UNIVERSITY FOR DEVELOPMENT STUDIES

WEST AFRICAN CENTER FOR WATER, IRRIGATION AND SUSTAINABLE AGRICULTURE

GREENHOUSE EXPERIMENT EVALUATION OF CONVENTIONAL DEFICIT IRRIGATION AND PARTIAL ROOTZONE DRYING UNDER VARYING WATER REGIMES WITH NITROGEN FERTILIZER ON SWEET CORN *(Zea mays L. var saccharata)*

NNADI CHINEDU COLLINS

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BY

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(B. Agric. Crop Science (Production)

(UDS/MID/0026/21)

THESIS SUBMITTED TO THE DEPARTMENT OF AGRICULTURAL ENGINEERING, SCHOOL OF ENGINEERING, UNIVERSITY FOR DEVELOPMENT STUDIES IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF PHILOSOPHY DEGREE IN IRRIGATION AND DRAINAGE ENGINEERING

AUGUST 2023

DECLARATION

DECLARATION BY CANDIDATE

I hereby, declare that this thesis is the result of my original work and that no part of it has been presented for another degree in this University or elsewhere:

Nnadi Chinedu Collins (UDS/MID/0026/21)	Signature	**11/09/2023** Date

DECLARATION BY SUPERVISOR

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

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ABSTRACT

This study addresses the pressing challenges of water scarcity and nitrogen management in sweet corn cultivation within the Guinea savannah zone of Ghana. It investigated the influence of conventional deficit irrigation (DI) and partial root zone drying (PRD) techniques, along with varying water regimes and nitrogen fertilization, on the growth, yield, water productivity, and nitrogen use efficiency of sweet corn (*Zea mays L. var saccharata)*. The experiment was carried out in a greenhouse from April to July 2023 at the Council for Scientific and Industrial Research-Savanna Agricultural Research Institute (CSIR-SARI), Nyankpala, near Tamale, Ghana. The experiment was a 3 x 3 x 2 split-plot design arranged in a randomized complete block design (RCBD) with three replications. The 18 treatment combinations include three deficit irrigation techniques (C-DI, A-PRD, F-PRD), three levels of water regimes (100%, 80%, and 60% ETc), and two levels of nitrogen (N) fertilizer (3.2 g/plant and 5.5 g/plant). CROPWAT model showed that the seasonal water needs for sweet corn ranged from 195.4 mm at 60% ETc to 325.6 mm at 100% ETc. The soil textural class was sandy loam, and the field capacity of the topsoil is 20.3 g. The result of the experiment showed that interactions of CI+100% ETc+N2 gave the highest ($p > 0.05$) shoot wet and dry mass, root wet and dry mass, total dry mass, and root N uptake. Shoot N uptake was the highest under this treatment and difference was significant. Kernel yield was highest ($p < 0.05$) with C1+100% ETc+N1. Water productivity in kernel yield was highest under interaction of C-DI+80% ETc+N1 but water saved did not maintain or improve yield. The interaction of F-PRD+60% ETc+N1 significantly gave the highest nitrogen use efficiency (NUE), but reduced the kernel yield by 74.5%. In conclusion, this study found that saving water through deficit irrigation did not result in the maintenance or improvement of sweet corn yields. The most effective approach for sweet corn cultivation in a greenhouse involves irrigating at full crop water requirement using a conventional method and applying the optimal fertilizer rate.

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DEDICATION

This work is dedicated to my cherished family whose unwavering love and support have been my constant source of strength and inspiration.

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LIST OF ACRONYMS

ABA	Abscisic Acid
AN	Analysis of Variance
ANOVA	Analyses of Variance
AWC	Available Water Content
BD	Bulk Density
CEC	Cation Exchange Capacity
CSIR	Council for Scientific and Industrial Research
EC	Electrical Conductivity
ET	Evapotranspiration
ETo	Reference Evapotranspiration
FAO	Food and Agricultural Organization
FC	Field Capacity
FI	Full Irrigation
GENSTAT	General Purpose Statistical Computing System
IRg	Irrigation Requirement
Irn	Net Irrigation Requirement
K_2O	Potassium Oxide
KNO^3	Potassium Nitrate
LSD	Least Significant Difference
Mg	Magnesium
MAP	Monoammonium
NH^{4+}-N	Ammonium Nitrogen
NO^{3-}N	Nitrate Nitrogen
OC	Organic Carbon

P_2O_5	Phosphorus Pentoxide
PRD	Partial Root-Zone Drying
PWP	Permanent Wilting Point
RDI	Regulated Deficit Irrigation
RH_{MAX}	Maximum Relative Humidity
RH_{MIN}	Minimum Relative Humidity
SARI	Savannah Agricultural Research Institute
TAW	Total Available Water
TDS	Total Dissolvable Solids
T_{MAX}	Maximum Temperature
T_{MIN}	Minimum Temperature
USDA	United States Department of Agriculture
WAP	Weeks After Planting
WP_{dy}	Water Productivity in Total Dry Biomass Yield
WP_{ky}	Water Productivity in Kernel Yield
WUE	Water Use Efficiency

CHAPTER ONE

INTRODUCTION

1.1. Background

Sweet corn (*Zea mays L. var* saccharate) is a highly valuable vegetable crop that can be consumed fresh or processed (Oktem *et al*., 2010; Chavan *et al*., 2020). It contains double the sugar content compared to field corn due to a mutation at the sugary locus (Ngenoh *et al*., 2015). However, sweet corn faces challenges related to water scarcity during prolonged droughts, as it requires ample water for growth (Tafrishi *et al*., 2013; Rou *et al*., 2017). Additionally, nitrogen (N) is crucial for sweet corn's vegetative growth, photosynthetic activity, and overall development (Oktem *et al*., 2003; Szymanek and Piasecki 2013). Managing water and nitrogen resources is critical for crop output and quality (Wang *et al*., 2013).

Agriculture uses over 70% of the freshwater consumed worldwide (FAO, 2007; Hannah and Max, 2017). According to Liu *et al.* (2021), irrigated agriculture consumes a large portion of the world's freshwater, and is primarily practiced in arid and semi-arid countries. To meet the food demand of the growing world population, estimated to exceed 7.5 billion by 2050, there is a need to increase the current global food supply by 50% (FAO, 2012; Janet *et al*., 2018). However, it is anticipated that global water resources may decrease in the future, particularly in semi-arid regions. In these regions, there will be less water available due to future climate predictions of an increase in temperature and a decrease in rainfall (IPCC, 2007; Yomo *et al*., 2020). Improved irrigation water management strategies are needed to address these issues and ensure that there is enough food to feed the growing population (Giordano *et al*., 2017).

Rainfall in Ghana, particularly in the Northern region, is insufficient to supply crops with water throughout the year. This increases the risk of food insecurity (Asmamaw et al., 2021a) Meanwhile, northern Ghana's Guinea Savanna ecological zone (GSEZ) is primarily an agricultural region (Ahmed et al., 2016). The GSEZ experiences longer dry seasons than wet ones, and during the former, most crops are grown under complete irrigation. Despite the fact that irrigated agriculture greatly increases food security and produces more than twice as much produce as rainfed agriculture (Sepaskhah and Ahmadi, 2010), becoming more and more reliant on it causes a considerable strain on water resources. In the near future, there may probably not be enough water available for irrigation due to the rising water demand, which is also being exacerbated by rising population and the impending climatic variability. Consequently, irrigation management will ultimately shift from production per unit area to production per unit volume of water consumed (Fereres and Soriano, 2007a). This has necessitated the current advocacy for water conservation in the management of agricultural water while supplying the increasing demand for crops for the growing population (Kassam *et al.*, 2007).

