ploughing. These techniques reduce water waste due to soil evaporation and runoff, thus, enhancing the overall efficiency of water use in agriculture systems.

1.3 Research Hypotheses

1.3.1 Hypothesis 1

- Null hypothesis (H0): There is no significant difference in soil moisture content among the three soil conservation methods (raised beds, ridge tillage, and flats lands) when Supplementary irrigation is applied.

- Alternative hypothesis (H1): The three soil conservation methods (raised beds, ridge tillage, and flats lands), have a significant differential impact on soil moisture content when Supplementary irrigation is applied.

1.3.2 Hypothesis 2

- Null hypothesis (H0): There is no significant variation in crop water stress levels among the three soil conservation methods (raised beds, ridge tillage, and flats lands) when Supplementary irrigation is introduced.

- Alternative hypothesis (H1): there is significant difference in crop water stress levels among the three soil conservation methods, (raised beds, ridge tillage, and flats lands) show when Supplementary irrigation is introduced.

1.3.3 Hypothesis 3

- Null hypothesis (H0): There is no significant interaction between Supplementary irrigation and the specific soil conservation methods (raised beds, ridge tillage, and flats lands) in terms of their effects on soil moisture content, crop water stress, and crop yield.

- Alternative hypothesis (H1): The interaction between Supplementary irrigation and the chosen soil conservation methods significantly impacts soil moisture content, crop water stress, and crop yield, highlighting the importance of understanding their combined effects.

1.4 Research Objectives

1.4.1 Main objective

The main objective of the study was to assess the impact of Supplementary irrigation on soil moisture content and crop water stress under different soil conservation methods using amaranth as a test crop.

1.4.2 Specific objectives

- Determine the impact of Supplementary irrigation on soil moisture content under different conservations methods (raised beds, ridge tillage, and flats lands).
- Determine the effects of Supplementary irrigation on crop water stress under different conservations methods (raised beds, ridge tillage, and flats lands).
- Determine the effects of Supplementary irrigation on growth and yield parameters of amaranth crop under different conservations methods (raised beds, ridge tillage, and flats lands).

1.5 Research Questions

- ➢ How does supplementary irrigation treatments affects soil moisture content under different conservation methods, such as flats land, ridges and raise bed?
- ➢ How does supplementary irrigation treatments affects crop water stress under different conservation methods, such as flats land, ridges and raise bed?
- ➢ How does supplementary irrigation treatments affects the growth and yield parameters of amaranth crop under different conservation methods, such as flats land, ridges and raise bed?

1.6 Research Significance and Contribution

This study is of capital importance for farmers and, more importantly, for agricultural industries in regions affected by water shortages. The project will enrich the corpus of scientific knowledge on sustainable irrigation and conservation measures by assessing the impact of Supplementary irrigation and different soil preparation practices on amaranth crop production. The study will provide farmers in Nyankpala and similar localities with evidence-based suggestions on the most productive farming practices for sustainable amaranth production. This will help for better water resource management, increasing crop yields, and consequently food security in these regions. In addition, the study will help to advance environmentally-friendly farming methods and raise the standard of living for farmers in semi-arid areas. Overall, this study is important because it addresses broader issues such as sustainable agriculture, food insecurity and water scarcity, which go beyond the small community of Nyankpala. It is also useful for researchers, policy-makers and agricultural practitioners. Finally, it will also serve as a basis for future research and policy development aimed at resolving the challenges facing agriculture in regions where water resources are limited.

CHAPTER TWO

LITERATURE REVIEW

2.1 Irrigation Overview

Irrigation is the process of supplying water to agricultural fields, landscapes or other areas in a systematic and controlled manner to ensure adequate plant growth and development. This is a vital practice in areas where natural rainfall is not enough to meet the water demands of crops and vegetation. Irrigation methods include a range of techniques adapted to specific terrain, water availability and crop types, with the aim of maximizing water distribution and improving agricultural productivity.

2.1.1 Surface irrigation

Surface irrigation, as evidenced by its historical roots going back millennia, is the oldest and most widely used method of irrigating agricultural land worldwide. While it has often been criticized for its apparent inefficiency, it is essential to understand that much of the sub-optimal performance associated with surface irrigation can be attributed to design imperfections or poor water management rather than inherent flaws in the system itself (Humpherys, 1967). In contrast to pressurized irrigation solutions such as sprinklers and drip systems, which are renowned for their precision and adaptability but require greater investment, surface irrigation offers a unique advantage. In many cases, it avoids the need for pumping on the farm and relies on gravity to help the water flow. This reliability not only minimizes operating costs, but also emphasizes respect for the environment. In addition, surface irrigation is highly affordable in terms of manpower skills, often requiring only low-skilled labor to manage effectively. Although the portion of cultivated land using surface irrigation has declined in some regions for reasons of labor savings, the resurgence of labor costs could act as a catalyst for a resurgence in the adoption of surface irrigation, given its economic advantages and its ability to meet the needs of the population (Gillies et al., 2018).

2.1.2 Drip irrigation

Drip irrigation, a contemporary innovation in agricultural water management, functions as a low-pressure, low-volume watering system, capable of keeping optimal moisture levels around plant roots without saturating the soil. Drip irrigation is characterized by its ability to distribute water in a slow, controlled manner, resulting in significant water savings compared to conventional irrigation methods (Fayed, 2020). This micro-irrigation system is designed to provide precise, measured rates of water delivery straight to the plant's roots. This strategy not only saves water, but also minimizes nutrient losses. One of the key features of drip irrigation is its ability to deliver water fast to the root zone while limiting evaporation losses, thus saving even more water. The complexities of a drip irrigation system include a network of valves, pipes, tubes and emitters, all harmoniously orchestrated to facilitate the efficient transport of water. The efficacy of such a system depends on several critical factors, including its initial design, careful installation, regular maintenance and rigorous operational monitoring. These factors collectively underline the value of a comprehensive approach to optimizing the performance of drip irrigation, ensuring its role as a durable solution for precision agriculture and water resource management.

2.1.3 Sprinkler irrigation

According to Laycock (2007), sprinkler irrigation is a highly adaptable and efficient technique for the selective application of water to crops and vegetation. This method harnesses the power of pressurized water and ingeniously distributes it through a network of engineered sprinklers. These strategic devices, similar to natural rainfall, disperse water into the air, enabling it to fall gracefully on waiting plants. One of the great advantages of sprinkler irrigation is its ability to impart a uniformity to the landscape, ensuring that every corner of the cultivated expanse receives its fair share of hydration. This feature, combined with the method's adaptability, makes it an essential tool in agriculture. By adopting sprinkler irrigation, farmers can manage their water resources, optimizing distribution and significantly reducing the risk of wastage. What's more, sprinkler irrigation has an integral flexibility that enables it to perfectly harmonize with the diverse natural conditions found across the agricultural spectrum. Whether it's different climates, different soil compositions or nuanced hydrogeological factors, sprinkler irrigation is ready to adjust and customize its approach accordingly. This adaptability results in a highly customizable irrigation process, guaranteeing the precise water delivery required for the health and growth of crops and for plants. In essence, sprinkler irrigation is not only an impressive technological achievement, but also a pragmatic and environmentally-friendly solution for the needs of modern agriculture. Its ability to imitate nature's hand in distributing the water necessary for life, combined with its adaptability to diverse environmental contexts, highlights its central role in the ongoing quest for sustainable, efficient irrigation practices (Samiev et al., 2023).

However, sprinkler irrigation systems also have certain disadvantages. One of the main ones is the risk of water loss through evaporation. As water is sprayed into the air, some of it may be lost to evaporation before it reaches the crop, reducing the overall efficiency of the irrigation system. This can increase water consumption and potentially raise costs for farmers. In some cases, the use of irrigation systems in windy conditions can further aggravate water losses, as wind can deflect water away from its target. It is therefore important that farmers and agricultural practitioners carefully consider the advantages and disadvantages of sprinkler irrigation systems in choosing an irrigation method suited to their specific needs. By taking these factors into account, farmers can make informed decisions to optimize water use and maximize crop productivity.

2.1.4 Subsurface irrigation

Underground irrigation, a relatively recent innovation in agricultural water management, offers a paradigm shift in the way water is delivered to plant roots, encouraging greater precision and resource conservation. This innovative irrigation method is based on the idea of delivering water directly to the root zone under the soil surface. This approach contrasts strongly with conventional surface irrigation techniques, as it reduces water contact with the foliage above ground. As a result, reducing foliar interaction not only reduces the risk of disease, but also substantially reduces water losses due to evaporation and surface runoff. Subsurface irrigation is distinguished by the way it organizes the flow of water. The system relies on a network of concealed tubes or pipes, discretely buried to facilitate the discreet distribution of water precisely where it's needed most - the plant roots. During this below-ground journey, the water remains sheltered from the environment's vagaries, effectively protecting it from the wasteful reach of evaporation and run-off, while ensuring a direct, nutritive embrace of the plant's vital root zone (Lamm, 2007).

According to Alrubaye et al. (2022), the underground irrigation system further on introduces an intriguing technological touch - the use of inverted closed plastic bottles (ICPB) connected to an elevated closed reservoir. This ingenious system works under slight negative pressure, performing a carefully synchronized exchange between water and air bubbles. This not only enables water flow to be precisely regulated, but also facilitates the propagation of wetting fronts, optimizing the distribution of moisture in the soil. In essence, subsurface irrigation reflects the ability of innovation to reshape the agricultural landscape, offering a promising route to water-efficient, disease-resistant and accurately controlled irrigation practices.

2.1.5 Flood irrigation

Flood irrigation, often called submersion irrigation, is a particular method of delivering water to agricultural fields, characterized by the imitation of natural inundation processes. In this method, the whole field surface is intentionally flooded, reproducing the appearance of light flooding. This allows the water to penetrate the soil and eventually reach the complex network of plant roots nestling beneath the surface.

Flood irrigation has traditionally found its place in specific agricultural contexts, in particular rice paddies and vast flatlands. Although it may be perceived as being relatively less efficient in terms of water use, it undeniably offers several advantages that make it a sustainable choice in specific contexts. In fact, it excels at providing uniform water coverage over large areas of land, an attribute that is invaluable in situations where crops are grown on a large scale. This global approach to flooding is in line with the historical use of flood irrigation, and takes advantage of its ability to reproduce natural flooding processes, thus facilitating the supply of plant roots to the entire field (Kincaid & Buchleiter, 2004).

2.1.6 Localized irrigation

Localized irrigation, a precise approach to crop watering, is a technique designed to deliver water directly to the root zone of individual plants or small groups of vegetation. This precision irrigation strategy aims to maintain soil moisture levels at optimum field capacity, thereby nourishing plants with the utmost efficiency. Two main techniques are at the center of the localized irrigation concept: micro-sprinkler irrigation and drip irrigation. These methods have been widely recognized for their unique water-saving features and high application efficiency. Studies have investigated the profound impact of localized irrigation on various crops, with sugarcane in particular profiting from this approach, which translates into amplified stalk yields and increased productivity (Manoel et al., 2015). In comparative studies evaluating different irrigation systems, localized irrigation is consistently shown to be the best choice in many critical areas, including crop productivity and water demand management. One of the main advantages of localized irrigation methods is their precise targeting of the root zone. By delivering water exactly where it's needed most, these systems limit water losses due to evaporation and runoff. This increased efficiency is in line with the overall objective of resource conservation, making localized irrigation not only a viable choice, but also a powerful tool for optimizing agricultural productivity while reducing the environmental footprint.

In its most basic form, localized irrigation techniques represent the marriage of precision and efficiency in modern agriculture. By focusing on the crop's root zone and minimizing water wastage, these methods represent an essential stage on the road to sustainable, responsible management of water resources in the cultivation of plants and vegetation.

Localized irrigation systems, such as drip and subsurface irrigation, offer a number of advantages, not least high application efficiency and better water conservation. But these systems also have their drawbacks. One of the main problems is the risk of clogged water outlets, which can reduce the overall efficiency of the irrigation system and lead to unequal water distribution. This can lead to water stress and reduced crop yields. What's more, localized irrigation systems can be costly to install, requiring a large amount of piping and other equipment. This can represent a significant obstacle for small-scale farmers or those with limited resources. Thirdly, the constant availability of water in localized irrigation systems can lead to a drop-in root depth, which can reduce plant stability and increase their susceptibility to pests and disease.

It's important for farmers and agriculture practioners to closely examine the advantages and disadvantages of localized irrigation systems when choosing an irrigation method suited to their particular needs. By considering these factors, they can make informed decisions to make the best use of water and maximize crop productivity (Vermeiren & Jobling, 1980).

2.1.7 Manual irrigation

Traditional irrigation refers to the practice of manually applying water to crops or plants using simple tools or techniques. In this practice, farmers physically control the distribution of water through methods such as the use of buckets, watering cans, hoses or other portable devices to deliver water directly to the plants' root zone. Hand irrigation is a labor-intensive method commonly used by small-scale farmers and gardeners to ensure that crops receive the right amount of water for their growth and development. Although obsolete, this irrigation method is still the most widespread in villages and farming communities. It is used mainly because of its low cost and accessibility.

Manual application techniques, such as bucket irrigation and furrow irrigation, can be labor intensive and time consuming. These techniques require farmers to manually transport water from a source to the crop, and this can be physically demanding and time-consuming. Also, hand irrigation techniques can be inefficient, potentially wasting water and reducing crop yields. It can be difficult to distribute water evenly across a field using manual methods, which can lead to an excess of water in some areas and a lack of water in others. This can result in water stress and reduced crop quality. Lastly, manual irrigation techniques may not be sustainable in the long term, as they depend on a constant input of labor and water resources, which may not be available or feasible in all agricultural contexts.

When choosing an irrigation method to suit their specific needs, it's always advisable for farmers and agricultural practitioners to thoroughly consider the advantages and disadvantages of different manual irrigation techniques. By keeping these factors in mind, they can make informed decisions to optimization water use and maximize crop productivity (Monty, Capraro, & Doig, 2011).

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2.1.8 Smart irrigation

Smart irrigation is an advanced approach to water resource management in agriculture. It leverages the power of technology to maximize water use, improve crop yields and contribute to sustainable agricultural practices. This innovation methodology relies on a series of sensors, real-time meteorological data and advanced software to make intelligent decisions about irrigation programming, leading to the most judicious use of water. The application of smart irrigation systems is particularly advantageous in regions characterized by water scarcity and highly unpredictable weather conditions (Greeshma et al., 2023).

Smart irrigation technology works on the principle of real-time data analysis and adaptive irrigation strategy. They are conceived to ensure that crops receive the precise amount of water required, reducing the risk of over- and under-watering. The systems can monitor crucial environmental factors, such as soil moisture content, temperature, humidity and rainfall, enabling farmers to make data-driven decisions. By coordinating the timing and volume of irrigation, smart irrigation not only enhances crop health, but also minimizes water wastage, reducing costs for farmers.

Smart irrigation system solutions adapt to a variety of existing irrigation systems and improve their efficiency through the incorporation of technology. The most commonly used irrigation methods include flood, sprinkler, center pivot, drip and micro-irrigation systems. Each of these can benefit from the implementation of intelligent irrigation software.

Sprinkler irrigation: In this type of system, water is delivered by high-pressure overhead sprinklers. Intelligent technology incorporates thermal and acoustic rain sensors that detect rainfall pattern and intensity. These sensors help to automate irrigation scheduling on the basis of real-time data, thus preventing excessive water use and over-watering due to natural precipitation.

Center pivot irrigation**:** Used extensively in agriculture, this method consists of a long pipe attached to a central tower that rotates in a circular pattern, irrigating plants with sprayers. Integrated systems analyze data from sensors in the field to adjust water flow and watering angles, ensuring a uniform coverage of the field. Meteorological and soil moisture data enable precise irrigation scheduling, which improves overall yield and harvest timing.

Drip irrigation*:* In drip irrigation, water is delivered directly to plant roots through pipes with small openings called drippers, preventing evaporation and runoff. Intelligent technology features real-time visibility of the irrigation process, notifying users via mobile applications of the start and end of irrigation. It also monitors soil parameters before and after irrigation for better management.

Micro-irrigation: Micro-irrigation systems are characterized by low-pressure, low-volume water application. Intelligent systems compute the exact water doses for each plant, relying on artificial intelligence algorithms to automatically recognize plants and adjust watering accordingly. While there is great promise for smart irrigation to optimize water management and enhance agricultural sustainability, it is essential to fully recognize certain challenges. The high upfront cost of implementing these systems can be a barrier for small-scale farmers with limited available resources. In turn, the efficient operation of smart irrigation systems requires a certain level of engineering expertise, which can be a challenge for some farmers. But the potential benefits far outweigh these difficulties. By taking strategic advantage of emerging technologies and innovative approaches, smart irrigation systems have the power to revolutionize water resource management in agriculture. They contribute to increasing crop yields, reducing water consumption and improving environmental management. At a time of changing climates and increasing water scarcity, the integration of smart irrigation represents an essential milestone in ensuring the long-term sustainability and resiliency of agricultural systems (Greeshma et al., 2023).

2.2 Definition of Supplementary Irrigation

Supplementary irrigation, often considered a proactive and strategic approach, is a deliberate practice involving the selective addition of limited amounts of water to rain-fed agricultural fields. This increase in natural precipitation is an essential response to counter the potential effects of soil water stress on rainfed crops, notably during prolonged periods of drought. The importance of supplementary irrigation becomes more apparent during the most critical phases of crop growth, such as flowering and fruiting. By carefully providing additional water precisely when crops need it most, farmers can effectively bridge the gap between rainfall variability and the constant hydration needs of their crops. This strategic provision of water resources plays an essential role not only in maintaining crop health, but also in ensuring that cultivated fields achieve their full yield potential. Supplementary irrigation can have a number of disadvantages, including water consumption, energy usage, soil salinization, waterlogging and increased pest and disease pressure. Irrigation can waste a lot of water, depending on the irrigation method used, which can harm the environment and increase costs for farmers. Some methods of irrigation, such as sprinklers, require significant energy inputs to operate, which can increase greenhouse gas emissions and therefore contribute to climate change. The excessive use of Supplementary irrigation can lead to soil salinization, which can decrease soil fertility and have a negative impact on crop yields. Oversupply irrigation can lead to soil waterlogging, which can reduce soil aeration and have a negative impact on root growth and development. In addition, over-watering can create favorable conditions for pests and diseases, which can increase the risk of crop damage and yield loss. When selecting an irrigation technique appropriate for their unique needs, farmers and agricultural professionals need to take the potential negatives of Supplementary irrigation seriously. They may make educated judgments to optimize water consumption and increase agricultural output by taking these aspects into consideration (Nangia & Oweis, 2016).

Figure 2.1: Supplementary Irrigation

Source: Pinterest

2.3 Definition of Crop Water Stress

Crop water stress is a central concern in agriculture, with substantial implications for global food security and environmentally sustainable farming practices. At root, crop water stress results from a difficult condition in which plants are faced with a lack of water to meet their physiological needs. This deficiency affects basic processes essential to plant health, including nutrient uptake, photosynthesis and transpiration. As a result, the repercussions are palpable: stunted growth, visible wilting and pronounced deterioration in crop quality and yield (Sadras et al., 2016).

A number of factors combine to precipitate water stress in crops, from irregular rainfall to sub-optimal irrigation practices, as well as soil characteristics and the growing influence of climate change. The interaction of these variables serves to demonstrate the complexity of managing and reducing water stress in agricultural environments. As a vital element of modern agriculture, effective monitoring and management of crop water stress is essential to achieve sustainable crop productivity. This effort relies on the implementation of irrigation strategies, which must be adapted to specific crop varieties and growth stages. In parallel, it is necessary to diligently assess soil moisture levels in order to accurately determine the plant's moisture status. To achieve this, technologies such as remote sensing and predictive modeling have become indispensable tools. These technologies provide real-time information on soil moisture dynamics, allowing precise decisions to be made on irrigation scheduling and water allocation. In this respect, the intelligent use of water resources becomes crucial. Making sure that crops receive the optimum amount of water during critical growth phases is a primary objective. This not only improves yields, but also takes a prudent approach to conserving precious water resources, in line with sustainable farming practices (Benea et al., 2018).

Figure 2.2: Crop Under Water Stress

Source: Pinterest

2.4 Impact of Climate Change on Supplementary Irrigation

Global agricultural systems are anticipated to be significantly impacted by climate change, especially the distribution and availability of water resources. Consequently, the importance of additional irrigation in reducing the negative effects of climate change on crop productivity has increased. In this section, we'll look at how climate change can affect Supplementary irrigation methods and how that might affect crop water stress and output.

The altering precipitation patterns are one of the most significant effects of climate change on Supplementary irrigation. Extreme weather events, such as droughts and floods, are predicted to become more often and intense as global temperatures rise. This can result in water scarcity and decreased soil moisture content, both of which can have a negative influence on crop productivity and quality. Changes in precipitation patterns can also have an impact on the efficacy of other irrigation methods, such as surface irrigation and drip irrigation, which rely on consistent and predictable water availability. Temperature differences caused by climate change can also have an impact on the requirement for Supplementary irrigation and the efficiency of various conservation strategies. Higher temperatures can hasten evapotranspiration, resulting in higher water loss and decreased soil moisture content. This can worsen crop water stress and lower crop output. Furthermore, temperature changes can have an impact on the performance of other soil conservation strategies, such as ridges and raised beds, which rely on ideal soil moisture content to work properly.

Extreme weather events linked to climate change, such as heatwaves and heavy rains, can potentially have an impact on the efficacy of Supplementary irrigation measures. Heavy rainfall, for example, can cause soil erosion and nutrient leaching, limiting the effectiveness of soil conservation strategies. Heatwaves, on the other hand, might raise the requirement for Supplementary irrigation, resulting in higher water consumption and possibly water scarcity.

Adapting Supplementary irrigation technologies to alleviate climate change impacts on agricultural systems brings both problems and opportunity. In the face of changing climate circumstances, emerging technologies such as precision irrigation and remote sensing can help maximize water use and crop productivity. Furthermore, novel soil conservation practices such as agroforestry and conservation agriculture can improve soil health and lower the danger of soil erosion and nutrient depletion. Finally, the influence of climate change on Supplementary irrigation techniques is a complicated and diverse problem that necessitates thorough assessment of the possible hazards and opportunities connected with various irrigation technologies and soil conservation strategies. We can assist assure the sustainability and resilience of agricultural systems in the face of climate change by adopting new techniques and using emerging technologies.

2.5 Soil Conservation Methods

Soil conservation is a fundamental agricultural practice, aimed at nourishing the land to establish the most favorable conditions for cultivation. It involves a dynamic approach, in tune with the diverse characteristics of different landforms, ranging from flat terrain to gently sloping ridges and raised beds of complex design. Soil conservation refers to techniques aimed at optimizing soil conditions for crops. These methods vary from tillage to advanced strategies, improving soil structure, nutrients and moisture. It can be adapted to different landscapes. On level ground, it includes contour farming to prevent erosion and capture rainwater. On slopes, it focuses on drainage and water runoff prevention. Raised beds enhance aeration and drainage to strengthen root systems.

2.5.1 Flat land

Flat land is characterized by uniform terrain, where soil conservation practices start with ploughing. The initial step is ploughing, the principal aim of which is to break up compacted soil layers and improve air circulation in the soil. This process enables the soil clods to be broken up, creating a more uniform, flatter bed suitable for planting crops. These steps in sequence are of key importance in preparing the soil for optimum crop growth, and ensuring that it provides the ideal conditions for the development of plants.

2.5.2 Ridges

Ridge cultivation is a farming technique that consists of intentionally shaping the soil to form raised rows or furrows. This method is a pro-active measure to solve drainage problems and manage excess water, minimizing the risk of waterlogging that can affect crop health. Ridges are especially useful in areas with excessive water accumulation, where the presence of stagnant water can pose a significant threat to plant health. The deliberate creation of these elevated structures not only keeps excess water away from crops, but also helps to effectively regulate water resources in agricultural areas. This practice demonstrates the genius of soil conservation strategies in protecting crops from the potential dangers of waterlogged conditions, providing a more favorable environment for agricultural production.

2.5.3 Raised beds

Raised beds offer a systematic approach as farming in which the ground is raised to form distinct planting zones. This unique technique has a number of advantages, mainly improving soil quality and optimizing growing conditions for crops. The process involves building raised mounds or beds, either by manual or mechanical means, which effectively raise the soil above ground level. This rise has multiple advantages, starting with better drainage management. By bringing the soil to a higher level, raised beds allow excess water to drain easily, reducing the risk of waterlogging, a condition that can be damaging to crop roots and overall plant health. In addition, raised beds are excellent at retaining heat, creating a microclimate that promotes crop growth, particularly in cooler climates. The raised position of the soil enables it to more effectively absorb and retain heat. In short, raised beds provide an ingenious approach to soil conservation. The soil is elevated in specific planting zones, offering such advantages as improved drainage, better heat storage and optimized root development.

Figure 2.3: Ridge Tillage

Rudmorijn, 2014

Figure 2.4: Raise Beds

Source : Zac Spade,2017

Figure 2.5: Flat Land

Source: Drazen Nesic ,2017

2.6 Soil Moisture Content

Soil water content in irrigation is a fundamental parameter that refers to the proportion of water present in the soil matrix, expressed as a percentage of the total soil weight or volume. This essential factor plays a crucial role in the delicate balance of water availability in the soil-plant-atmosphere continuum, profoundly influencing plant growth, physiological functions and overall agricultural productivity.

This involves the complex interplay between water retention, gravity drainage and capillary action that dictates the intricate movement of water through soil particles. It reflects the dynamic balance between water inputs (from precipitation or irrigation) and outputs (via evapotranspiration and drainage), thus determining the soil's capacity to supply water to plants while avoiding waterlogging or excessive water stress. In the irrigation context, soil water content is of paramount importance. Its real-time assessment allows farmers and agricultural practitioners to make informed decisions about the timing, frequency and volume of irrigation applications. By ensuring that soil moisture remains within an optimum range for plant growth, farmers can minimize waste, maximize water-use efficiency and improve crop yields while conserving precious water resources. Soil moisture monitoring can entail a range of techniques, ranging from traditional methods such as gravimetric sampling and soil moisture measurement to more advanced methods such as soil moisture measurement. Soil moisture content is an important agricultural characteristic since it has a large impact on crop development. There are various ways for measuring soil moisture content, each with its own set of pros and disadvantages.

2.6.1 Gravimetric analysis

This traditional method is frequently used as a foundation for other measurement techniques. It entails calculating the weight difference between a wet soil sample and the same sample after drying in an oven. The gravimetric approach measures the water content of the soil directly.

2.6.2 Time domain reflectometry (TDR)

TDR is an electromagnetic technique used to assess the moisture content of soil by measuring its dielectric characteristics. It operates by delivering an electromagnetic pulse through the soil and timing how long it takes for the pulse to return to the sensor. TDR is well-known for its precision and capacity to provide measurements in real time.

2.6.3 Capacitance sensors

Capacitance sensors monitor soil moisture content by measuring the dielectric constant of the soil. These sensors are made up of two electrodes that are put into the soil and measure the moisture content depending on the capacitance between the electrodes. Because of their ease of use and capacity to provide continuous data, capacitance sensors are widely used. Each of these methods has its own advantages and disadvantages. Gravimetric analysis is a reliable method for measuring soil moisture content, but it is time-consuming and requires a lot of effort. TDR is a non-destructive method that provides real-time measurements, but it is expensive and requires specialized equipment. Capacitance sensors are easy to use and provide continuous measurements, but they are less accurate than other methods.

Figure 2.6: Monitoring Soil Moisture Content

Source: Pinterest, (oldboysflowers.com.au)

2.7 Overview of the Amaranth Crop

The amaranth, which belongs to the genus Amaranthus, is of considerable importance to agriculture, due to its remarkable adaptability, nutritional value and diverse applications.

Amaranth has experienced a resurgence in cultivation due to its adaptability to a variety of environments, from arid to tropical regions. Its capacity to thrive on marginal lands and in conditions of limited water availability makes it a promising crop for meeting the challenges of food security. According to species and purpose, amaranth can be grown for its edible leaves, its nutrient-rich seeds or its ornamental value.

Amaranth's nutritional status is one of its most remarkable features. It is known to be a rich source of protein, essential amino acids, dietary fiber and micronutrients such as iron, calcium and magnesium. The leaves and seeds of amaranth offer a well-balanced nutrient package that contributes to its "superfood" status. This nutrient density makes it a potential candidate for combating malnutrition and enhancing diets in regions where dietary diversity is limited. Amaranth, a potential health-giving pseudo cereal, has distinguished itself by its remarkable ability to adapt to difficult growing conditions. The plant is attracting growing interest for its ability to survive in challenging environments. Enriched with bioactive compounds such as phytochemicals and antioxidants, amaranth embodies a crop that not only offers sustenance, but also health benefits. Those compounds contribute to its reputation as a nutritious and health-promoting food source, in line with today's emphasis on functional foods (Martínez-Núñez et al., 2019). The production of amaranth involves a series of well-defined steps designed to maximize growth and yield. First and foremost is the choice of an ideal planting site. Optimal soil conditions are characterized by sandy-loam or clay-loam soil, which should be ideally flat, well-drained, fertile and possess the qualities of fluidity or alkalinity conducive to amaranth growth.

Seed selection is equally crucial, with preference given to varieties such as large-leaf red leaf spinach, round-leaf spinach and pointed-leaf red leaf spinach. These cultivars are recognized for their robust characteristics, including heat and drought resistance, disease and pest resistance, and ability to provide superior yields and quality.

The sowing process itself adopts a specific mode adapted to amaranth, assuring the correct establishment of young plants. Field practices are then diligently implemented to maintain conditions of optimal growth and yield. These practices include techniques such as maintaining constant soil moisture through adequate irrigation of the vegetable field, employing sunshade netting to regulate temperature and humidity levels, and adopting comprehensive field management practices designed to maximize both the quantity and quality of the amaranth yield. By adopting this technical itinerary, amaranth cultivation strives to provide a structured and consistent approach to achieve high yields of this versatile and nutritious vegetable, while promoting sustainable and efficient farming practices.

Amaranth production faces a series of pest challenges, with lepidopteran defoliators being among the most important adversaries. These pests, especially leafrollers and leafworms, are a major threat to amaranth production. Leafrollers are known for their ability to crease, weave or glue amaranth leaves using silk threads while feeding, while leafworms cause characteristic, window-like damages to leaves without using any weaving techniques. It should be noted that these pests can persist right through the year, regardless of wet or dry seasons, posing a permanent risk to amaranth crops.

In fact, amaranth varieties vary in their susceptibility to these pests. For instance, the Abuk2 amaranth is more resistant, harboring fewer weevils and suffering less damage than the more vulnerable Abuk8 variety (Othim et al., 2018). In the fight against these destructive insects, nature offers some form of assistance in the shape of parasitoids such as Atropha tricolor and Apanteles sp.

These beneficial organisms engage in parasitism, effectively reducing defoliating Lepidoptera populations and mitigating damage to amaranth crops. These complex interactions within the amaranth ecosystem underline the importance of holistic pest management strategies to protect and maintain amaranth production. Growing amaranth involves several distinct phenological phases, each playing a fundamental role in the plant's growth and development.

Germination stage: In this phase, amaranth seedlings develop their first set of true leaves. They are still delicate and vulnerable at this stage and require special attention in terms of watering and protection against pests and adverse weather conditions.