Nitrogen (N) is the primary plant nutrient that restrict plant growth (Oktem *et al.*, 2010), and has been demonstrated to boast root water uptake of sweet corn. Increasing N fertilizer application can lead to loss in the soil (Fengbei *et al.*, 2017). The loss of Nitrogen is through volatilization, leaching, and denitrification (Oktem *et al.*, 2010). High concentration of fertilizer under high level of water deficit can cause salinity problems. Achieving a balance between irrigation and fertilizer management is important. Sustainable use of water and fertilizer in agriculture has taken on increased importance, coupled with the implementation of field management techniques that sustain sufficient yields, improving both nitrogen use efficiency and water productivity.

Water productivity (WP) is an indicator use in deficit irrigation management (Barideh et al., 2018a). Deficit irrigation management implies, devising a strategy to manipulate the placement of irrigation water in the soil, to increase crop WP (Hedley *et al*., 2014). In regions with limited water resources, innovations, such as conventional deficit irrigation (DI) are adopted to improve WP (Yazar *et al.*, 2009). Conventional DI implies irrigating the entire root zone below the crop evapotranspiration (ETc) requirement at mild stress and minimum effect on the yield (Sonawane and Shrivastava, 2022; Liu *et al.*, 2022). Though conventional DI can increase WP (Ertek and Kara, 2013), it is important to note that this does not necessarily translate to an increase in crop yield. However, the emphasis is on how deficit irrigation could maintain crop water status with minimal reduction in yield (Kriedemann *et al*., 2003).

Over time, a modified DI known as partial rootzone drying (PRD), which involves spatial separation of the dry and wet root zone, came into practice (Li *et al*., 2007). The partial rootzone drying (PRD) strategy involves alternate wetting and drying of a sub-part of the root zone during irrigation. According to Marsal *et al.* (2008) the water applied with this strategy should not be more than 50 – 70% of the water used in a full irrigation plan. Nevertheless, the principle of PRD is based on the theory that while the part of the wet rootzone maintains the water-plant status of the crop, the root on the dry soil signals a stress hormone; abscisic acid (ABA), to the shoot to reduce stomatal conductance (Jovanovic and Stikic, 2018). Partial closure of stomata under minimal soil water stress can increase WP (Liu *et al.*, 2005). This has been validated in experiments for some crops like; sweet waxy-maize (Liang *et al.*, 2013), tomato (Wang *et al.*, 2010) corn (Barideh et al., 2018a). However, depending on the type of crop, the PRD effect on the stomata is sustained by regularly alternating the wet and dry part over a period of 10 – 14 days (Stoll *et al*., 2000).

In addition to deficit irrigation regime and strategy, the level of nitrogen (N) fertilizer application to the crop is very important. The availability of nutrients in the soil and their uptake by plant roots may be impacted by water deficit (Wang and Xing, 2017). Nitrogen uptake and Nitrogen utilization are two component of nitrogen use efficiency (NUE), which is a measurement of biomass collected in the form of grain or forage yield produced per unit N

(Adu *et al.,* 2018). Nutrient utilization under rational fertilization level can increase productivity (Fengbei *et al.,* 2017). Conventional DI and PRD has been shown to boost water productivity and N use efficiency (NUE).

1.2. Problem Statement and Justification

Ghana's most consumptive use of water is for agricultural use, which accounts for 48% of the total water resources (Yeleliere *et al.*, 2018). Between 2000 and 2020, the volume of water employed for irrigation surged by a significant 48% (Agodzo *et al.*, 2023). Rapid increase in population, as well as climate change are increasing the stress on freshwater availability. As water scarcity becomes more challenging, the need for effective use of agricultural water resources becomes paramount for enhanced food production (Lubajo and Karuku, 2022). So, deficit irrigation has been adopted in recent times as a key irrigation management strategy geared toward water conservation. Meanwhile, problems with irrigation management frequently accompany fertilizer management. High fertilizer levels, particularly synthetic fertilizer, are widely used to promote high yields (Shoukat *et al.*, 2021). On the other hand, the increasing application may lead to nutrient loss due to improper fertilization and watering techniques (Fengbei *et al.*, 2017). According to some reports, when water deficit and nitrogen are managed appropriately, there may be an interaction effect between the two on yield and growth, as well as a potential rise in WP and NUE (Wang and Xing, 2017; Fengbei *et al.*, 2017; Elshahawy *et al.*, 2021). However, information is still limited on the comparative effect of PRD and DI under rational N fertilizer levels on WP and NUE of drip irrigated sweet corn; especially in the tropical climate of Northern Ghana.

1.3. Main Objective of the Study

The primary aim of this research is to assess the influence of partial root zone drying (PRD) and conventional deficit irrigation (CDI) methods, under varying water regimes and nitrogen fertilizer on the growth, yield. water productivity and nitrogen use efficiency of sweet corn in Guinea savannah zone of Ghana.

1.4. Specific Objective

i. To determine the physiochemical properties of the soil and irrigation water and formulate the fertigation plan for sweet corn.

ii. To determine the crop water requirement of sweet corn using CROPWAT for the study location.

iii. To determine the effects of partial root zone drying (PRD) and conventional deficit irrigation (CDI) strategies under varying water regimes and nitrogen fertilizer on the growth, yield, and water productivity of sweet corn.

iv. To determine the effects of partial root zone drying (PRD) and conventional deficit irrigation (CDI) strategies under varying water regimes and nitrogen fertilizer on the nitrate uptake and nitrogen use efficiency of sweet corn.

1.5. Conceptual Framework

The conceptual framework for this study aims to clarify how key variables affect sweet corn growth and productivity under different irrigation method and nitrogen fertilizer rates. Specifically, it explores the effects of two irrigation strategies, conventional deficit irrigation (CDI) and partial root zone drying (Alternate and fixed -PRD), under water regime, in combination with nitrogen fertilizer, on nitrogen uptake and root development in corn plants. This framework draws on principles of sweet corn production, plant stress physiology, water management strategies, irrigation water requirement, water productivity, and fertilization, to provide a theoretical foundation for the study's objectives. The subsequent flowchart illustrates the relationships and components integral to this research, guiding the exploration of these critical factors in the context of sweet corn production in the Guinea savannah zone of Ghana.

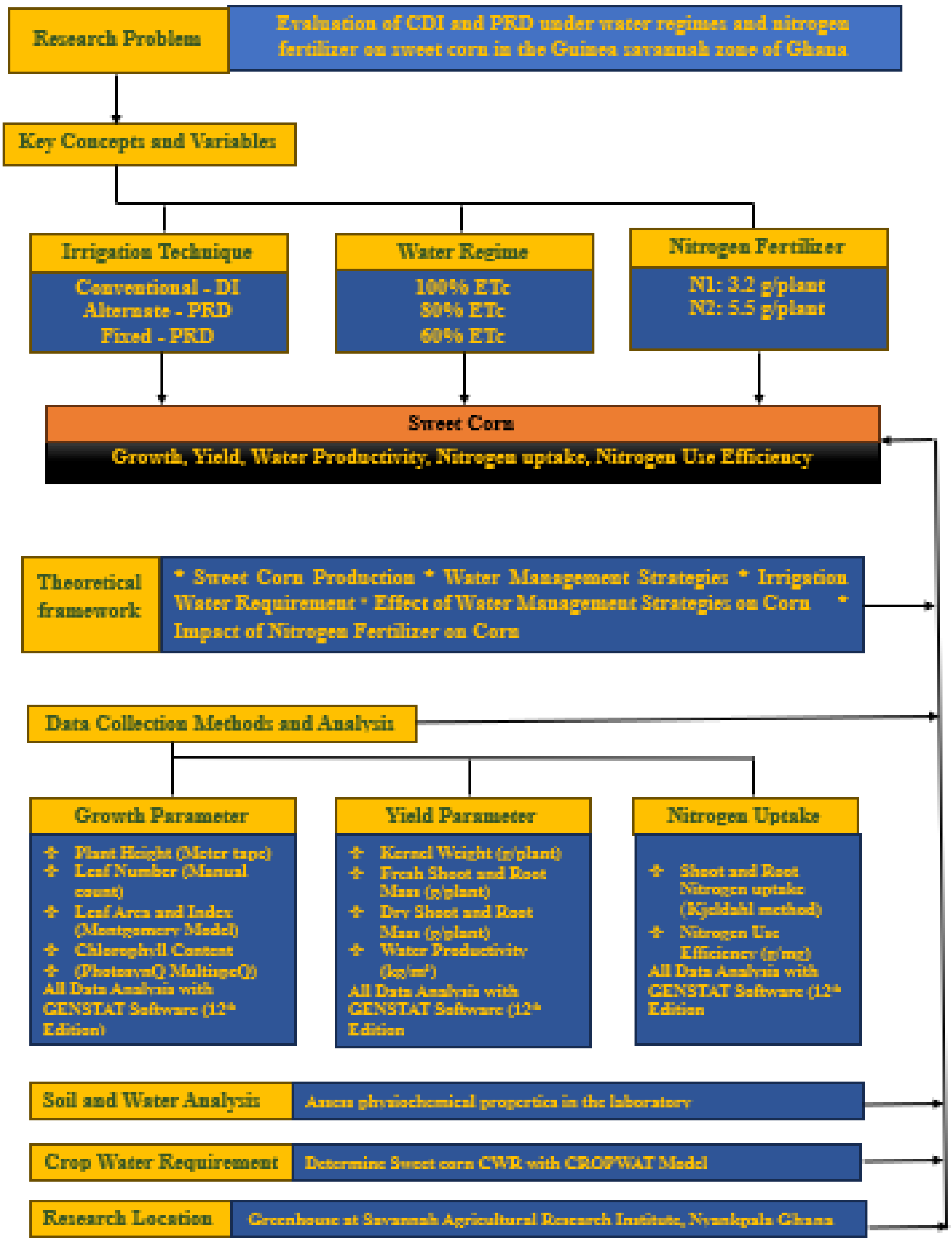

Figure 1.1. Flow Chat of the Research Study
Source: (Greenhouse Experiment, 2023)

1.6. Scope and Organization of The Study

The scope of this research study encompasses the influence of conventional deficit irrigation (DI) and partial root zone drying (PRD) techniques on the growth, yield, water productivity, and nitrogen use efficiency of sweet corn in the Guinea savannah zone of Ghana. Additionally, the study investigates the effects of varying water regimes and nitrogen fertilization with the irrigation techniques on sweetcorn. The research focuses on addressing the challenges associated with water scarcity and nitrogen management in sweet corn cultivation.

The organization of this study is structured to provide a clear and coherent flow of information. The introductory chapter lays the foundation by outlining the research background, problem statements and justification, and objectives. The subsequent chapter reviews relevant literature, establishing the context and identifying gaps that this study seeks to address. Methodology is presented in detail in chapter three, describing the experimental design, data collection, and analytical approaches.

Chapter four presents the findings of the study, organized according to specific objectives such as growth parameters, yield, water productivity, and nitrogen use efficiency. These findings are supplemented with relevant graphs, tables, and statistical analyses for clarity. Discussion and interpretation of the results follow, linking the outcomes to the research objectives and contextualizing them within existing literature.

Conclusion and recommendation are encompassed on chapter five, and this summarizes the key findings, emphasizes their implications, and suggests potential areas for further research. The bibliography provides a comprehensive list of references consulted during the study, while the appendices include supplementary information, data, and pictures.

CHAPTER TWO

LITERATURE REVIEW

2.1. Sweet Corn Plant and Agriculture in Northern Ghana

2.1.1. Overview of Sweet Corn Plant

Sweet corn (*Zea mays L* var saccharata) is a productive and valued plant in the *Poaceae* family. It distinguishes from other varieties of maize because of its high sugar content and soft kernels, making it suitable for vegetable consumption (Subaedah *et al.*, 2021). Sweet corn is grown primarily for human consumption and is renowned for its rich taste and lovely texture. It is frequently eaten raw, cooked, or as a component in other culinary recipes. Sweet corn is recognized for its adaptability; it may be used in salads, soups, stews, side dishes, and even desserts.

Sweet corn is categorized as one of the six primary varieties of maize, alongside dent, flint, pod, popcorn, and flour corn. Originating from native America, it has a long and intertwined history with the development of maize, where indigenous communities selectively bred and domesticated wild grasses to enhance desired characteristics like taste, size, and sweetness (Lertrat and Pulam, 2007). Through generations of careful cultivation, these endeavours eventually led to the emergence of sweet corn as a distinct and important variety of maize. (Swapna *et al.*, 2020)

Sweet corn is formed from a naturally occurring recessive mutation that occurred in the genes that regulate how sugar is converted to starch in the endosperm of the kernels. The kernel's endosperm has a creamy texture (Lahay *et al.*, 2019). The corn ear exhibits an accumulation of kernels along the axis, with an even number of kernel rows. The ear is tightly wrapped with leaves referred to as husk while the pistillate flowers that emerge from the husk is known as silk.

Sweet corn is harvested at an early stage, commonly referred to as the milk stage, in contrast to field corn, which is harvested once the kernels reach maturity and dryness (Swapna *et al.*, 2020). Following harvest, sweet corn is typically cooked and consumed as a vegetable. However, due to its limited storage capabilities, sweet corn is best consumed promptly or preserved through canning or freezing methods to prevent the kernels from developing a tough and starchy consistency (Revilla *et al.*, 2021). This phenomenon occurs as the maturation process entails the conversion of sugar into starch.

2.1.2. Corn Production in Ghana

Corn (*Zea mays*) holds a vital role as a staple crop in Ghana, significantly contributing to food security, income generation, and rural livelihoods (Nasiru and Sarpong, 2012). The most extensively cultivated cereal in Ghana, maize accounts for 50 - 60% of cereal production (Wongnaa *et al.*, 2019; Obour *et al.*, 2022). Flourishing predominantly in rain-fed environments, corn is cultivated by small-scale, under-resourced farmers across Ghana's ecological zones, particularly the northern savannah, where it demonstrates remarkable adaptability (Darfour & Rosentrater, 2016). Key maize production areas encompass the Eastern, Ashanti, and Brong-Ahafo regions, contributing over 80% of total maize production (Wongnaa *et al.*, 2019). Despite significant investments, Maize yield in Ghana remains relatively low on a global scale (Ragasa *et al.*, 2014). Factors affecting production include seed quality, fertilizer and agrochemical availability, credit access, mechanization, extension services, and market reach. Government policies, climate change, pests, diseases, and post-harvest losses also impact outcomes (Ragasa *et al.*, 2014). Corn remains pivotal for food security and socioeconomic progress in Ghana. Recognizing corns profitability, improving profit efficiency through road construction to production centers is vital (Wongnaa *et al.*, 2019). While sweet corns presence grows, its production is concentrated in the southern and middle belt regions, favored by favorable agro-climatic conditions. Actual sweet corn production data in Ghana is scarce. The demand for sweet corn and other staples is anticipated to rise due to urbanization, evolving diets, and heightened awareness of nutritional benefits, following trends across African nations (AGRA, 2020).