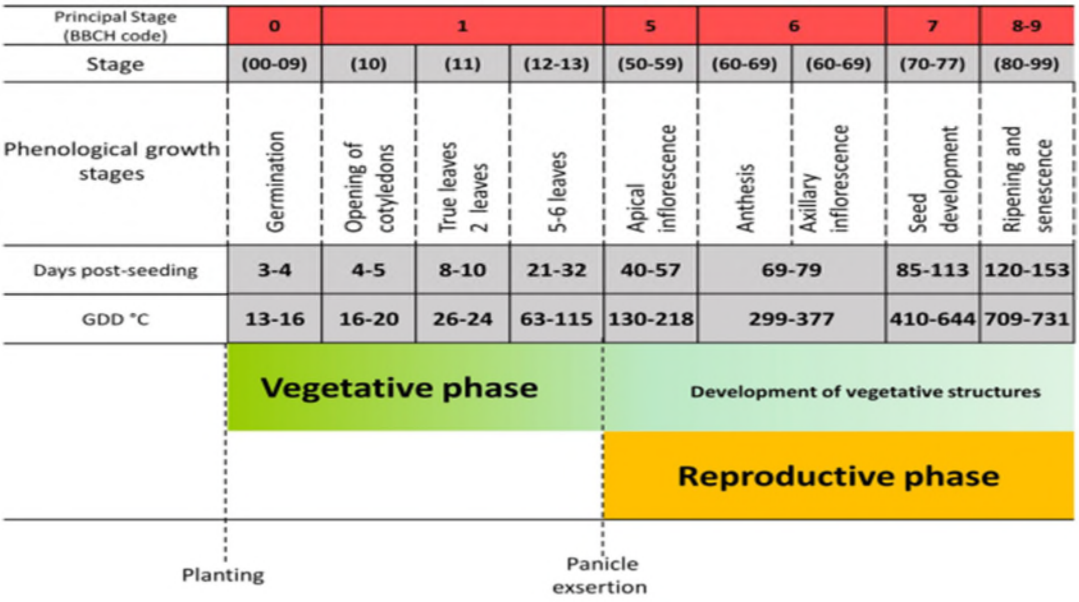
Vegetative growth: The vegetative growth phase is characterized by the rapid development of leaves and stems. Amaranth plants are concentrated on building a robust structure, preparing for the eventual production of flowers and seeds.

Flowering phase: As it matures, amaranth enters the flowering stage, where it produces clusters of vibrant, acorn-like flowers. These flowers contain the male and female reproductive organ and are essential for the production of seeds.

Seed formation: Following successful pollination, the plant starts the seed formation process. The seeds grow inside the flower clusters, gradually filling up and mature over time.

Harvest: The plant can be harvested once the seeds have matured and dried. The leaves and stems of amaranth are also edible and can be harvested at different stages for consumption.

Senescence and seed dispersal: The plant eventually becomes senescent, the leaves and stems drying out. Mature seeds are dispersed, often falling to the ground to facilitate the growth of new amaranth plants in the following season.



Principal Stage (BBCH code)	0	1			5	6		7	8-9
Stage	(00-09)	(10)	(11)	(12-13)	(50-59)	(60-69)	(60-69)	(70-77)	(80-99)
Phenological growth stages	Germination	Opening of cotyledons	True leaves 2 leaves	5-6 leaves	Apical inflorescence	Anthesis	Axillary inflorescence	Seed development	Ripening and senescence
Days post-seeding	3-4	4-5	8-10	21-32	40-57	69-79		85-113	120-153
GDD °C	13-16	16-20	26-24	63-115	130-218	299-377		410-644	709-731

Figure 2.7: Phenological Stages of Amaranth

Source: M. Martínez-Núñez, 2019

Figure 2.8: Amaranth Under Ridge Tillage

Source: Joshua,2022

2.8 Previous Research on Irrigation and Crop Production

The use of water for irrigation is a crucial practice in agricultural production, particularly in regions where rainfall is insufficient to maintain crops. Supplying water to crops at key growth stages, known as Supplementary irrigation, can increase crop yields and mitigate the effects of water stress on plants. The types of crops, of soil, and the conservation practices employed to lessen water loss from soil evaporation and runoff are factors that affect how effective Supplementary irrigation is. Previous studies on irrigation and crop production have looked at several aspects of plant growth and development under varying water stress conditions. One study, for example, looked at the effect of different levels of water stress on the development and fertility of Palmer amaranth and discovered that water stress had a substantial impact on plant height, survival, and seed output (Chahal *et al.*, 2018).

Another publication shows that crop yields increased six-fold over traditional methods when rainwater harvesting and fertilizer use were combined. Small-scale farmers were able to switch to more diversified crops thanks to the use of rainwater harvesting, improving household food security, diet, and economic returns (Biazin et al., 2012). Besides irrigation, the use of fertilizers is also essential to enhance crop yields. However, conventional synthetic fertilizers are costly and can have adverse effects on the environment. Therefore, there is growing interest in using alternate fertilizers such as compost extract, which is cost-effective and environmentally friendly. Research has shown that fertigation with compost extract significantly improved the growth and yield parameters of amaranth. The compost/water ratio, soaking time, and water temperature had a significant effect on the growth and yield parameters of both vegetables (Oyewusi & Osun Bitan, 2021).

Researchers have argued that greater research attention and understanding of amaranth's nutritional properties could promote its acceptance and application in key agricultural value chains, improving food and nutritional security in the end (Emmanuel & Babalola, 2021). These studies highlight the importance of understanding the impact of water stress on crop growth and development, as well as the potential benefits of under-utilized crops such as amaranth in alleviating food insecurity problems. In more detail, these studies show that in semi-arid zones, rainwater harvesting and management systems are another essential component of agricultural production. Similarly, proper use of in situ and micro-capture techniques can increase soil water content in the rooting zone by up to 30%. Considering further research results, a study conducted in coastal Kenya showed that rigorous assessment, encompassing parameters such as emergence rates, plant height, leaf area, and chlorophyll content, it was unveiled that seeds sown in freshwater exhibited a more pronounced emergence rate in comparison to their saline water counterparts (Oluoch et al., 2021,).

In a similar vein, another in-depth study explored the complex terrain of the impact of drought stress on various pigweed genotypes. The results revealed different responses from these genotypes, elucidated by their alterations in root, stem and leaf dry mass ratios under the stress of drought conditions. A notable observation was that water use efficiency (WUE) remained unchanged despite the stress imposed, indicating the innate ability of these genotypes to deploy water resources efficiently (Liu & Stützel, 2004). Another investigation was carried out into the adaptability of amaranth to water stress in the vicinity of the Northern Great Plains. The elaborate study showed a fascinating facet: the crop responds to water stress by increasing root depth, making it able to cope with multiple soil moisture scenarios. The exploratory trip highlighted clear disparities between various amaranth cultivars, particularly with regard to key plant attributes such as biomass yield, plant height and harvest index.

In addition, the research revealed that amaranth's water requirements were significantly lower than those of other major crops, making it a water-efficient competitor (Johnson & Henderson,2002). Finally, a comprehensive and complex analysis has made it possible to increase the quality and yield of water-stressed amaranth using innovative foliar treatments. This investigation revealed a cascade of effects arising from water shortage, culminating in alterations to stomatal conductance and forage quality.

However, the story took an optimistic turn with the revelation that foliar applications of abscisic acid, salicylic acid and potassium sulfate continuously increased leaf water potential, forage yield and overall quality. This experimental background has led to the revelation of these treatments as potential saviors, capable of reversing the harmful effects of water stress, while promoting increased quantities and superior quality of amaranth production (Farshbaf-Jafari et al., 2020).

Further on, (Baghdadi et al., 2021) studied the implementation of Fixed Alternate Furrow Irrigation (FFI) and Alternate Furrow Irrigation (AFI), resulting in substantial water savings. More specifically, FFI led to a remarkable 22.5% reduction in irrigation water use, while AFI achieved a commendable 19.7% reduction. In terms of intercropping strategies, interesting information was also gathered. Among these, the highest dry matter (DM) yield of 15.5 Mg ha-1 was observed in the context of conventional furrow irrigation (CFI), in combination with a sorghum-amaranth intercropping ratio of 50:50 (S50-A50). This research highlighted irrigation water use efficiency (IWUE), with sorghum monoculture and S75-A25 intercropping demonstrating the highest IWUE values of 3.4 and 3.3 kg m-3, respectively. Conversely, the amaranth crop alone had an IWUE of 1.7 kg m-3. In the case of sorghum, the study looked at the land equivalent ratio and the monetary benefit index, pointing out that sorghum could benefit from intercropping as long as its proportion within the intercropping arrangement exceeded 25%.

In another study (Okunade et al., 2008), the compared impact of different irrigation methods on crop yields was examined. Both drip and sprinkler irrigation methods were found to be significantly superior in terms of yield to furrow and basin methods, showing their potential for optimizing crop production. In parallel, the study monitored plant height and leaf area index at different growth stages, providing valuable information on the dynamic growth patterns of okra and amaranth crops. In conjunction, economic analyses were carried out to assess the profitability and profitability of crop growth under the four distinct irrigation methods, providing valuable considerations for agricultural decision-makers.

2.9 Effect of Supplementary Irrigation on Crop Water Stress

Supplementary irrigation is a widely used strategy for reducing crop water stress and increasing agricultural yields. Due to the lack of fresh water supplies, efficient water usage in agriculture has become increasingly fundamental. As a result, it is capital to investigate the impact of additional irrigation on agricultural water stress. Several papers have explored this relationship by evaluating the effects of different levels of water stress on crop growth, and water use efficiency and found that plants maintained at field soil capacity ≤25% did not continue to survive beyond 35 days after the plantation. However, plants under continuous water stress

≥50% of soil capacity were able to survive and give rise to a significant number of seeds with no effect on seed germination. The number of leaves the plants produced was unaffected by the water stress regimes of 100%, 75%, and 50% soil capacity. Nevertheless, plant height was reduced with increasing water stress levels, as plants at 100% soil field capacity reached a maximum height of 178 cm as compared to 124 and 88 cm at 75% and 50% soil field capacity, respectively (Chahal et al., 2018). It has been shown that Supplementary irrigation is a promising climate-smart practice for dryland agriculture, as it can effectively improve and stabilize yields of rainfed crops during dry spells when rainfall is insufficient for normal plant growth (Nangia & Oweis, 2016). A study analyzed the impact of different irrigation levels on amaranth cultivation in the peri-urban area of Bujumbura.

Using three different irrigation regimes - T1 (10% irrigation rate), T2 (30% irrigation rate) and T3 (60% irrigation rate) - the research aimed to discern their impact on both growth parameters and yield results. T2 applied at a 30% irrigation rate proved to be the most effective, distinctly improving key growth indicators such as leaf number, stem diameter, plant height, leaf spread and root development. At the same time, T2 showed increased water use efficiency when juxtaposed with other treatments.

This finding underlines the significant potential of a 30% irrigation rate in increasing the global growth and yield of amaranth in the peri-urban context of Bujumbura (Chantal et al., 2018). Another study attempted to identify how variation in ridge/furrow ratios and Supplementary irrigation affected crop productivity and water use efficiency (WUE) in a ridge and furrow rainwater harvesting (RFRH) system with mulches. Ridge/furrow ratios were found to have a substantial effect on crop yield and yield components in the study. When compared to the 60:60 cm ridge and furrow system, the 120:60 cm ridge and furrow system enhanced yield by 27.9%, seed weight per head by 14.8%, seed number per head by 7.4%, and 1000seed weight by 4.7%. There were no variations in WUE between the two ratio schemes. The most efficient ridge size for crop yield appears to be 60cm. Additionally, Supplementary irrigation in the RFRH system was found to be benefit to the crop (Li & Gong, 2002).

Moreover, studies show that Supplementary irrigation significantly affected grain yield during all three crop seasons. The use of fertilizer also produced noticeably increased grain production. Notably, the maximum average grain yield was obtained when additional irrigation and fertilizer treatment were combined. There were various levels of dry spells experienced during the trials carried out during the rainy seasons, with a significant dry spell occurring in each season that had an impact on the crop growth stages. These findings emphasize the significance of considering supplementary irrigation and soil nutrient management as viable methods to reduce water stress and increase crop output (Fox & Rockström, 2003). Other research looked at the costs connected with the relationship between amaranth's growth factors and water use under various irrigation techniques. The researchers examined the impact of each irrigation method on crop growth, yield, and water use, using statistical analyses such as ANOVA and least-squares mean analysis. The results showed that the drip irrigation system was the most profitable approach for growing amaranth. These results strongly recommend that the application of drip irrigation may be a favorable choice for farmers seeking optimal crop growth, water use efficiency and economic gains in amaranth production (Okunade et al., 2008).

2.10 Effect of Supplementary Irrigation on Soil Moisture Content

The effect of Supplementary irrigation on soil moisture content has been the subject of several studies, each providing valuable information on the interaction between irrigation strategies and soil moisture content. A study by Lin & Wang (2017) assessed six different irrigation treatments, ranging from rain-fed conditions to targeted irrigation at different soil layers. Particularly, the treatment with targeted relative soil moisture at 0-40 cm (W3) showed the highest photosynthesis and transpiration rates, as well as superior water use efficiency. Also, this treatment gave the highest grain production and water use efficiency, clearly underlining the importance of appropriate moisture levels at this soil depth. Fox & Rockström (2003) studied the influence of Supplementary irrigation on winter wheat, considering different soil layers and growth stages. Their conclusions point to the importance of adapted irrigation strategies, with the W2 treatment proving optimal for balancing irrigation quantities, grain yield and water-use efficiency. In the study by LI Shi-hua (2010), the influence of Supplementary irrigation on sorghum yields in Burkina Faso was examined over three rainy seasons. Variable rainfall distribution and dry spells during these seasons highlighted the critical role of Supplementary irrigation in attenuating moisture deficits at different stages of crop growth. In addition, research into soil moisture variation under different irrigation rates revealed distinct responses to irrigation levels. The study demonstrated that increasing irrigation quotas resulted in an increase in soil moisture content at specific depths, providing practical insights into water resource management and irrigation practices. LIU et al (2012) looked at cotton yields in response to different irrigation frequencies and water quotas. Excessive irrigation, as well as high-frequency irrigation, produced the highest cotton yields, underlining the importance of precise irrigation scheduling.

Finally, according to Çetİn and Üzen (2018) a recent study investigating the impact of surface drip irrigation (SDI) and subsurface drip irrigation (SSDI) on soil moisture variation and soil water tension in cotton crops has produced some interesting findings. Using tensiometers, the researchers measured soil water tension at different soil depths before and after irrigation. For SDI, precise irrigation times were identified, namely 55 and 47 centibars (cb) for soil depths of 15 and 45 cm, respectively. On the other hand, SSDI showed similar characteristics, with irrigation durations of 52 and 45 cb for soil depths mirroring those of SDI. Furthermore, the study revealed that a 40% deficit allowed by management proved appropriate for both SDI and SSDI systems, contributing to our understanding of optimal Supplementary irrigation practices in cotton cultivation. These results not only broaden our knowledge, but also underline the importance of informed irrigation strategies for improving soil water content and agricultural productivity. Taken together, these studies highlight the complex relationship between supplementary irrigation and soil water content, underlining the need for appropriate irrigation strategies to optimize crop yields and the use of water resources.

2.11 Conservation Methods and their Effect on Crop Production

The soil preparation methods play a critical role in optimizing crop productivity. A number of studies have examined the effects of different conservation methods on weed emergence and cropping management. In a two-year field study, researchers investigated the effect of tillage on the emergency of common hemp from the soil seed bank. The findings showed that no-till resulted in three times greater emergence of common hemp than tillage with chisel. While tillage had no effect on initial emergence time, the time to reach 50% emergence was longer in the no-till system. Additionally, common hemp seeds were mostly concentrated near the soil surface in the no-till plots, while the no-till plots contained seeds primarily from 9 to 15 cm deep. The late and increased emergence observed in the no-till system may contribute to more difficulty in managing common wheat hemp as compared to the tillage plots (Refsell & Hartzler, 2009).

A second study examined the effects of soil inversion, cover crops and spring tillage techniques on Palmer amaranth control in glufosinate-resistant cotton. The study found that red clover, cereal rye and winter fallow had the highest cover biomass. Also, Palmer amaranth density was observed to be decreased by soil inversion tillage than by non-inversion tillage. Furthermore, timely application of the post-emergence tank mixture of glufosinate and S-metolachlor considerably improved Palmer amaranth control in both inversion and non-inversion tillage methods. The maximum cotton yields were attained when soil inversion tillage and red clover cover crop were combined (Aulakh et al., 2013). Additionally, a study that was undertaken in several states sought to ascertain the effect of tillage practices and herbicide applications on the continuous emergence of Amaranthus species in glufosinate-resistant soybean over the course of the growing season. No-tillage, minimum tillage, conventional tillage and deep tillage, were all included in the examined tillage systems, and each was combined with one of two herbicide programs. The deep tillage system, followed by the conventional tillage system, shows the greatest reduction in amaranth species emerging, according to the data. The Indiana results differed from the other sites, however, as they showed that emergence was reduced more by the conventional tillage system than by the no-till system (Farmer et al., 2017).