2.2. Water Management Strategies in Agriculture

2.2.1. Deficit Irrigation

In the past, crop irrigation practices did not consider water supply restrictions, and the need for irrigation was determined without accounting for moisture availability, which is a critical factor limiting crop yields (FAO, 2002). However, in the 1970s, the concept of deficit irrigation (DI) emerged (Yu *et al.,* 2020). The term deficit irrigation was first coined by James et al. in 1971 while discussing the economics of water resource planning (Capra *et al*., 2008). Over the years, DI has gained attention due to the growing concern of diminishing global water resources. To enhance the efficiency of water usage in agriculture, significant modifications in irrigation management and scheduling are required, especially in arid and semi-arid regions where municipal and industrial water demands are increasing (FAO, 2002). Consequently, deficit irrigation has been adopted as a key irrigation management strategy for water conservation in dryland areas(Geerts & Raes, 2009). Numerous research studies on DI have been conducted in the last three decades.

Deficit irrigation involves intentionally providing less water than the crop's total evapotranspiration (ETc) requirement, inducing mild stress while minimizing the impact on yield (Fereres and Soriano, 2007; Liu and Neumann, 2022;Sonawane and Shrivastava, 2022). The concept of deficit irrigation recognizes that not all crops require maximum water supply throughout their growth cycle and that judicious water management can still achieve satisfactory yields (Kriedemann *et al.,* 2003). By providing less water than the crops evapotranspiration (ET) requirement, deficit irrigation aims to strike a balance between water availability and crop needs. The goal is to ensure that essential plant functions are sustained while reducing non-essential water consumption (Suna *et al.*, 2023). This approach is particularly relevant in regions facing water scarcity, arid or semi-arid climates, and situations where limited water resources need to be allocated efficiently (Darko *et al.*, 2019).

There are different strategies for implementing deficit irrigation. Conventional deficit irrigation involves consistently applying water below the crop's ET requirements throughout the entire growing season (Kaman *et al.*, 2011). This strategy induces mild stress, ensuring that the essential growth stages of the crop are sustained while minimizing water usage during less critical periods. Another approach is regulated deficit irrigation, where water supply is adjusted at specific stages of crop development. This strategy recognizes that crops have different sensitivities to water stress during various growth stages (Chai *et al.*, 2016). By providing optimal water supply during critical growth stages and slightly reducing water supply during less sensitive stages, regulated deficit irrigation seeks to maximize water productivity and minimize the overall impact on yield (Hayashi & Dogliotti, 2021).

Determining the crop's entire ET requirements is essential before implementing DI (Fereres and Soriano, 2007). The success of deficit irrigation depends on accurate estimation of crop water requirements. Various methods, such as reference evapotranspiration equations (Allen *et al.*, 1998), crop coefficients (Pereira *et al.*, 2021), and soil moisture monitoring (Hanson *et al.*, 2000), can be used to determine the appropriate irrigation levels. It is important to consider factors like crop type, growth stage, soil characteristics, climate conditions, and local water availability when implementing deficit irrigation practices.

Benefits of deficit irrigation include improved water-use efficiency, reduced water consumption, increased resilience to drought, and potential cost savings in irrigation operations (Fereres & Soriano, 2007b). However, it requires careful management and monitoring to avoid excessive water stress that could adversely affect crop health and productivity (Rallo *et al.,* 2017). Cutting-edge approaches are being developed to improve the precision and efficacy of deficit irrigation practices. These include the utilization of advanced techniques such as precision deficit irrigation and remote sensing-based monitoring (Adeyemi *et al.,* 2017; Kang, C. *et al.*, 2023).

2.2.2. Plant Physiological Response to Water Stress

Crop growth and development are profoundly influenced by the availability of water resources (Anjum *et al.*, 2017). Adequate water supply is essential for critical cellular activities such as the cell cycle, cell production, and cell turgor maintenance. When faced with water scarcity, plants employ various adaptive mechanisms to mitigate the effects of drought stress. These mechanisms include limiting transpiration area, stomatal closure to reduce water loss from leaves, and enhancing root water uptake (Dodd and Ryan, 2016). To maintain proper physiological functions and gas exchange, plants rely on stomata, the small pores on the leaf surface. Stomatal conductance, which affects transpiration, is influenced by stomatal density and size (Du *et al*., 2015). Stomatal density refers to the number of stomata per unit area, while stomatal size refers to the dimensions of individual stomata (Fanourakis *et al*., 2015). Studies have shown that plants can regulate stomatal density and size in response to water stress (Xu and Zhou, 2008; Pitaloka *et al*., 2022). Under drought conditions, plants often exhibit a decrease in stomatal density to reduce water loss (Wang *et al.*, 2016). Additionally, stomatal size may decrease, resulting in smaller stomata, which helps to limit transpiration rates and conserve water (Du *et al.*, 2015). Also, in response to water deficit, plants are capable of detecting changes in soil moisture levels through their root systems (Rodriguez-iturbe *et al.*, 2001). This enables them to trigger adaptive responses even before experiencing severe water stress. Root-to-shoot communication plays a crucial role in signalling the need for stomatal closure and adjusting physiological processes to conserve water (Rodrigues *et al*., 2008).

Mild soil drying can stimulate root growth, while alternating wetting and drying of the soil promotes increased root biomass and lateral root development (Dodd and Ryan, 2016). Roots possess the ability to continue growing at water potentials that hinder the growth of other plant organs. Accumulation of the plant hormone ABA in roots exposed to drying soil plays a role in regulating root growth. ABA inhibits root growth in moist soil but becomes essential in limiting ethylene synthesis, another growth-inhibiting hormone, in dry soil (Aslam *et al.*, 2022). Moreover, ABA accumulation is necessary for the synthesis of osmolytes like proline, which facilitates continued water uptake by the roots (Dodd and Ryan, 2016).

Sweet corn (*Zea mays* var. saccharata) is more vulnerable to environmental stress than dent corn types. Optimal maize flowering occurs at 25 °C to 35 °C, with 25 °C ideal for maximum grain yield. Different maize varieties tolerate temperatures differently; exceeding 40 °C causes stress. Reproductive phases, especially flowering and early grain filling, are heat-sensitive. High temperatures during tassel stages cause delayed silking, tassel damage, pollen drying, and silk death, disrupting fertilization and reducing yields (Alam *et al.*, 2017).

2.2.3. Partial Rootzone Drying (PRD)

Partial root-zone drying (PRD) is a modified technique for deficit irrigation (DI). In this approach, irrigation is applied to only one portion of the root zone in each irrigation cycle, while the remaining half is permitted to desiccate to a predetermined soil water content. Subsequently, the irrigation is shifted to the previously dry side, rewetting it (Sepaskhah and Ahmadi, 2010; Al-Kayssi, 2023). Researchers have implemented PRD in two main forms: alternate partial root-zone drying (APRD) and fixed partial root-zone drying (FPRD) (Kang *et al.*, 2003; Topak *et al.*, 2016; Ghafari *et al.*, 2020). In the APRD method, one-half of the root zone is kept wet while the other half remains dry during a particular irrigation period. This pattern is then reversed in the subsequent irrigation interval. On the other hand, the FPRD method involves maintaining one sub-part of the root zone as completely dry and the other half as wet throughout the entire irrigation cycle (Al-Kayssi, 2023).