2.12 Knowledge Gaps and Research Opportunities

Research has revealed significant gaps in knowledge and potential areas for research into the impact of Supplementary irrigation on crop water stress when used in combination with various conservation techniques. Studying how Supplementary irrigation and conservation methods work together, particularly with regard to cover crops, tillage techniques and rainwater harvesting, is essential to filling these gaps. Knowing how these strategies interact can help to efficiently manage crop water stress and improve water-use efficiency to maximize crop yields.

In addition, it is essential to look at how different crops respond to increased irrigation and soil preparation techniques. A focus on specific crops such as amaranth enables us to tailor irrigation strategies and soil conservation practices to their particular needs. By taking this targeted research further, we aim to discover methods that promote optimal crop growth and yield under different environmental conditions. The results of this research will help to develop specific irrigation and conservation guidelines for certain crops. Implementing these guidelines will enable us to significantly enhance crop yields and make better use of water resources in agriculture. This effort is essential for sustainable agricultural practices and to ensure food security while efficiently managing our water supply.

CHAPTER THREE

MATERIAL AND METHOD

3.1 Study Area

The experiment was carried out at the WACWISA experimental site at UDS-Nyankpala precisely in Tolon District in the Northern Region of Ghana. The Region is characterized by a unimodal rainy climate with average annual rainfall of 1111mm (Buerkert, 2018).

It is located between 9° 16 and 9° 34 north latitude and 0° 36 and 0° 57 west longitudes. It has strong northeast winds (harmattan) during the dry season, from November to February, and only one rainy season per year.

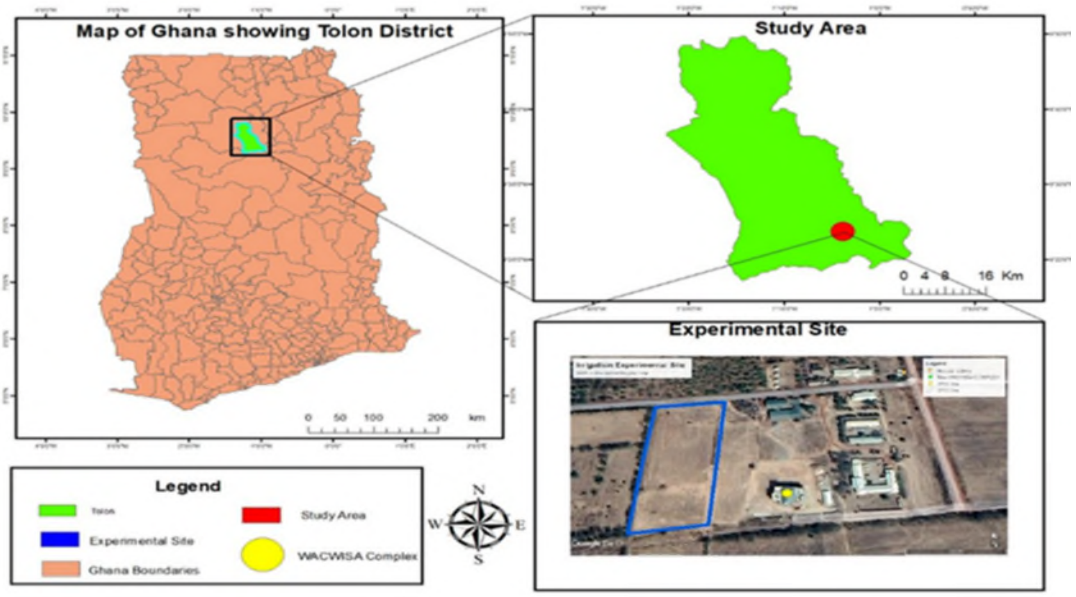


Figure 3.1: Map of The Location

Source: Google earth,2022

3.2 Culture Practices

3.2.1 Land preparation

The first steps in the site preparation practice consisted of a series of simple but essential tasks. It was started by marking out the designated plot area, clearly marking the boundaries to ensure precise management. Next, was weeding of the soil, removing any undesirable vegetation that might hinder subsequent farming activities. Next, the plot was divided into two distinct sections, each with its own approach to water management. The first section was designated for Supplementary irrigation, where a strategic approach to ensure consistent moisture levels for crops throughout the growing season was considered.

In contrast, the second section relied solely on natural precipitation as the main source of moisture. Within these distinct compartments, various soil preparation techniques adapted to the specific needs of each zone were implemented. Raised beds were produced, an approach that involves elevating parts of the soil to create distinct planting zones. At the same time, the ridges were well positioned and allocated space for flat land, recognizing the importance of adapting the soil management techniques to take account of different crops and environmental conditions.

3.2.2 Nursery

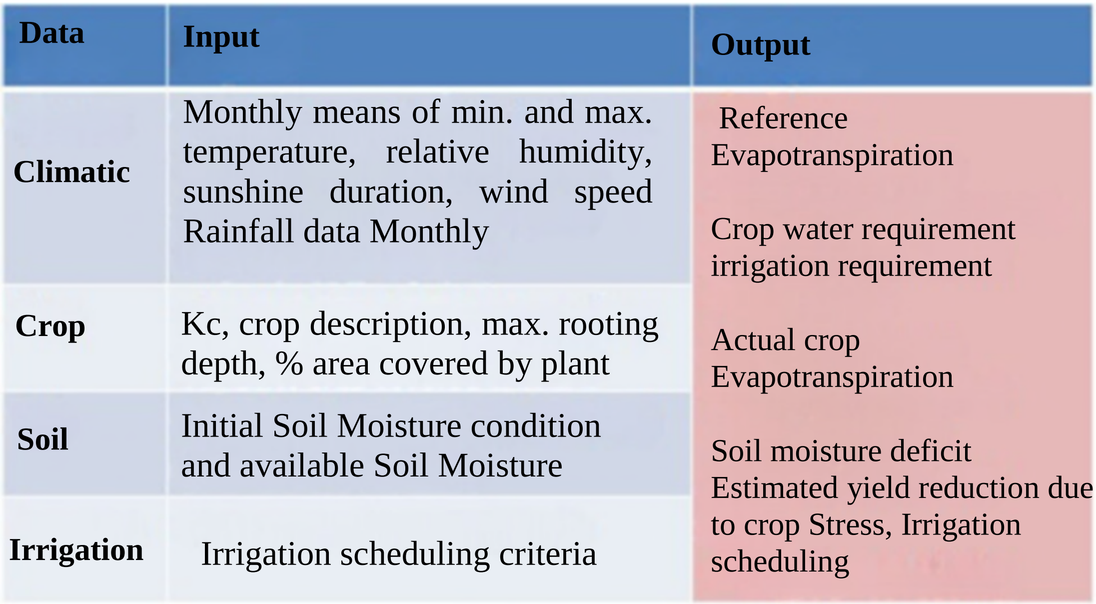
In the early stages of the research project, a plot was created for nursery, which served as the source of seedlings for the study. This nursery was meticulously designed, as its importance cannot be understated. Its establishment required the careful selection of a small plot of land, which was then ploughed down to an ideal structure of raised beds. The soil, essential to the flourishing of our future crops, underwent a rigorous enrichment process, benefiting from the nutrient-rich supply of cow dung as a natural fertilizer.

The three-week nurturing phase was an essential part of our research. During this period, the nursery was managed, maintaining its conditions with the utmost precision. Weeding regularly and watering constantly were an integral part of the daily routine. These seemingly mundane tasks were crucial to our scientific methodology, ensuring that our chosen crop, the amaranth variety Kabore, benefited from an optimal environment for its early stages of growth. The selection of the amaranth variety Kabore was not random; it was the result of careful thought and alignment with our research objectives. Our selection of Kabore amaranth was guided by its unique characteristics, which fit perfectly with the overall objectives of our study. The significance of picking the right cultivar cannot be overstated. It gave a representative topic for in-depth examination, guaranteeing that the findings were both relevant and applicable.

3.2.3 Water application

Two distinct levels of water application were administered: rain-fed conditions and supplementary irrigation at 70% of reference evapotranspiration (ETc). ETc was quantified using CropWat software, which considers monthly climatic data such as rainfall, temperature, relative humidity, sunshine duration, and wind speed. In the supplementary irrigation treatment, 350mm of water was applied using a watering can. During the experiment, it rained for 11 days with a total rainfall of 46.3mm. Therefore, the total amount of water applied to the amaranth crop in the supplementary irrigation treatment was 396.3mm. (table 3.1).

Table 3.1: Data requirements for Cropwat output, Source: FAO,2010



Data	Input	Output
Climatic	Monthly means of min. and max. temperature, relative humidity, sunshine duration, wind speed Rainfall data Monthly	Reference Evapotranspiration Crop water requirement irrigation requirement Actual crop Evapotranspiration Soil moisture deficit Estimated yield reduction due to crop Stress, Irrigation scheduling
Crop	Kc, crop description, max. rooting depth, % area covered by plant	
Soil	Initial Soil Moisture condition and available Soil Moisture	
Irrigation	Irrigation scheduling criteria	

This step not only provided a sound scientific basis for irrigation decisions, but also highlighted the reliance on advanced tools to inform the experimental setup. Water quantities were supplied on a daily basis according to the water requirements calculated by the software. In practice, water quantities were measured and applied using a watering can.

3.2.4 Pest control

During the cultivation phase, the research experienced a variety of pests and diseases that harmed the amaranth plants. One notable problem was the infestation of the crops by ravenous locusts, which caused considerable damage to the leaves, affecting the amaranth's overall health and output potential. Furthermore, a confusing issue occurred when select plant stems began to show signs of rot, raising concerns about the condition's potential to spread to surrounding plants. While the precise name of the disease responsible for the decaying stems requires further investigation, it highlights the varied character of agricultural research difficulties. To address these insect and disease challenges, a systematic and scientifically based pest control method was used. In response to the locust infestation, a selective insecticide (pyrethrin) was used in a focused intervention. This selected treatment was carefully chosen to have the least amount of environmental damage while efficiently controlling the locust menace. This insecticide was applied precisely, conforming to authorized dosage and administration techniques, ensuring that the intervention was consistent with responsible agricultural practices. The difficulties experienced during the research's "Pest Control" phase served as a reminder of the dynamic nature of agricultural ecosystems and the necessity for adaptive and science-driven tactics to preserve crop health and optimize yields. While more research is needed to identify the pathogen causing the stem rot, the reaction to the locust invasion demonstrated the need of balancing pest control with the preservation of the environment (Plate 3.1).

Figure 3.1: Infested Plant

3.2.5 Cultivation and harvest

The research's culture phase was distinguished by a set of rigorous agricultural procedures aimed at promoting optimal growth and protecting the general health of the amaranth plants. Among these measures was the careful method of weeding 3 times, which helped maintain a weed-free environment and reduced competition for key nutrients and minerals. We replenished the soil with a carefully measured application of NPK fertilizer at a rate of 400 kg/ha in accordance with the suggested guidelines stated in the technical cultivation itinerary. This strategic nutrient management method proved critical in promoting healthy plant development and increasing crop yields. Certain amaranth plants failed to thrive throughout the transplanting process and died as a result of unfavorable conditions. To guarantee the integrity of the research and the veracity of the findings, these non-viable plants were promptly replaced, in accordance with best standards for maintaining consistent experimental settings. The harvest phase was the climax of the study efforts, during which data collection took center stage. A prudent strategy was used to evaluate and quantify the yield, which was harvested two months after planting. A total of 15 amaranth plants were grown, but for data collection, a representative subset of five plants was chosen.

Figure 3.2: Crop Harvesting

3.3 Field Experiment

3.3.1 Experimental design

In this study, a 2x3 factorial design under split-plot, involving three replications, was used as a strategic approach to address the complex set of variables introduced by the experimental setting. This design was selected to effectively address and examine the multi-faceted factors that contribute significantly to the dynamics of crop growth and performance. The spacing between plants was 0.25m, between lines 0.5m (Figure 3.2). The length of the ridge was 1.5m, and each ridge carried 5 plants. The spacing between each plot was 0.5m, and each block was 1m.

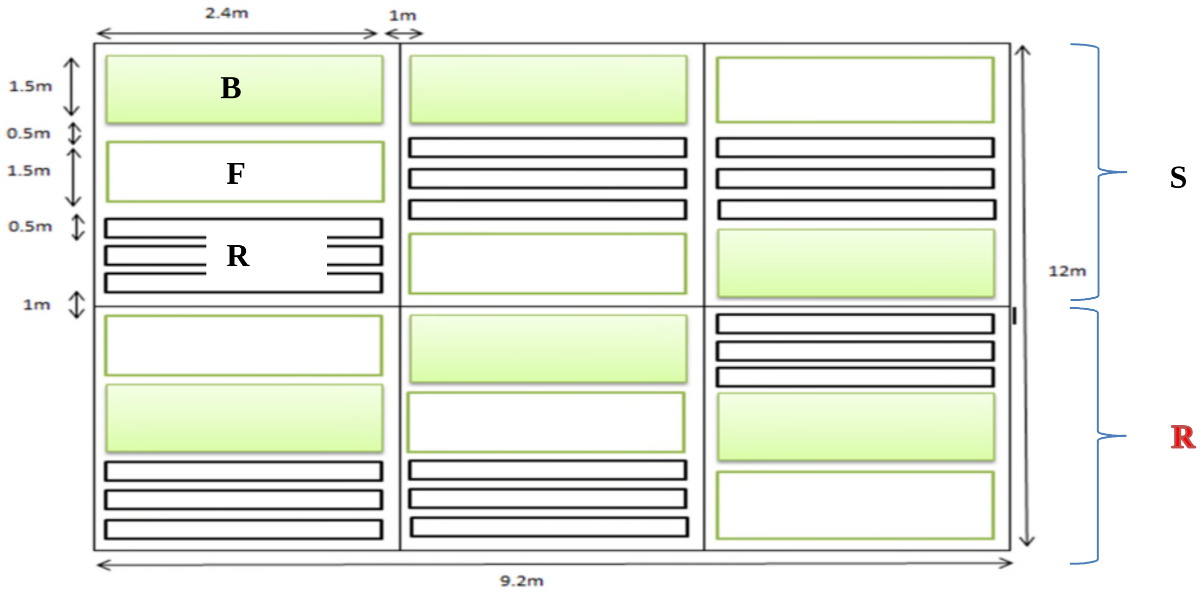


Figure 3.2: Field Layout

RR - Rainfed and Ridge

RB - Rainfed and Bed

RF - Rainfed and Flat

SR - Supplementary and Ridge

SB - Supplementary and Bed

SF - Supplementary and Flat

3.3.2 Treatment details

Main treatments

The main factor being irrigation, with two main treatments, the first of which is supplementary irrigation estimated at a rate of 70% of crop evapotranspiration, and the second treatment based on plot dependence on rainfall.

Sub treatments

Three different soil preparation methods - raised beds, flat lands and ridges - were used. Each method influenced crop growth, which was important for setting up the experiment. Thus, there were six different treatments, each with a different combination of the amount of water used and the way the soil was prepared. This configuration made it possible to create 18 different test zones.

3.4 Data Collection and Measurement Techniques

Different types of data were collected to assess plant growth and progression over time. During the initial phase of data collection process, groundwork was carried out to ensure an accurate measurement of soil water content. To ensure close monitoring of soil moisture levels and the crop water stress that water levels can cause, sensors were used. To this end, a 6 of holes were dug in the study area using a number of specialized tools, including hammers and various pieces of metal equipment. These holes were strategically placed to provide representative sampling points throughout the experimental site. Once the holes had been dug, specialized tubing was carefully inserted. These tubes enabled precise soil moisture measurements to be taken using the Delta T Soil HH2 moisture meter. Readings were taken at regular three-day intervals. Similarly, the same procedure was applied to assess crop water stress levels. After inserting tubes into the holes dug to measure soil moisture, this methodology extended to monitoring crop water stress by planting tensiometers. To do this, tensiometers were strategically placed in the new holes. By placing tensiometers carefully at different depths of the soil profile, the soil tension was monitored at regular intervals. This enabled real-time data to be obtained on crop water stress levels. The combined approach of using tensiometers with the Delta T Soil HH2 moisture meter allowed a comprehensive assessment of soil moisture content and crop water stress, improving the depth and precision of our data collection process.

Figure 3.3: Delta T Soil Hh2 Moisture Meter

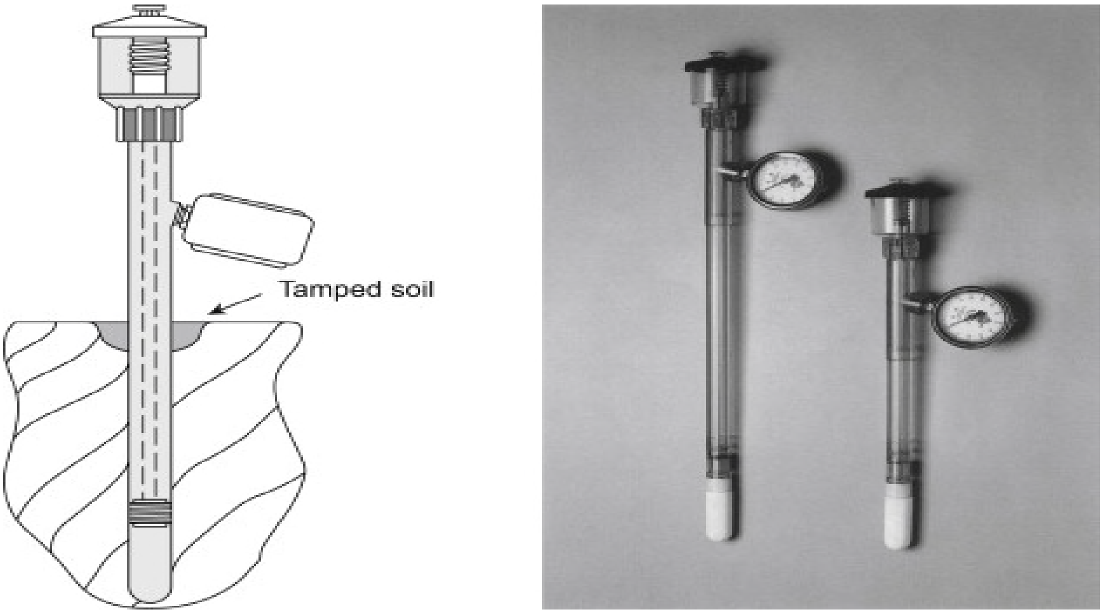


Figure 3.4: Tensiometers

Source: M.B. Kirkham, 2014

To better understand plant development, the height of the plant were measured from its base to the end of its stem (Table 3.2). In addition to measuring height, the number of leaves on each plot were also counted. The amount of chlorophyll present in the leaves were also measured using chlorophyll meter and measurements were taken three weeks after planting (plate 3.3).

Plate 3.3: Data Collection

Figure 3.5: Chlorophyll Meter

Source: ebay.com

At the same time, the number of branches of each plant were also measured. The stem girth was also determined using a caliper measuring tool (Table3.2). This detail was important to understand how different treatments influenced plant growth patterns. In parallel, the fresh weight of the plants were examined using a digital balance. This enabled determination of the weight of the plant material.

Table 3.2:I ollected

Data	Definition	Process for collecting	Equipment used
Plant hei m)	The total plant height	Measurement from the base to the top of the stem using a tape measure	Tape measure
Number ves	Number of leaves per plant at each plot	Count the number of leaves on each plant.	By hand
Chloroph ntent	Chlorophyll levels in selected mid-maturity leaves at mid-branch height of each plant	Measurement of chlorophyll content in selected mid-maturity leaves within each plant	Chlorophyll Meter
Soil Mois ontent	The Soil moisture content in the soil	Measurement of soil moisture content at different depths	Moisture Meter
Crop Wa ress	Soil Water tension in the soil	Measurement of soil water tension in the soil	Tensiometers
Number nches	Total number of branches per plant	Count the number of branches for each plant	By hand
Stem girt	Diameter of the stem	Measure the diameter of the stem per plant	Caliper

3.5 Statistical Analysis

The data were processed using Excel. A mixed-effects model was used to assess the impact of factors (irrigation and soil preparation method) on soil moisture content, plant water stress, and agronomic parameters. The “Anova” function from the “car” package in R-software was used to visualize these effects. To examine the significance of individual or combined effects, the "emmeans" and "cld" functions from the "emmeans" and "multcomp" packages was employed to separate means at a 5% confidence level.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Soil Physical Properties

Table 4.1 lists the characteristics of the soil at a depth of 30 cm

Table 4. 1:Soil properties

Soil properties	Value
Soil pH (1 :2.5) H_2O	5.92
Clay	6.82 %
Sand	63.94 %
Silt	29.24 %
Gravel greater than 2 mm to the total mass of soil, %	48 %
Soil texture	Sandy loam
Organic carbon	1.08 %
Total nitrogen	0.16 %
Phosphorous	4.51 mg/kg
Potassium	60 mg/kg
Organic matter	1.836 %
Bulk density/ Unit weight of soil	1.63 g/cm^3
Field capacity	196.28 mm/m
PWP	61.6 mm/m

Source: UDS Soil laboratory results, 2022

Laboratory soil tests showed that the experimental soil is a gravelly sandy loam with a high sand content, some silt and clay, and a high bulk density. Sandy loam soils are characterized by a high percentage of sand (63.94%) and a moderate percentage of silt (29.24%). Clay content is relatively low (6.82%).

Sandy loam soils have good drainage and aeration, but they can hold less water and nutrients than other types of soil. This means that sandy loam soils may need to be watered and fertilized more frequently than other types of soil. The soil pH of the soil in the table is 5.92, which is slightly acidic. Most plants prefer a soil pH of 6.5 to 7.0. If the soil pH is too acidic, it can limit the availability of nutrients to the plants and reduce yields. The organic matter content of the soil in the table is 1.836%. Organic matter is important for soil health and fertility. It helps to improve water retention, drainage, and aeration. It also provides nutrients to the plants. Overall, the soil in the table is a sandy loam soil with slightly acidic pH and moderate organic matter content. This type of soil is suitable for a variety of crops such as amaranth, but it may need to be watered and fertilized more frequently than other types of soil.

4.2 Presentation of Climatic Characteristics

Weather parameters, including temperature, precipitation and other relevant parameters, were collected throughout the experimental period. The data, recorded in terms of temperature fluctuations, precipitation and other climatic factors, provide a complete picture of the prevailing climatic conditions.

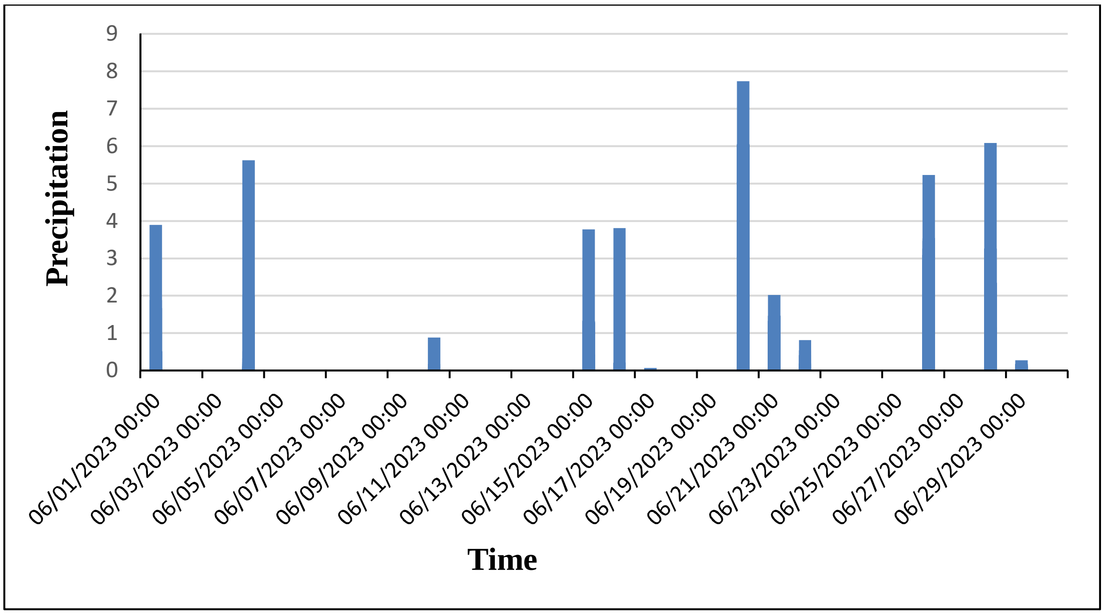


Figure 4.1: Monthly Rainfall (June)

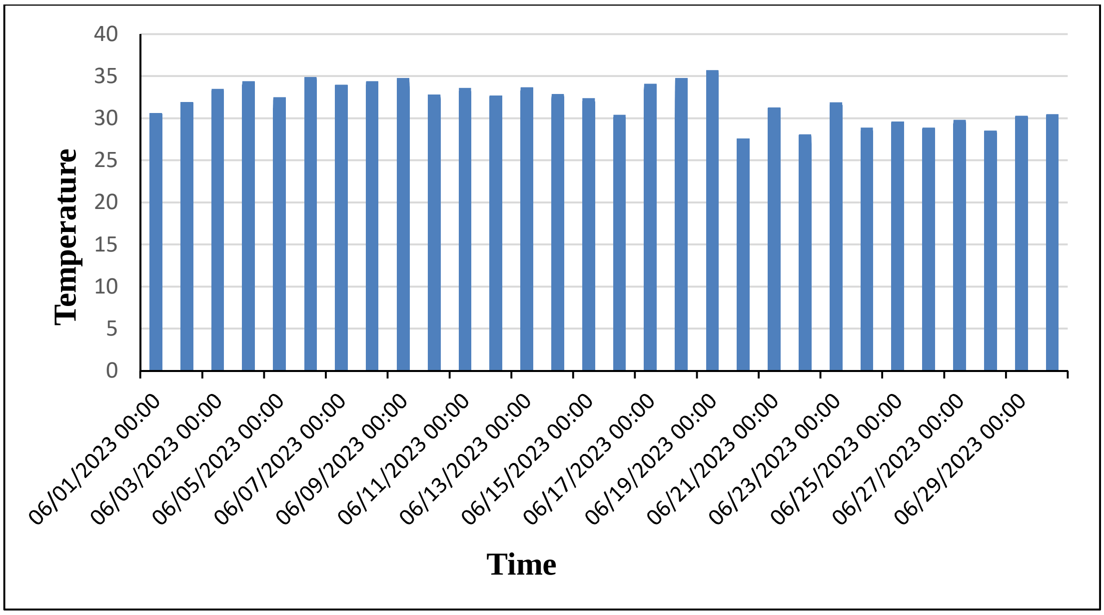


Figure 4.2: Monthly Temperature (June)

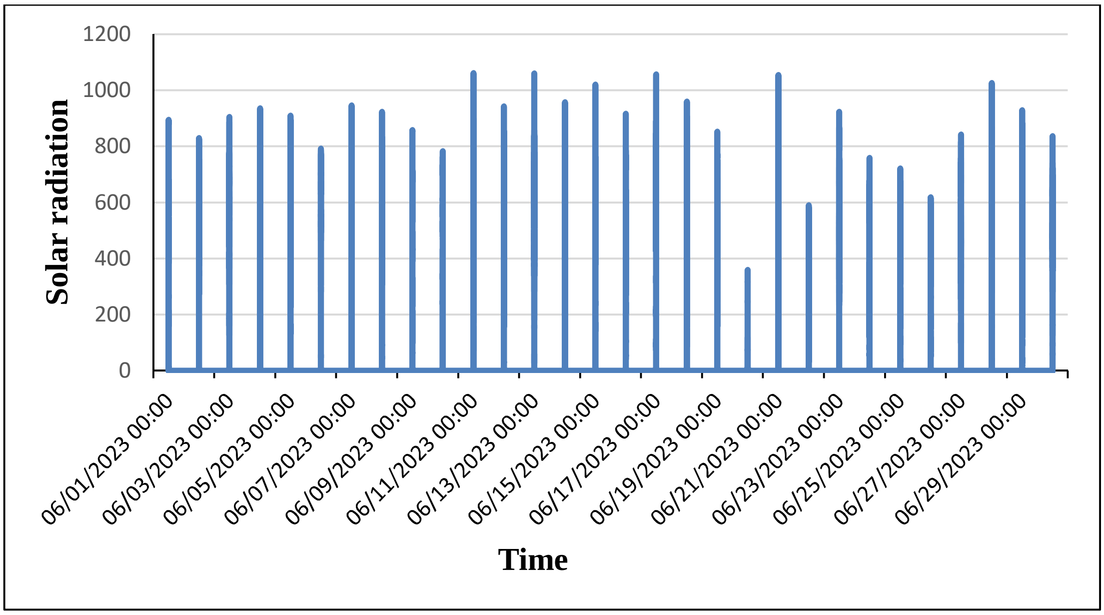


Figure 4.3: Solar Radiation (June)

4.3 Effect of Irrigation and Conservations Techniques on Soil Moisture Content

The results have demonstrated a highly significant effect of the treatments on soil moisture content. Specifically, the interaction between supplementary irrigation and the flat soil preparation method (SF) revealed the highest soil water content (24.96%) throughout the crop production cycle (Figure 4.4). As for the interaction between supplementary irrigation and ridges (SR) yielded a value of 20.85 %. Regarding the interaction between supplementary irrigation and the bed land preparation method (SB), a soil moisture content value of 12.4% was obtained.

The interactions between plots dependent on rainfall and ridges (RR), flat lands (RF), and bed land preparation (RB) yielded respective soil water content values of 13.95%, 18.51%, and 18.28%. The findings affirm the partial conclusion that additional irrigation has had a significant impact on the soil moisture content. This conclusion is reinforced by the consistent utilization of the same soil structure types throughout the entirety of the experimentation process. As a result, it becomes evident that only the plots that received increased water quantities have demonstrated substantial increases in soil moisture levels.

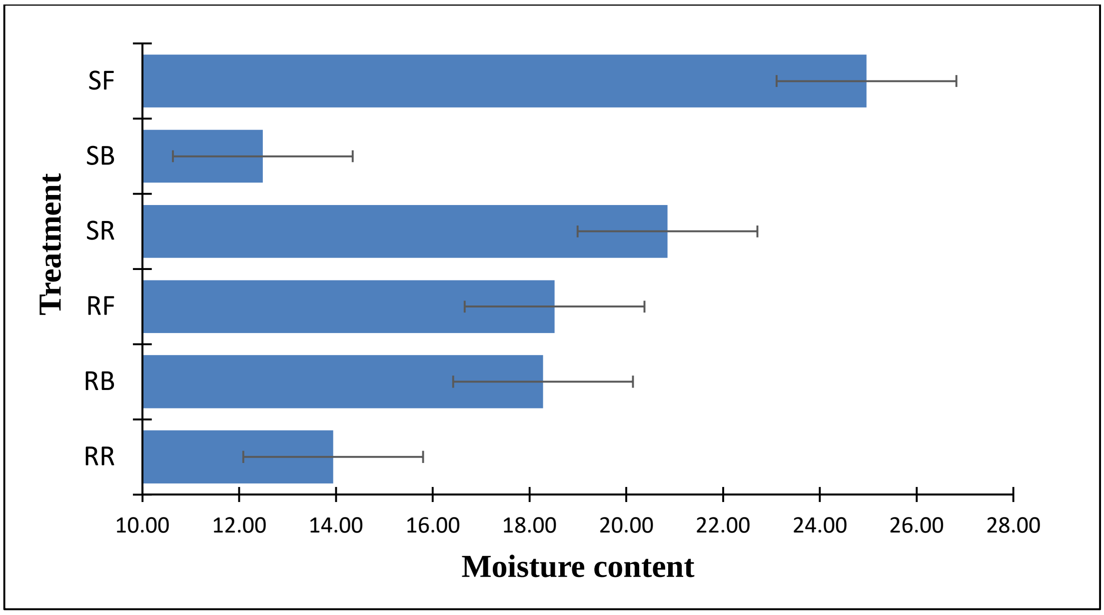


Figure 4.4: Soil Moisture Content Under Different Treatments

Once again, these findings underscore the significant influence of different irrigation practices and soil preparation methods on soil moisture levels throughout the crop production cycle.