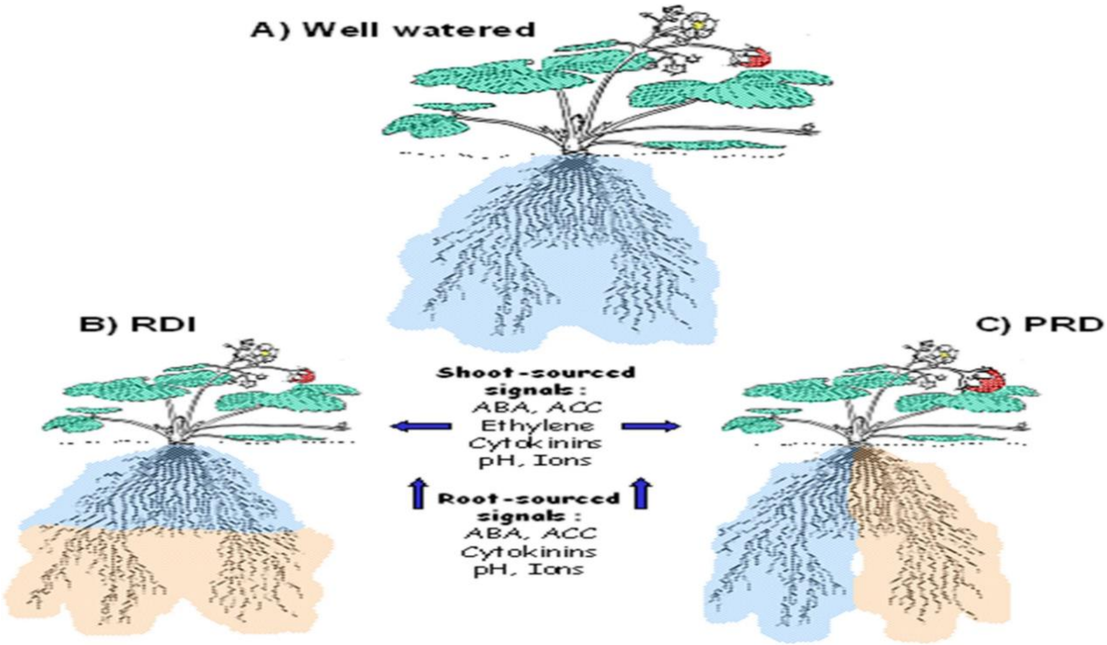

Figure 2.1. Irrigation Pattern of Full Irrigation, Regulated Deficit Irrigation, and Partial Root-Zone Drying
Source: (Davies and Hartung, 2004)

The underlying principle of PRD is based on the theory that while the wet portion of the root zone maintains the water-plant status of the crop, the roots in the dry soil trigger the release of a stress hormone called abscisic acid (ABA) to the shoot, resulting in reduced stomatal conductance (Jovanovic & Stikic, 2018). However, FPRD poses a challenge because reduced irrigation water uptake by plants from roots in the dry section also limits the capacity of the roots to generate chemical signals, including ABA. Consequently, sap flow from roots in the drying soil may cease entirely (Tamrat, 2020). In contrast, APRD allows for alternating wet and dry zones within the root system, enabling some roots to remain in a drying state while continuously producing and transporting signals to the shoot (Jovanovic & Stikic, 2018; Tamrat, 2020).

The duration of wet and dry alternation significantly influences water absorption and ABA concentrations. Generally, for PRD to have a sustained effect on stomatal regulation, the wet and dry sides need to be alternated over a period of 10-14 days, depending on the crop type *(Stoll et al.*, 2000). However, it is important to note that this time frame is not universally applicable, as other factors such as the plant's developmental stage, evaporative demand, soil texture, and water balance can influence the optimal wetting and drying period (Saeed *et al*., 2008). Determining the optimal timing for switching between wet and dry sides is crucial. When there is minimal soil water extraction from the dry side, the wetting should shift from the irrigated side to the non-irrigated side (Kriedemann *et al.*, 2003; Sepaskhah and Ahmadi, 2010). Some argue that the basis for switching should be the maximum soil water content at which xylem abscisic acid (ABA) concentration is formed (Liu *et al*., 2008). Careful consideration of these factors ensures effective implementation of the PRD technique in agricultural practices.

PRD has been successfully implemented in various crops, including grapevines (Stoll *et al*., 2000), citrus (Hutton & Loveys, 2011), tomatoes (Sun *et al*., 2014), olives (Dbara *et al*., 2016), and cereals (Chandra *et al*., 2018), demonstrating its versatility and potential for broad application . Research has shown that PRD can significantly improve water use efficiency, resulting in reduced water consumption without compromising crop yield and quality (Hutton and Loveys, 2011). The technique has also been associated with several additional benefits, such as enhanced root system development, improved nutrient uptake efficiency, increased tolerance to drought and salinity, and potential mitigation of certain diseases (Slamini *et al*., 2022). Moreover, PRD can contribute to sustainable agriculture by reducing the environmental impact of irrigation and conserving water resources (Saeed *et al*., 2008).

While PRD offers promising advantages, there are certain challenges that need to be addressed for successful implementation. Determining the optimal wetting and drying periods, as well as the appropriate switching points between wet and dry sides, is crucial and requires careful consideration of various factors, including crop type, growth stage, soil properties, and environmental conditions (Sepaskhah & Ahmadi, 2010). Additionally, proper irrigation management and system design are essential to ensure accurate water distribution and prevent potential negative impacts, such as salt accumulation in the dry side (Iqbal *et al.*, 2020). It is also important to note that the effectiveness of PRD may vary depending on crop species, agroclimatic conditions, and soil types, highlighting the need for site-specific optimization (S. Kang & Zhang, 2004).

2.2.4. Comparative characteristics of PRD and CDI

Partial Rootzone Drying (PRD) alternates irrigation between root halves, promoting stress adaptation and efficient water use. Conventional Deficit Irrigation (DI) uniformly applies reduced water, conserving resources but potentially affecting growth. PRD emphasizes adaptation, while DI prioritizes conservation. Choice depends on goals and conditions.

Table 2.1. Comparative characteristics of PRD and Conventional DI

Criteria	Conventional Deficit Irrigation	Partial Rootzone Drying (PRD)
Development	First developed with fruit trees and later expanded to include grapevines	First started with grapevines and later expanded to fruit trees and other crops
Plant Response on Hot Days	Frequently wilt when insufficient irrigation is provided	Plants remain turgid, but stomatal conductance is decreased if PRD is successfully applied
Crop Risk	Arises only with severe deficit	Crop not vulnerable when PRD is efficiently applied

Soil Type Tolerance	Soil type not critical	Best chances for success in deep porous light sandy loam soils
Irrigation Scheduling Method	Generally based on measuring Epan or calculating ETcrop and adjusting water application based on crop coefficient	Length and timing determined more directly by measuring water content of the rootzone of the soil

Source: (Kriedemann *et al*., 2003).

2.3. Irrigation Management and Water Requirements

2.3.1. Irrigation Requirement

Irrigation requirement plays a crucial role in ensuring adequate water supply to meet the water demands of crops (Chiarelli *et al.*, 2020). Understanding and accurately estimating irrigation requirements are essential for efficient water use, improved crop yield, and sustainable agricultural practices (Kang *et al.*, 2021). The irrigation requirement of a crop is influenced by several factors, including climatic conditions, crop type, growth stage, soil characteristics, and management practices (Fang & Su, 2019). Climatic factors, such as temperature, solar radiation, wind speed, and humidity, directly impact the rate of evapotranspiration, which represents the combined process of water evaporation from the soil surface and plant transpiration (Ghiat *et al.*, 2021). Evapotranspiration is the primary driver of crop water consumption and serves as a basis for determining irrigation needs (Kumar *et al.*, 2011). Different crops exhibit varying water requirements throughout their growth stages (Al-Kaisi & Broner, 2014). During the initial stages of crop establishment, water is critical for seed germination and early root development (Queiroz *et al*., 2019). As the crop progresses to the vegetative and reproductive stages, water demand increases to support leaf expansion, nutrient uptake, flowering, and fruit development. Understanding the specific water needs of different crops at each growth stage is crucial for timely and appropriate irrigation scheduling.

Soil characteristics significantly influence irrigation requirements by affecting water holding capacity, drainage characteristics, and root zone depth (Arshad and Coen, 1992; Scherer *et al*. 2017). Soils with high water-holding capacity can retain more moisture, reducing the frequency and amount of irrigation required. Conversely, soils with low water-holding capacity or poor drainage may necessitate more frequent irrigation to prevent water stress (Lin *et al*., 2018). Determining soil moisture content and understanding the soil-water relationship are critical in assessing the irrigation requirements accurately (Dobriyal *et al.*, 2012). Management practices also play a vital role in determining irrigation requirements. Factors such as irrigation system efficiency, water application uniformity, and crop water use efficiency can significantly influence the overall irrigation demand (Irmak *et al.*, 2011). Well-designed irrigation systems, such as drip irrigation or precision sprinklers, with high application efficiency and uniformity, can minimize water losses and optimize water use (Arshad, 2020).

Accurately estimating irrigation requirements requires the integration of multiple approaches and tools. Evapotranspiration models, such as the Penman-Monteith equation, provide a scientific basis for estimating crop water needs by considering meteorological data, crop characteristics, and soil conditions (Pereira *et al.*, 2015). These models utilize parameters such as solar radiation, temperature, humidity, wind speed, crop coefficients, and soil moisture data to calculate crop evapotranspiration rates (Zotarelli *et al*., 2010).

2.3.2. Greenhouse Crop Production and Evapotranspiration Estimation

Greenhouse crop production has gained significant importance in modern agriculture. It serves as a vital tool for addressing the challenges posed by changing climate conditions while promoting sustainable food production (Samaranayake *et al.*, 2021). Initially, greenhouses were primarily associated with cool climates, but the conservation of water resources has emerged as a key driver for the expansion of the greenhouse industry, particularly in arid and semi-arid regions (Marcelis *et al.*, 2019). Greenhouses provide growers with a controlled environment that allows precise adjustments of factors like temperature, humidity, and light levels. This capability creates optimal conditions for plant growth, reducing the risk of pests and diseases, improving crop quality, and extending the growing season. Consequently, greenhouses ensure a consistent food supply year-round (Ilahi, 2009).

To determine the water needs of crops in a greenhouse, the Penman-Monteith ETo calculation is widely accepted. This method considers various climatic parameters, including temperature, humidity, wind speed, and solar radiation, offering a robust approach for estimating reference evapotranspiration. However, estimating crop evapotranspiration (ETc) in a greenhouse often relies on outdoor calibrated ETo equations, leading to uncertainty regarding their applicability in greenhouse conditions (Moazed *et al.*, 2014). This uncertainty arises because protected crop ET in a greenhouse environment is influenced by the energy balance of the entire system within the greenhouse, strongly dependent on greenhouse characteristics and climate control equipment.

A significant challenge in greenhouse operation is obtaining precise measurements of the internal climate. This challenge is due to limitations in facilities, equipment, expertise, and budget (Ilahi, 2009). Consequently, many greenhouse operators resort to using climate data from nearby weather stations to estimate external greenhouse conditions. While this approach can provide valuable insights, it may not accurately represent the specific microclimate within the greenhouse. To leverage external data effectively, a correction factor that adjusts for inside conditions may be necessary. However, the absence of specific microclimatic information for a particular location makes it challenging to adopt a suitable correction factor.

Some studies have compared ETo values for low technology greenhouse (screen houses) with those for the external environment (Fernández *et al.*, 2010; Moazed *et al.*, 2014). These studies suggest that in absence of internal microclimatic data, the Penman-Monteith ETo calculation can be applicable.

2.3.3. Reference Evapotranspiration (ETo)

Reference crop evapotranspiration (ET_o) is a fundamental concept in agricultural water management, providing valuable insights into the water needs of crops and the overall water balance in an agricultural system. ET_o represents the amount of water that would be evaporated and transpired by a well-watered reference crop under optimum growing conditions (Zotarelli *et al.*, 2010). It serves as a benchmark for estimating the water requirements of different crops and is widely used in irrigation scheduling, water resource management, and agricultural planning. The concept of a reference surface in ET_o calculations is crucial for standardizing the estimation process. The reference surface is an imaginary grass reference crop that closely resembles a broad expanse of uniformly tall, green, well-watered grass covering the ground. The assumption of specific crop characteristics, such as a crop height of 0.12 m, fixed surface resistance of 70 s m^{-1}, and albedo of 0.23, allows for a standardized representation of the reference surface (Allen *et al.* 1998; Carvalho *et al.* 2013). These characteristics help create a consistent basis for comparing and assessing the water requirements of different crops and agricultural systems.

Various methods have been developed to estimate ET_o, ranging from simple empirical equations to more complex models based on physical principles (Castro *et al*., 2018). The four traditional methods frequently employed for estimating reference evapotranspiration are the Blaney-Criddle, Radiation, Pan evaporation, and Penman-Monteith methods (Allen *et al*., 1998) . Among these, the Penman-Monteith method, recommended by the FAO, has gained widespread acceptance as the most accurate and reliable approach for computing ETo from meteorological data (Carvalho *et al*., 2013).

The Penman-Monteith equation (equation 2.1) incorporates several meteorological parameters, including net radiation, air temperature, humidity, wind speed, and vapor pressure deficit (Sentelhas *et al*., 2010). Net radiation represents the energy available for evapotranspiration, while air temperature, humidity, and wind speed influence the rate of evapotranspiration by affecting the vapor pressure gradient and the aerodynamic resistance to water vapor transfer. The vapor pressure deficit, which represents the difference between the saturation vapor pressure and the actual vapor pressure, provides an indication of the atmospheric demand for water (Allen *et al*., 1998). The following is how the Penman-Monteith equation was arrived at:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T_{mean}+273} u_2 (e_s - e_a)}{\Delta + \gamma (1 + 0.34 u_2)} \qquad \text{Equation 2.1}$$

Where;

ET_o = reference evapotranspiration [mm/day],

Rn = net radiation at the crop surface [$MJ/m^2/day$],

G = soil heat flux density [$MJ/m^2/day$] which can be neglected (G = 0),

T_{mean} = mean air temperature [°C],

u_2 = wind speed measured at 2 m height [m/s],

e_s = saturation vapor pressure [kPa],

e_a = actual vapor pressure [kPa],

e_s-e_a = saturation vapor pressure deficit [kPa],

D = slope vapor pressure curve [kPa/°C],

g = psychrometric constant [kPa/°C].