The result showed a highly significant effect of the treatments on soil water content, which is in line with the results as reported in a previous study (Mankotia & Sharma, 2020). Specifically, the interaction between supplemental irrigation and the flat soil preparation (SF) method in the study revealed the highest soil water content (24.96%) throughout the crop production cycle, closely mirroring the observation made in the article where soil moisture and relative leaf water contents (RLWC) were found to be higher at 0.8 PE (Effective precipitation) than at 0.4 PE. The study also revealed that the interaction between supplemental irrigation and ridging (SR) produced a soil water content value of 20.85%, confirming the trend observed in the paper where water use efficiency (WUE) was highest at an irrigation level of 0.4 PE. This is consistent with the conclusion that supplementary irrigation has a significant impact on soil water content.

Furthermore, the observed variations in soil moisture content underscore the interaction between irrigation strategies and soil preparation techniques. These data provide valuable information on optimizing water management in agricultural contexts, especially in the field of crop irrigation.

On the other hand, the diverse treatments exhibited a discernible impact on soil moisture content over the course of the study period (Figure 4.5). Treatments denoted as (RR), (RF), and (RB) subtly contributed to a positive influence on soil moisture content trends over time. It is noteworthy that the (RB) treatment manifested consistent values holding to soil water content across nearly the entire production period. Conversely, treatments identified as (SF), (SR), and (SB) yielded the most substantial and consistent increases in soil moisture content over the temporal span of the experiment.

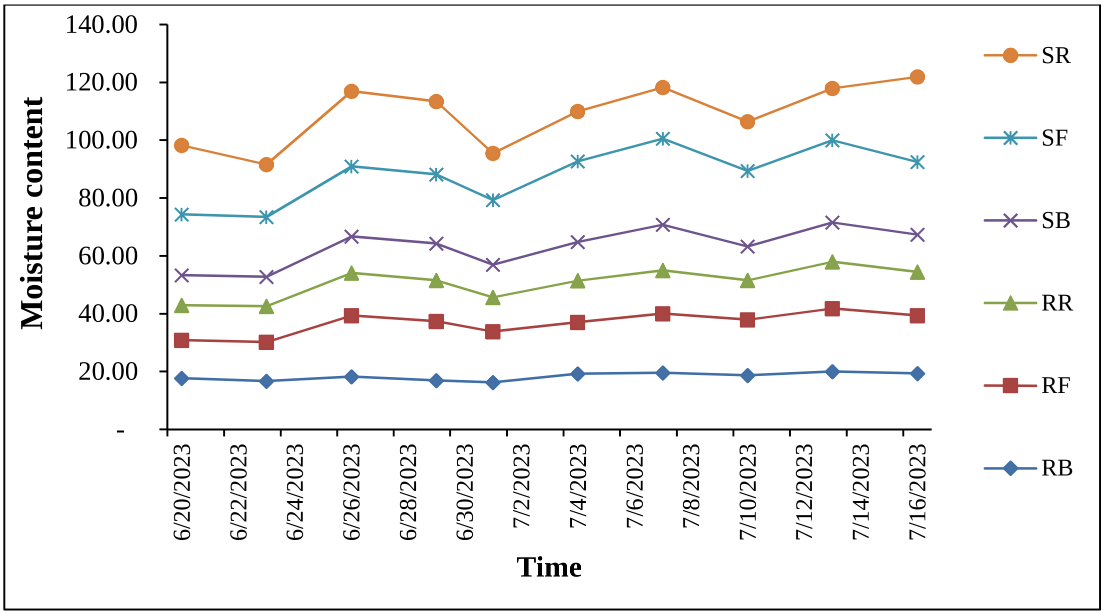


Figure 4.5: Time Series analysis of soil Moisture Content

It should be noted that the data points that make up these curves systematically show an upward trend, indicating a continuous and progressive improvement in the values measured. This persistent rising trend underlines the effectiveness and positive impact of the treatments applied to the parameters under consideration. Those observations underscore the efficacy of these treatments in enhancing soil moisture content and availability upon the time.

Importantly, the crop rooting zone in this study extends to a depth of 30 cm. This depth is significant as it corresponds to the exact levels where treatments (SF), (SR) and (SB) demonstrated positive effects. With regard to soil water content, variations with depth were observed, particularly at depths of 100 mm, 200 mm, 300 mm, 400 mm, 600 mm and 1000 mm for each treatment. Notably, in treatments (SF), (SR) and (SB), favorable increases in soil moisture content were identified as progressed from a depth of 100 mm to 200 mm, and similarly from 200 mm to 300 mm (Figure 4.6).

However, when examined the (RR), (RF) and (RB) treatments, a different trend emerged. At depths of 100 mm, 200 mm and 300 mm, these treatments showed negative values in terms of soil water content. This shows that the 300 mm depth, which corresponds to the crop's rooting zone, plays a key role in influencing the results of these treatments. The positive impacts observed in treatments (SF), (SR) and (SB) at this depth underline their effectiveness in improving soil water content, contributing to a favorable environment for crop growth.

By contrast, the negative values observed in treatments (RR), (RF), and (RB) at these depths indicate their limited effectiveness in maintaining adequate soil moisture levels in the crop rooting zone. Beyond the depth of 300 mm all treatments exhibited a decrease in soil moisture values that eventually turned negative before reaching a depth of 400 mm.

Subsequently there was a resurgence in soil moisture values for all treatments up to the depth of 600 mm before stabilizing and declining thereafter. Mainly, only the treatment labeled as (SR) continued to show increasing values until reaching a depth of 1000 mm. This is likely due to the fact that the top layer of soil is the most exposed to the atmosphere. As a result, it is more likely to be affected by changes in weather conditions, such as rainfall or evaporation.

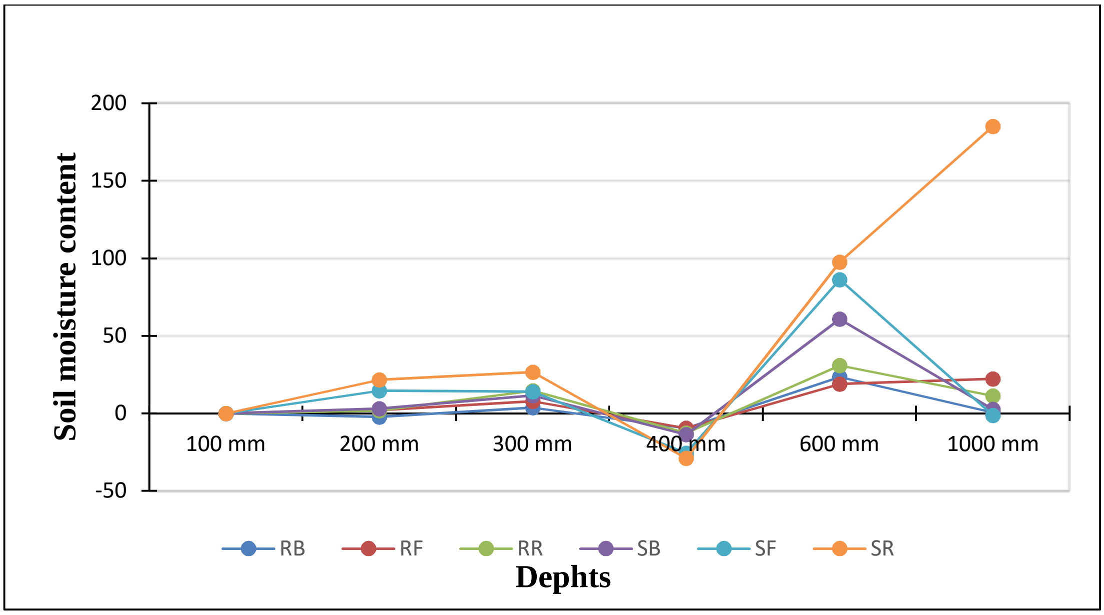


Figure 4.6: Variation in Soil Moisture Content at Different Depths

The results of this study closely align with the observations made by Chahal et al. (2018) in their study, which also outlined the significant implications of water stress on critical crop functional traits. In particular, they highlighted the effect of water availability on parameters such as plant height, number of leaves, which parallels our own results. Our findings are also confirmed by the in-depth study carried out by Li and Gong (2002), which looked at the link between ridge/furrow ratios and crop performance. Li and Gong's (2002) study not only highlighted the significant impact of ridge/furrow ratios on overall crop yield, but also examined their influence on various crop components. The concordance between the results of this study and the findings of these earlier research studies accentuates the coherence and consistency of the conclusions. This concordance helps to reinforce the wider applicability of the findings in the field of irrigation and crop management, further substantiating the practical implications of this research findings. By corroborating the observations with this previous research, this work has contributed to a better understanding of the relation between water stress, cropping practices and crop yield dynamics, thus promoting a comprehensive basis for informed agricultural decision-making and sustainable crop management strategies.

4.4 Effect of Irrigation and Conservations Techniques on Crop Water Stress

Interactions between irrigation and different soil preparation methods had a highly significant effect on (Soil Water Tension) SWT. The SR, SF, and SB treatments had lower soil tension values than the RR, RF, and RB treatments (Figure 4 .7). Plants in the SR, SF, and SB treatments were therefore less stressed than those in the RR, RF, and RB treatments.

Our findings closely match the results of Yadav et al. (2023), where drip irrigation was applied with a maximum allowable deficit (MAD) of 50% for wheat crops. The common goal of improving water use efficiency and alleviating crop water stress through controlled irrigation practices is the similarity. While this study used manual supplemental irrigation, the other study used a drip irrigation system. Both approaches underline the importance of efficient water management in agriculture. Specifically, the study showed that reduced water stress, achieved through controlled irrigation practices, can effectively improve crop performance. They found that implementing drip irrigation improved water use efficiency and reduced water stress in wheat crops. This is consistent with this observation that supplementary irrigation treatments (SR, SB and SF) resulted in lower SWT values, indicating reduced water stress for crops under these conditions.

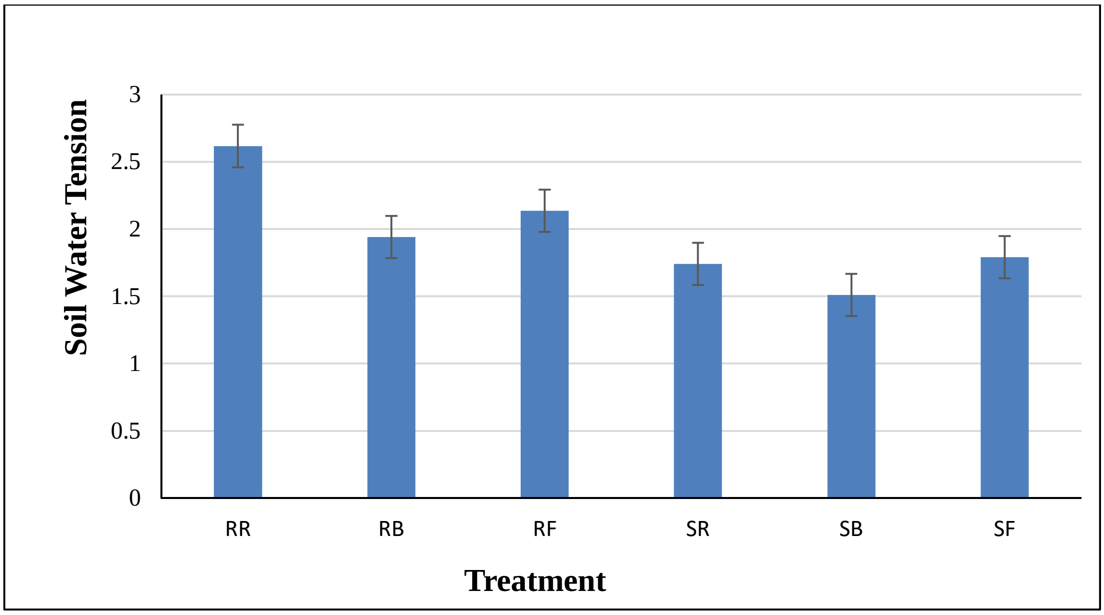


Figure 4.7: Variation of Soil Water Tension Under Different Treatments

Further on, the evolution of soil tension over the entire production period was observed. It was noticed that values for plants subjected to RR, RF and RB treatments reached 2 and even exceeded this value. As for plants subjected to treatments SR, SF, and SB, soil water tension values vary around 1.5 (figure 4.8). Similarly, soil tension varied greatly over time according to the different treatments. Figure 4.8 shows that the SR, SF and SB treatments gave decreasing values tending towards 1.5, particularly at the end of the plant cycle. On the other hand, treatments RR, RF and RB showed fairly increasing values, greater than or equal to 2.5. Based on the results described above, a key factor in understanding water availability for crops is soil water tension. Soil water tension plays a key role in regulating plant access to water stored in the soil. This tension is directly related to the observed soil moisture content. In the context of this study, the evolution of soil water tension reveals valuable information. In particular, plants exposed to RR, RF and RB treatments experienced soil water tension values that reached, and in some cases even exceeded, the threshold of 2. In contrast, plants treated with SR, SF and SB showed more favorable soil water tension values, hovering around 1.5. This observation underlines the complex relationship between soil water tension and soil moisture content, elucidating how the different treatments influence the soil's ability to supply water to crops as they progress through their growth cycle. Overall, it can be stated that the plants that received the additional water treatments were less subject to water stress, and consequently made better use of the water available in the soil.

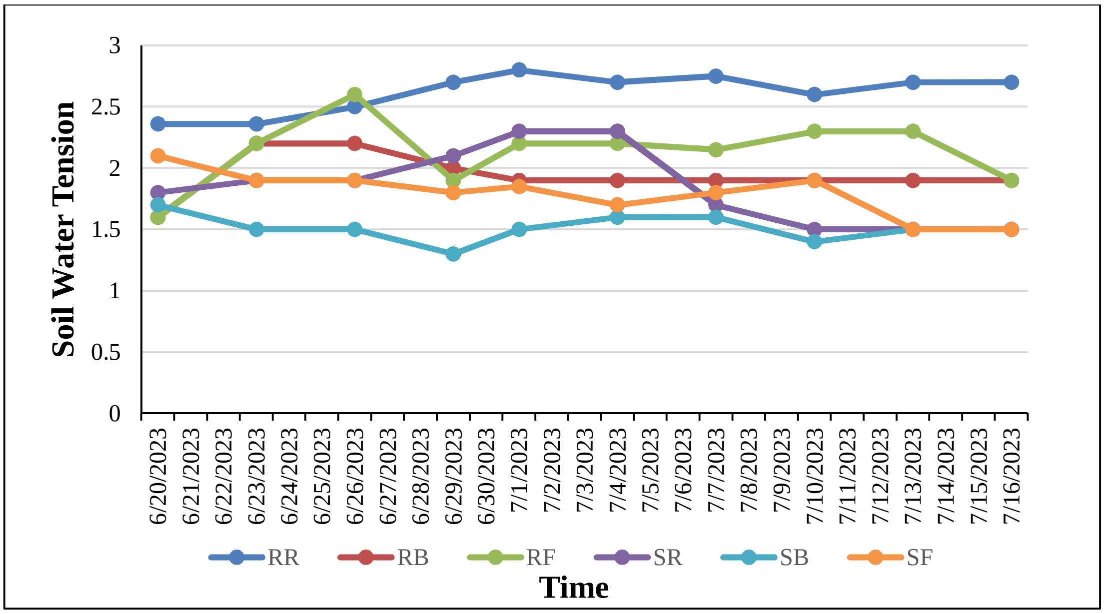


Figure 4.8: Variation in Soil Water Tension Over The Time

Chahal et al. (2018) delved deeper into the impact of water stress on plant growth, uncovering a nuanced relationship. Their results highlighted those plants facing severe soil water shortage (≤25% of soil capacity) exhibited compromised growth, while those enduring higher levels of water stress (≥50% of soil capacity) showed a surprising degree of adaptability and resilience. This study confirms a similar trend, particularly evident in treatments characterized by lower soil tension (SR, SF, SB), where plants showed remarkable resilience in the face of unfavorable conditions. On the contrary, treatments associated with high soil tension (RR, RF, RB) showed a decrease in plant performance, underlining the repercussions of intense water stress. This alignment between the results of this research and the ideas put forward by Chahal et al. supports the idea that this model is consistent across different studies.

By providing further details on these results, this study contributes to a better understanding of the link between water stress levels and plant responses, thus deepening the body of knowledge on plant resilience under a variety of environmental conditions. In essence, the study highlights the importance of considering nuanced gradients of water stress to develop effective strategies for sustainable crop management and improved agricultural productivity.

4.5 Effect of Irrigation and Conservation Techniques on Crop Growth Parameters.

The interaction between irrigation and soil preparation methods had a highly significant effect on crop growth parameters. Treatments SR, SF and SB achieved relatively high values for crop functional parameters compared with treatments RR, RF and RB. In terms of plant height, the SB treatment achieved the highest plant height, with an average value of 75 cm (figure 4.9). Next came the SR treatment, which produced a value of 55 cm. The SF treatment gave an average value of 30 cm. Treatments RR, RF and RB gave respectively average plant height values 27 cm, 26 cm and 47 cm.

The results are in line with those of Waqas et al. (2021), which show that Ridge sowing under furrow irrigation (RF) resulted in the maximum percentage of crop performance parameters. Also, bed planting under drip irrigation treatments outperformed the control practice (RF) for various parameters, including water savings, water productivity and total crop yield. The significant improvement in growth parameters found in treatments involving raised beds and ridges can be attributed to a number of key factors. Firstly, raised planting beds and ridges help improve soil drainage and aeration, thereby reducing the risk of waterlogging and root asphyxia, which can interfere with plant development. In conjunction, these soil preparation methods effectively condense available moisture around plant roots, promoting more efficient water use by crops. In this way, raised beds and ridges create a micro-environment favorable to root growth and nutrient absorption, facilitating plant access to essential resources. The combination of better water management, improved soil profile and optimal root conditions collectively contributes to the higher growth parameters observed in treatments using these practices. This information highlights the possibility of optimizing farming practices to enhance crop productivity while preserving precious water resources.

However, it is essential to recognize that specific crop types and local variations can influence the effectiveness of these practices, thus requiring further research and adaptability of farming strategies to ensure that their benefits are maximized in different contexts.

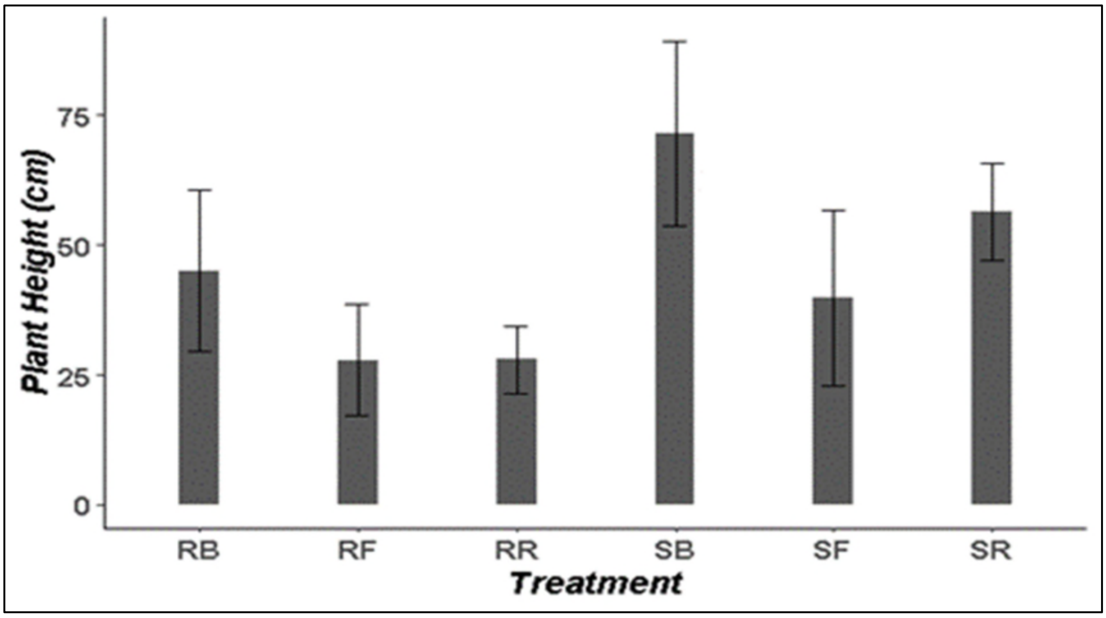


Figure 4.9: Variation of Plant Height Under Different Treatments

Results remained identical for parameters relating to the number of branches per plant, the number of leaves and stem diameter (figures 4.10, 4.11, 4.12). The SR, SF and SB treatments expressed the highest values for plant functional parameters. The treatments with the highest mean values were SB and SR respectively. With regard to the RR, RF and RB treatments, it can be seen that only the RB treatment achieved the highest average values in all cases. This leads to the partial conclusion that the raised beds soil preparation method plays a very crucial role in plant development, as it achieved the most significant results at the plant level, whether or not supplementary irrigation was used.

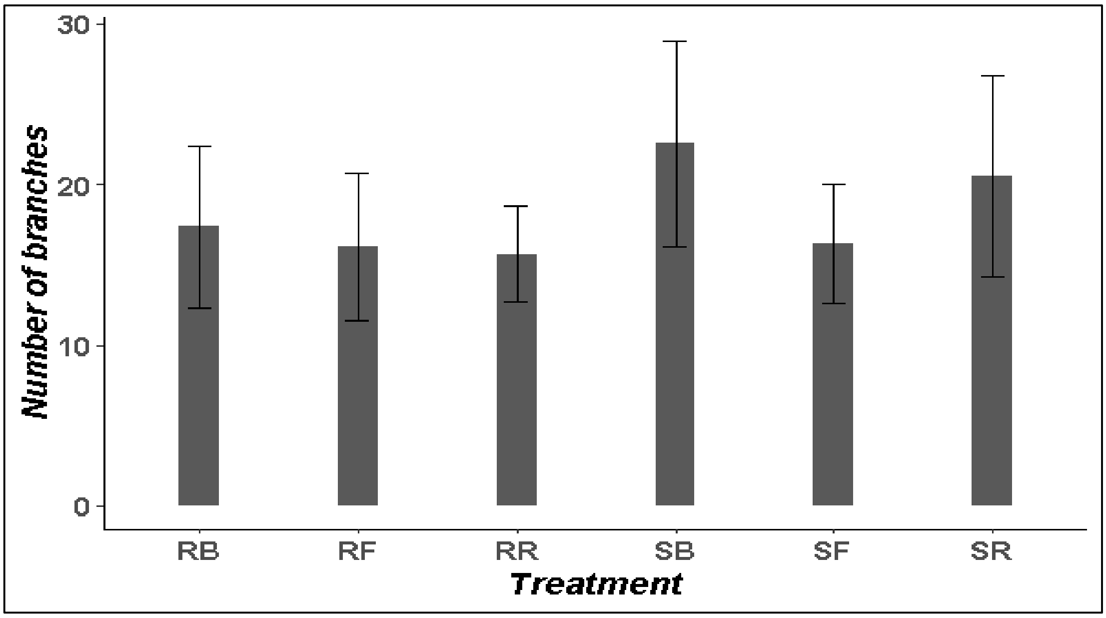


Figure 4.10: Variation of Number of Branches Under Different Treatment

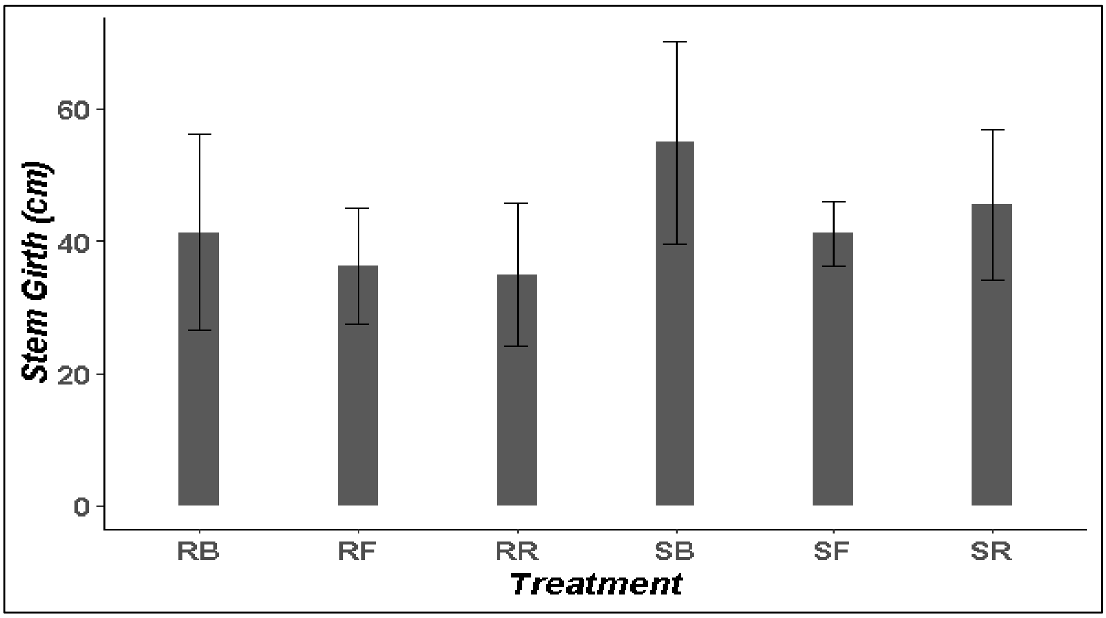


Figure 4.11: Variation of Stem Girth Under Different Treatments

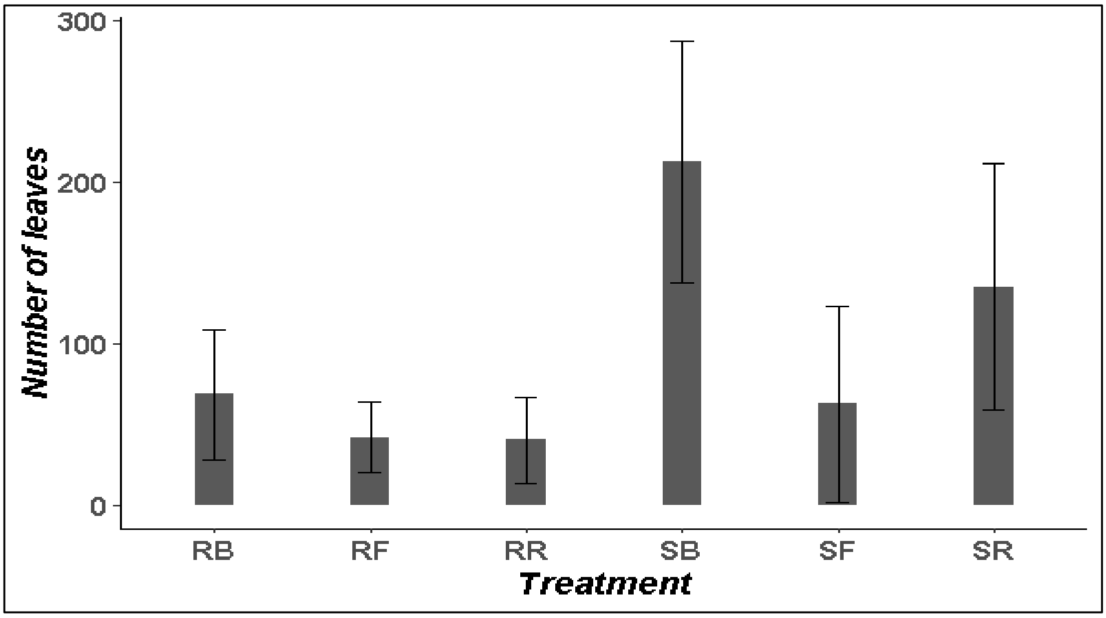


Figure 4.12: Variation of Number of Leaves Under Different Treatments

The results contrasted significantly with those reported by Chantal et al. (2018) in a related study looking at irrigation rates and their impact on crop growth and yield parameters. Notably, the investigation revealed that treatments incorporating supplemental irrigation (SR, SF and SB) consistently outperformed rain-fed treatments (RR, RF and RB) for various plant functional parameters, including number of branches per plant, number of leaves and stem diameter. In the SB and SR treatments in particular, the mean values for these parameters were the highest, pointing to the effectiveness of supplementary irrigation in promoting effective crop development. This divergence in results can be attributed to several factors.

One of the most important differences between this study and Chantal et al. (2018) study lies in the similar results obtained despite the irrigation rates used. Whereas this study used a supplementary irrigation approach, providing 70 % of the crop's water requirements in addition to the rainfall amounts, the referenced article used a significantly lower irrigation rate of 30%. This substantial difference in water allocation may explain the different results observed. The greater water input in this study probably contributed to the higher growth parameters, as a more abundant water resource enables plants to thrive and maximize their growth potential. In this respect, the specific soil characteristics and environmental conditions of this study area may have also played a key role in the results. Remarkably, even without supplementary irrigation, the RB treatment using raised beds achieved remarkable results for all plant parameters, underlining the critical role of soil preparation techniques in promoting plant development. It is worth pointing out that this study focuses on supplemental irrigation, in which rainwater is supplemented with an additional 70% of crop water requirements. This approach reflects actual real-world scenarios in regions facing water scarcity or irregular rainfall.

Finally, the differences between the results of this study and those of Chantal et al. (2018) come from variations in irrigation rates, soil properties and the emphasis placed on supplemental irrigation in this experiment. The findings underline the importance of water availability and soil preparation techniques, particularly raised beds, in optimizing plant growth parameters. While this study shows the benefits of supplementary irrigation, it also highlights the importance of adapting irrigation strategies to specific agricultural contexts and water availability scenarios to achieve optimal results.

Looking at the amount of chlorophyll in the plants, it's clear that the use of supplementary irrigation (S) makes a big difference. The SR treatment stood out, with an average value of 60 umol/m² (figure 4.13). Similarly, treatments SF and SB gave almost the same average results. This shows that these two different approaches are very similar in terms of efficacy. This tells us that supplying additional water to the plants, whether on the surface (SF) or below the surface (SB), has a consistently positive effect. The good results of the SR treatment underline the usefulness of supplementary irrigation. The fact that SF and SB have similar results tells us that, however supplementary water was provided, it really helps the plants. This information reminds us how important it is to use supplementary irrigation intelligently. The success of the SR treatment with more chlorophyll shows that targeted supplementary watering can really help a plant to thrive. As for treatments RB, RF and RR, it was noted that the values corresponding to chlorophyll content are not significantly different from treatments SB, SF and SR. It's important to remember that plants that benefited from treatments RB, RF and RR were in water deficit compared to plants that benefited from treatments SB, SF and SR.

The results are in line with those of Farshbaf et al. (2014) highlighting the impact of irrigation practices on critical plant physiological characteristics. Specifically, this study revealed a difference in chlorophyll content between different irrigation treatments, supporting the relevance of water management strategies in crop development. The study by Farshbaf et al. pointed to the interaction between irrigation and plant density, revealing significant effects on various physiological characteristics and biological yield, including leaf chlorophyll content. In particular, their research showed that increasing plant density under water-deficit conditions resulted in higher chlorophyll content, mainly attributed to increased leaf thickness. This corresponds to this result, to the extent that RB RF, RR rainfall-dependent plants under water-deficit conditions showed increased chlorophyll production, not significantly different from plants subjected to SB, SF, SR treatments benefiting from additional water quantities. Moreover, the evidence of a positive correlation between energy efficiency photosystem efficiency, relative water content (RWC) and biological yield in the study by Farshbaf et al. is in line with the observations of improved chlorophyll content in the RB, RF and RR treatments. These trends highlight the wider implications of water management, not only on chlorophyll content, but also on other critical plant physiological parameters. While this study highlights the positive impact of supplemental irrigation on chlorophyll content, the research by Farshbaf et al. has provided further insight into the influence of plant density under water-deficit conditions. This strengthens the importance of considering multiple factors, including irrigation practices and plant density, to optimize crop growth and yield.

In summary, the results and those of Farshbaf et al. outline the central role of irrigation practices in influencing chlorophyll content and other plant physiological characteristics. The agreement of the results with their research underscores the continuing benefits of supplementary irrigation and enhances the importance of intelligent water management strategies in promoting crop health and productivity. However, it remains essential to recognize the diverse nature of plant responses to water availability, as illustrated by their study of the influence of plant density. This points to the need for the adoption of well-rounded approaches to farm management, considering a range of factors to achieve optimal results in diverse contexts.