2.3.4. Crop Water Requirement (ETc)

Crop water requirement (CWR) refers to the amount of water needed to make up for a cropped field's evapotranspiration losses during a predetermined time period (Maeda *et al.*, 2011). Evapotranspiration is the simultaneous occurrence of the evaporation of water from the soil surface and the transpiration of water from plants (Ghiat *et al.*, 2021). CWR is typically expressed in millimetres per day, month, or season and plays a crucial role in agricultural water management, including irrigation planning and scheduling (Todorovic, 2005). Precise determination of crop water requirements is imperative to achieve effective water management and promote sustainable crop production (Aydin, 2022). Several factors contribute to the calculation of crop water requirements (CWR), encompassing climatic conditions, crop attributes, soil characteristics, and agricultural management techniques (Andreas *et al*., 2002). In order to facilitate the estimation of CWR, some models and software applications have been devised to aid in this process (Markovic *et al.*, 2021).

One widely used model is the CROPWAT model, developed by the Food and Agriculture Organization (FAO) of the United Nations (Derek *et al.*, 2000; Maingi *et al.*, 2020). The CROPWAT model integrates inputs such as weather data, crop information, soil characteristics, and irrigation practices to estimate crop water requirements and develop irrigation schedules (Allen *et al.*, 1998). The model allows for customization based on local conditions and provides valuable insights into water management decisions.

Additionally, the CROPWAT model generates irrigation schedules and calculates scheme water supply for different crop patterns (Godfrey *et al*., 2022). It utilizes standard crop and soil data when local data is unavailable, and allows for modification or creation of data files when local data is accessible. Irrigation schedules in CROPWAT are based on a daily soil-water balance, with user-defined options for water supply and irrigation management conditions (Godfrey *et al.*, 2022). Proper estimation of crop water requirements using tools like the CROPWAT model can significantly improve water use efficiency and reduce water wastage in agriculture (Maingi *et al*., 2020).

2.3.5. Irrigation Scheduling

Plants require adequate water to grow and achieve optimal yields, and effective scheduling ensures that water is applied at the right time and in the appropriate quantity (Gu *et al.*, 2020). Only if the air and water levels in their root zones are appropriately regulated will plants be able to reach their full growth potential (Anjum *et al*., 2011). To determine the timing and amount of irrigation, several factors come into play. Firstly, the intervals between irrigations and the volume of water applied during each irrigation are influenced by the water-holding capacity of the root zone and the absorption rate of the crop. Additionally, the depth of the effective root zone, the type of crop being cultivated, and the stage of crop growth all play significant roles in irrigation scheduling decisions (McMullen, 2000). Also, soil texture, structure, and water absorption capacity are important considerations.

Various methods are employed for irrigation scheduling. One involves directly measuring soil moisture using techniques like modified atmometers, tensiometers, and electrical resistance (Speer 2015). Another employs soil water balance calculations, comparing inputs (precipitation plus irrigation) with losses (runoff, drainage, and evapotranspiration) to determine soil moisture changes (Rai *et al.*, 2017). Decision support tools and computer models are also utilized, factoring in soil properties, crop characteristics, weather patterns, and water availability for optimized irrigation schedules (Chen *et al*., 2019). However, local farmers and rely on personal experience and visual assessments of plant and soil conditions for informed irrigation decisions (Guo *et al*., 2023). Practical knowledge and observational skills contribute to understanding irrigation needs.

In addition to these methods, farmers and agricultural experts often rely on personal experience and visual assessments of plant and soil conditions to make informed decisions regarding irrigation scheduling (Guo *et al.*, 2023). Practical knowledge and observational skills contribute to the overall understanding of irrigation needs.

2.4. Water Management Strategies on Water Productivity

2.4.1. Concept of Water Use Efficiency and Water Productivity

Water Use Efficiency (WUE) and Water Productivity (WP) are two terms commonly used in the literature to indicate water conservation practices in agriculture (Sharma *et al.*, 2015). While these terms are often used interchangeably, it is essential to understand their concept and clarify their meanings (Ragab, 2014). WUE and WP serve as crucial indicators for sustainable management of agricultural water resources. Traditionally, WUE has been defined as the ratio of biomass production to water consumed consumed (Jovanovic & Stikic, 2018; Hatfield & Dold, 2019). It measures how effectively water is utilized by a crop to produce plant biomass. Improving WUE enables farmers to maximize crop productivity while minimizing water consumption (Singh *et al.*, 2010). This is particularly significant in regions where water resources are limited or face increasing competition from various sectors (Kang *et al.*, 2017). Water Productivity (WP), on the other hand, takes into account not only the efficiency of water use but also additional factors influencing agricultural productivity. It is defined as the ratio of biomass produced to water used (Kilemo, 2022). WP considers both the quantity and quality of crop yield in relation to the amount of water utilized. By incorporating yield as a key component, WP offers a comprehensive perspective on the overall productivity achieved with a given amount of water.

While WUE and WP are related, it is essential to understand that a high WUE does not always translate into a high WP (Jovanovic and Stikic, 2018). In some cases, improving WUE may result in water conservation without a significant impact on overall productivity. Several factors contribute to this disparity. First, WP is influenced by plant-specific characteristics such as genetics, physiological traits, and growth patterns (Sadras *et al.*, 2011). Different crops exhibit varying water requirements and responses, which can affect their overall productivity even with similar levels of water use efficiency (Asmamaw *et al.*, 2021b). More so, factors such as excessive runoff, low infiltration rates, and high rates of soil surface evaporation can significantly impact yield, even if the water is efficiently delivered to the plants (Cook *et al.* 2006; Kilemo, 2022). Therefore, achieving a high agricultural WP is essential to increase productivity while optimizing water resources. Recently, the Food and Agriculture Organization (FAO) has clarified the usage of WUE and WP, bringing more clarity to the field. According to the FAO's guidelines, the term "efficiency" is now reserved for engineering applications, while "water productivity" is used to describe agricultural ratios such as yield per unit evapotranspiration or yield per supplied water (Sharma *et al*., 2015; Kilemo, 2022).

2.4.2. Deficit Irrigation Impact on Water Productivity of Field Crops

Under conditions of low water supply, crop response to deficit irrigation is increasingly being taken into account when developing irrigation management methods. It has been shown that deficit irrigation can increase crop quality, speed up seed germination, increase Water productivity (WP), and conserve irrigation water without adversely reducing yields (Okwany *et al.*, 2009). The term "water productivity" (WP) as earlier stated refers to the amount of carbon assimilated as biomass or grain produced per unit of water consumed by the crop (Hatfield and Dold, 2019). It can also be expressed as the ratio of the amount of water consumed by the crop to the amount of water delivered to the crop. Deficit irrigation has been found to improve crop WP, as evidenced by various studies conducted on different vegetable crops such as tomato (Mohawesh and Karajeh, 2014; Wang and Xing, 2017; Al-Ghobari and Dewidar, 2018), hot pepper (Ahmed *et al.* 2014; Abdelkhalik *et al.* 2020), cucumber (Mao *et al.*, 2003; Kirnak and Demirtas, 2006; Zakka *et al.* 2020), eggplant (Mohawesh and Karajeh, 2014; Darko *et al.* 2019), sweet corn (Oktem *et al.* 2003; Ertek and Kara, 2013). Although DI can increase WP, this is true at mild stress as severe deficit irrigation can negatively affect deficit irrigation as reported for eggplant (Badr *et al.*, 2020).