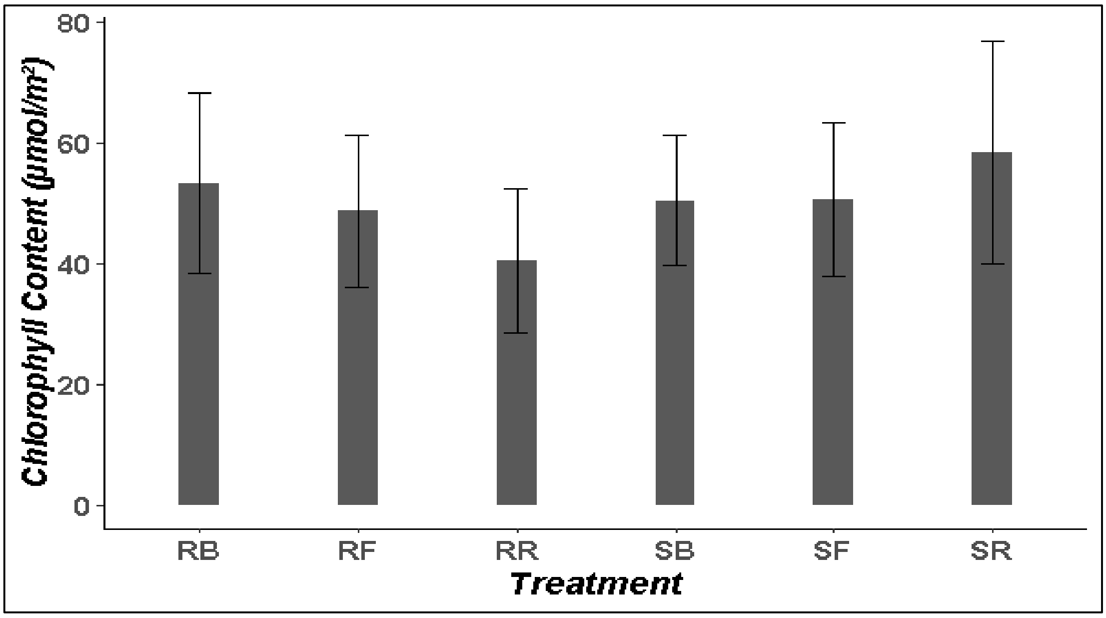


Figure 4.13: Variation of Chlorophyll Content Under Different Treatments

For further, more in-depth conclusions, concerning the results of Li & Gong (2002), which showed a correlation between ridge/furrow ratios and crop yield, our analysis of the "raised bed" technique also highlighted notable improvements in both crop yield and growth dynamics. This difference in results highlights the interactions between farming practices and the multiple variables that exert a considerable influence on the resulting crop development and production processes. While Li & Gong's investigation focused primarily on ridge/furrow ratios, this further experimental exploration highlights the essential role of diversified methodological approaches, such as the innovative "raised bed" methodology, in boosting crop yields and sustaining overall growth paths. This research serves as evidence of the multiple dimensions that make up agricultural studies. It underscores the need to engage with diverse methodologies, amplifying the scope of the "raised bed" technique in this case. As such, the study contributes to the researchers' mission of navigating, dissecting and finding the multiple influences shaping the field of agronomic research.

4.6 Effect of Irrigation and Conservations Techniques on Crop Yield

The different methods of irrigation and soil preparation had a significant influence on final crop yields in this study. Among the treatments evaluated, namely SR, SB and SF, these specific techniques yielded the highest crop quantities, as visually shown in figure 4.14. It should be noted that treatments SR and SB gave an average yield of 1.6 kilograms/120m^2 from a designated set of five plants in the experimental plot. Next, treatment SF gave a yield of around 1.2 kilograms/120m^2. In contrast, the other treatments, designated RR, RB and RF, showed a more diverse range of average yields from(0.6 kilograms to 1 kilogram) /120m^2. Notably, treatment RB proved to be the most productive of these, as shown in figure 4.14.

These observations underline the substantial impact of different irrigation and soil preparation methods on crop yields. In particular, the SR, SB and SF approaches showed a consistent propensity to promote increased crop productivity. The parallel yield results of the SR and SB treatments, which consistently generate around 1.6 kilograms of crop from the designated set, accentuate their viability. Similarly, the SF treatment, although slightly lower at around 1.2 kilograms, still illustrates its effectiveness.

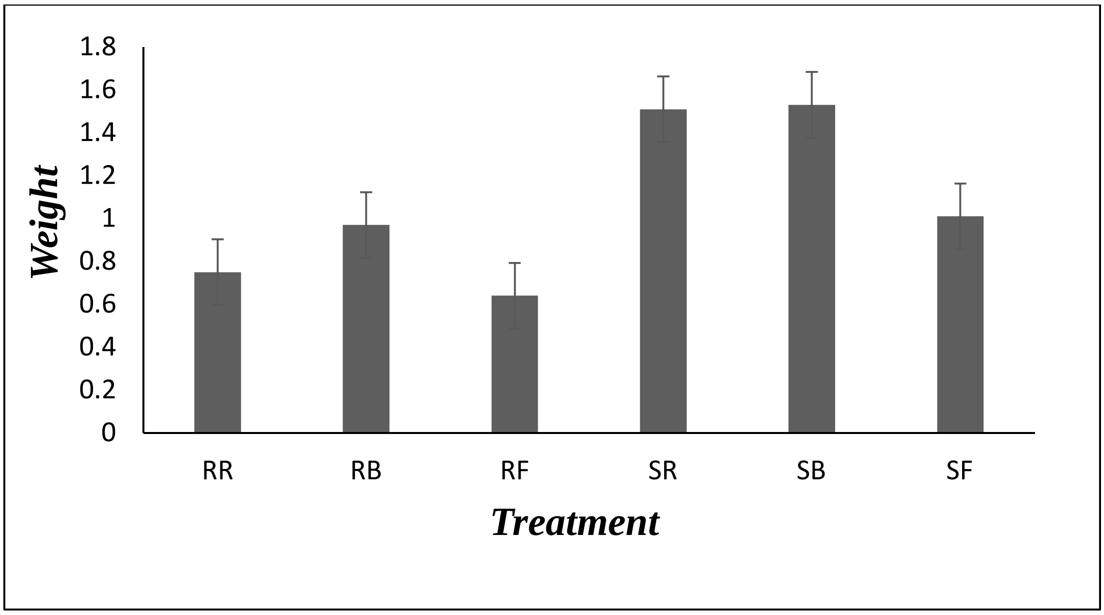


Figure 4.14: Variation of Fresh Weight Under Different Treatments

The results concerning the evaluation of the impact of irrigation and conservation techniques on crop yield show significant differences from the results reported by Chantal et al. Whereas this study focused on combining supplementary irrigation at 70 % of crop water requirements with different soil preparation methods, Chantal et al. examined different irrigation rates (10%, 30% and 60%) on amaranth growth and yield parameters. This major difference in experimental design highlights the key factors contributing to the divergent results observed in the respective studies. One of the principal distinctions lies in the amount of water applied. In this study, the application of 70% of crop water requirements in the SR, SB and SF treatments facilitated consistently high yields, with an average of 1.6 kilograms /120m^{2}harvested from a set of five plants in the experimental plot. The effectiveness of these treatments in obtaining high yields can be attributed to the targeted and substantial supply of water, attenuating water stress and promoting optimized crop growth. In terms of yield, this study included different soil preparation methods, which greatly influenced the results. In contrast, Chantal et al. reported that an irrigation rate of 30 % (T2) was the best for improving amaranth growth and yield parameters. This lower irrigation rate, compared with the 70 % application in this study, improved both fresh and dry leaf weights, indicating an increase in amaranth yield. The variations in results can be attributed to the distinct experimental conditions and objectives, pointing to the importance of considering the context in which irrigation research is carried out. It is essential to note that specific yield values for amaranth were not provided in the Chantal et al study, thus making direct comparisons difficult. Nevertheless, the observed improvements in growth parameters and yield attributes associated with the 30 % irrigation rate suggest that it had a positive impact on amaranth yields in their study area.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The results of this study revealed that supplementary irrigation with raised beds and ridge tillage soil preparation methods significantly improved soil moisture content, reduced crop water stress, and increased crop yield. This suggests that these soil conservation methods are effective in improving crop productivity in water-limited environments. The findings of this study have important implications for agricultural practices in water-scarce regions. By adopting raised beds or ridge tillage and supplementary irrigation, farmers can improve crop productivity while reducing water use. This is essential for ensuring sustainable agriculture in the face of climate change and other challenges. Overall, the study provides strong evidence that supplementary irrigation with raised beds or ridge tillage is an effective strategy for improving crop productivity in water-limited environments.

5.2 Recommendations

Based on the results offered, the following recommendations are to guide agricultural practices. Implement the combined strategy of Supplementary irrigation with bed and ridge soil preparation to enhance water efficiency and alleviate plant stress. By embracing these recommendations vegetable producers can harness the combined potential of Supplementary irrigation and specialized soil preparation methods leading to more sustainable and productive agricultural systems in water-constrained settings.

However, more research may be needed to explore the long-term effects of these irrigation strategies on crop productivity, soil health and water resource management. In addition, it could bring more insight into the nuanced interaction between irrigation rates, soil conditions and crop growth parameters.

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APPENDIX

Appendix 1: View of Experimentation

Appendix 2: Crop After Harvest

Appendix 3: Culture Under Development

Appendix 4: Sample Selection

Appendix 5: Analysis of variance table

Data	Test Statistic (LR Chisq)	Degrees of Freedom (Df)	Probability (Pr (>Chisq)
Plant Height	177.89	17	< 2.2e-16 ***
Chlorophyll Content	61.72	17	5.452e-07 ***
Number of Leaves	190.79	17	< 2.2e-16 ***
Number of Branches	62.407	17	4.188e-07 ***
Stem Girth	129.91	17	< 2.2e-16 ***

SCRIPTS

```
# Analyse de la base
library(readxl)
library(dplyr)
library(ggplot2)
library(psych)
library(car)
str(base)
#♠Test de normality
shapiro.test(base$`PLANT HEIGHT`)
shapiro.test(base$`CHLOROPHYLL CONTENT`)
shapiro.test(base$`NUMBER OF LEAVES`)
shapiro.test(base$`NUMBER OF BRANCHES`)
shapiro.test(base$`STEM GIRTH`)
#Matrix de coorelation
corPlot(base[,2:6],main='MATRIX OF CORRELATION',numbers=TRUE,stars=TRUE)
#Test anova
## stem lenght
model_stem <- glm (base$`PLANT HEIGHT`~base$Treatment,
 data = base, family = "gaussian")
Anova(model_stem)
## chlorophyl
model_cholo <- glm (base$`CHLOROPHYLL CONTENT`~base$Treatment,
data = base, family = "gaussian")
Anova(model_cholo)
## number of leaf
model_leaf <- glm (base$`NUMBER OF LEAVES`~base$Treatment,
data = base, family = "gaussian")
Anova(model_leaf)
## number of branches
model_branche <- glm (base$`NUMBER OF BRANCHES`~base$Treatment,
data = base, family = "gaussian")
```

```
Anova(model_branche)
## number of diameter
model_diameter <- glm (base$`STEM GIRTH`~base$Treatment,
  data = base, family = "gaussian")
Anova(model_diameter)
## Construction du diagramme de barres d'erreurs(écart type)
## Barplot surmonté de barres d'erreurs (écart type)
colnames(base)=c("treatment",
"PLANT_HEIGHT","CHLOROPHYLL_CONTENT","NUMBER_OF_LEAVES",
"NUMBER_OF_BRANCHES","STEM_GIRTH", "treat")
stem=base%>%
 mutate_if(is.character,as.factor)%>%
 group_by(treat)%>%
 summarize(sd_stem=sd(PLANT_HEIGHT),mean_stem=mean(PLANT_HEIGHT))
stem_g=ggplot(stem)+
 geom_bar(aes(x = treat, y=mean_stem), stat = 'identity', width = 0.25)+
 geom_errorbar(aes(x = treat, ymin=mean_stem-sd_stem, ymax=mean_stem+sd_stem),width = 0.15, size=0.5)+
 ylab("PLANT Height (cm)")+xlab("Treatment")+
  theme_classic()+
  theme(axis.title.x = element_text(size=14, face = "bold.italic"),
 axis.title.y= element_text(size=14, face = "bold.italic"),
 axis.text.x = element_text(size=13, face = "bold"),
 axis.text.y = element_text(size=13, face = "bold"))
cc=base%>%
mutate_if(is.character,as.factor)%>%
group_by(treat)%>%
summarize(sd_cc=sd(CHLOROPHYLL_CONTENT),mean_cc=mean(CHLOROPHYLL_CONTENT))
cc_g=ggplot(cc)+
 geom_bar(aes(x = treat, y=mean_cc), stat = 'identity', width = 0.25)+
 geom_errorbar(aes(x = treat, ymin=mean_cc-sd_cc, ymax=mean_cc+sd_cc),width = 0.15, size=0.5)+
 ylab("Chlorophyll Content (µmol/m²)")+xlab("Treatment")+
 theme_classic()+
 theme(axis.title.x = element_text(size=14, face = "bold.italic"),
```

```
  axis.title.y= element_text(size=14, face = "bold.italic"),
  axis.text.x = element_text(size=13, face = "bold"),
  axis.text.y = element_text(size=13, face = "bold"))
  nl=base%>%
  mutate_if(is.character,as.factor)%>%
  group_by(treat)%>%
  summarize(sd_nl=sd(NUMBER_OF_LEAVES),mean_nl=mean(NUMBER_OF_LEAVES))
  nl_g=ggplot(nl)+
  geom_bar(aes(x = treat, y=mean_nl), stat = 'identity', width = 0.25)+
  geom_errorbar(aes(x = treat, ymin=mean_nl-sd_nl, ymax=mean_nl+sd_nl),width = 0.15, size=0.5)+
  ylab("Number of leaves")+xlab("Treatment")+
  theme_classic()+
  theme(axis.title.x = element_text(size=14, face = "bold.italic"),
  axis.title.y= element_text(size=14, face = "bold.italic"),
  axis.text.x = element_text(size=13, face = "bold"),
 axis.text.y = element_text(size=13, face = "bold"))
 nb=base%>%
 mutate_if(is.character,as.factor)%>%
 group_by(treat)%>%
 summarize(sd_nb=sd(NUMBER_OF_BRANCHES),mean_nb=mean(NUMBER_OF_BRANCHES))
nb_g=ggplot(nb)+
 geom_bar(aes(x = treat, y=mean_nb), stat = 'identity', width = 0.25)+
 geom_errorbar(aes(x = treat, ymin=mean_nb-sd_nb, ymax=mean_nb+sd_nb),width = 0.15, size=0.5)+
 ylab("Number of branches")+xlab("Treatment")+
  theme_classic()+
  theme(axis.title.x = element_text(size=14, face = "bold.italic"),
  axis.title.y= element_text(size=14, face = "bold.italic"),
  axis.text.x = element_text(size=13, face = "bold"),
  axis.text.y = element_text(size=13, face = "bold"))
dd=base%>%
 mutate_if(is.character,as.factor)%>%
 group_by(treat)%>%
 summarize(sd_dd=sd(STEM_DIAMETER),mean_dd=mean(STEM_DIAMETER))
```

```
dd_g=ggplot(dd)+
geom_bar(aes(x = treat, y=mean_dd), stat = 'identity', width = 0.25)+
 geom_errorbar(aes(x = treat, ymin=mean_dd-sd_dd, ymax=mean_dd+sd_dd),width = 0.15, size=0.5)+
 ylab("Stem Diameter (cm)")+xlab("Treatment")+
 theme_classic()+
 theme(axis.title.x = element_text(size=14, face = "bold.italic"),
axis.title.y= element_text(size=14, face = "bold.italic"),
axis.text.x = element_text(size=13, face = "bold"),
axis.text.y = element_text(size=13, face = "bold"))
library(egg)
ggarrange(stem_g,cc_g,nl_g,nb_g,dd_g, widths = c(3,2))
```