To effectively manage DI, one must comprehend how a crop reacts to water. The crop water productivity (WP) describes the relationship between the yield or value of a crop and the amount of water used (Trout *et al.*, 2020). The yield and WP values of the same crop exhibited significant variation despite receiving the same amount of irrigation water (Asmamaw *et al.*, 2021b). Many elements, including varying soil fertility levels, salinity, field management methods, climate fluctuation, drainage, pests, disease, soil water evaporation, and others, are likely to be to responsible for this (Asmamaw *et al*., 2021b). Plant performs at optimal at full irrigation. However moderate water stress have shown promising result in yield and quality of fruit, such as in tomato (Wang and Xing, 2017; Al-Ghobari and Dewidar, 2018), hot pepper (Ahmed *et al*., 2014), sweet pepper (Abdelkhalik *et al.*, 2020), cucumber (Zakka *et al.*, 2020), eggplant (Mohawesh and Karajeh, 2014; Darko *et al.*, 2019), sweet corn (Ertek and Kara, 2013). Generally, based on these reports, DI at 50 % ETc and below significantly reduces the yield of crop.

2.4.3. Partial Rootzone Drying Influence on Field Crops

Partial Rootzone Drying (PRD) has emerged as a promising water-saving strategy, capable of reducing water usage by up to 50% while maintaining crop yields (Loveys *et al.*, 2000; *Barideh et al.* 2018). The key mechanism behind this technique lies in the roots of plants situated in dry soil, which release a biochemical signal called abscisic acid (ABA) to the shoot. This signal reduces stomatal conductance, enabling the wetted rootzone to preserve the plant's water potential (Jovanovic and Stikic, 2018).

Research indicates that implementing PRD can enhance farmers' net income and water productivity (WP) (Fereres and Soriano, 2007b). However, the outcomes depend on various factors, including the crop type, soil hydraulic properties, and other variables. (Liang *et al.* (2013) found that alternate-PRD improved WP in sticky maize based on dry biomass, but not in terms of seed yield. This disparity was attributed to the high stress levels experienced by the crop during the final stages of development under PRD. In contrast, Fengbei *et al.* (2017) reported that alternate-PRD increased the WP of sweet-waxy maize based on dry seed. Additionally, (Barideh *et al.* (2018) demonstrated that alternate-PRD increased WP in corn, whereas fixed-PRD significantly reduced crop yield.

It is expected that mild stress levels associated with alternate partial rootzone drying (PRD) will be recognized as a beneficial practice, enhancing water productivity (WP) and sustaining yields in various crops. Promising results have been reported in numerous studies including, hot pepper (Kang *et al.*, 2001), tomato (Kirda *et al.*, 2004; Campos *et al.*, 2009), potato (Shahnazari *et al.*, 2007), maize (Barideh *et al.* 2018; Cheng *et al*. 2021), and cucumber (Abdelraouf *et al.*, 2023).

In contrast, fixed-PRD has been shown to potentially reduce corn yield (Liang *et al*. 2013; Fengbei *et al*. 2017). This can be attributed to the compromised ability of roots to adjust their metabolism and produce chemical signals, particularly abscisic acid (ABA), when experiencing reduced water absorption from the dry section of the root system. Additionally, applying PRD below 50% ETc (crop evapotranspiration) has been shown to result in substantial yield reduction (Liang *et al*., 2013) or no significant positive effect on WP or yield. Notably, PRD at 75% ETc was found to significantly reduce the yield (harvest index) of corn (Yazar *et al.*, 2009). However, these contradictory findings may stem from the ineffectiveness of partial separation in the experimental setup.

2.4.4. Comparative Effect of PRD and DI on Field Crop

The advantage of PRD over conventional DI is that although the moist side of the root system consumes water to maintain the plant's water status, the dry side of the root system promotes an increase in ABA production (Abdelraouf *et al.,* 2023) that reduces stomatal conductance and enhances water use efficiency (Sepaskhah and Ahmadi, 2010). Though the stomatal conductance may be reduced in PRD, the photosynthetic rate is not significantly reduced compared to full irrigation. This assertion was true for potato (Ahmadi *et al*. 2010; Zin El-Abedin *et al*. 2019), tomato (Campos *et al.,* 2009). It is anticipated that crops cultivated under partial rootzone drying (PRD) will exhibit higher yields compared to those grown under conventional deficit irrigation (DI), even when receiving the same amount of water. Practical results suggest that the implementation of PRD can lead to improved yield and increased water productivity (WP) in crops such as potato (Shahnazari *et al.,* 2007) and rabi maize (Cheng *et al.,* 2021). However, in the case of common bean, both PRD and DI are were reported to enhance WP, but no significant difference was observed between the two techniques when applied at the same level of water supply (% ETc) (Wakrim *et al.,* 2005).

2.5. Effect of Nitrogen Fertilizer and Deficit Fertilizer on Nitrogen Uptake and Use Efficiency of Corn

Sweet corn requires a lot of nitrogen (N) during vegetative growth in order to maintain their ability to photosynthesize, start and grow leaves, and establish stems and roots. So, Nitrogen is the primary plant nutrient, which is responsible for controlling its growth and influencing the quality and mineral content of kernels (Oktem *et al*., 2010). Proper application of nitrogen fertilizer plays a pivotal role in stimulating robust plant growth, leading to taller sweet corn plants, expanded leaf area, and enhanced overall plant vitality (Huang *et al*., 2022). Consequently, these favourable growth conditions contribute significantly to achieving higher crop yields and improved quality of sweet corn kernels. Furthermore, the application of nitrogen fertilizer has a direct impact on the mineral composition and nutritional value of the harvested sweet corn kernels, enhancing their overall nutritional content (Oktem *et al.*, 2010).

However, increasing the level of N fertilizer can lead to loss of nutrient (Zotarelli *et al.*, 2009; Fengbei *et al.*, 2017). Leaching of nitrogen (N) can harm both surface and groundwater resources, but it can also be prevented by providing N at a rate that is less than ideal and/or by adopting a variable deficit irrigation scheduling regime (Gheysari *et al.*, 2009). Improving WP and fertilizer use efficiency is the most efficient strategy to save water and lower fertilizer input while increasing farmer income (Wang and Xing, 2017). Achieving a good balance of conventional DI and rational fertilizer application has been shown to increase water productivity and nitrogen use efficiency of various crops. Promising results have been reported in some crops such as; tomato (Ullah *et al.*, 2021); peanut (Rathore *et al.*, 2021); wheat (Shoukat *et al.*, 2021). Also, partial rootzone drying and fertigation has shown potential to improve yield, N uptake, WP and NUE. This has been reported for maize (Hu *et al.*, 2009; Barideh *et al.*, 2018; Elshahawy *et al.*, 2021); sweet corn (Fengbei *et al.*, 2017); tomato (Wang *et al.*, 2013; Wang and Xing, 2017). Future research is expected to continue investigating the efficacy of partial rootzone drying (PRD) compared to conventional deficit irrigation (DI) in terms of nitrogen fertigation under deficit irrigation strategies. Promising results have already been observed in studies focusing on various crops such as maize (Topcu *et al.*, 2007); potato (Wang and Xing, 2017), and it is reported that PRD outperforms DI when subjected to the same water regime. These findings suggest that PRD may offer a more efficient and effective approach to optimize water and nutrient management in agricultural practices in the future

CHAPTER THREE

MATERIALS AND METHODS

3.1. Experimental Setup and Design

3.1.1. Study Area

The experiment took place in a controlled environment (screen house) at the Savannah Agricultural Research Institute (SARI) of the Council of Scientific and Industrial Research in Nyankpala, located in the Northern region of Ghana. The research facility is situated at coordinates 9° 30’0“N latitude and 1°30’0“W longitude. Nyankpala is positioned approximately 20 kilometres southwest of Tamale in the Tolon-Kumbungu district of Northern Region, Ghana (Omane *et al*., 2020). The topology of the area of study is largely flat, and the soil type is sandy loam.

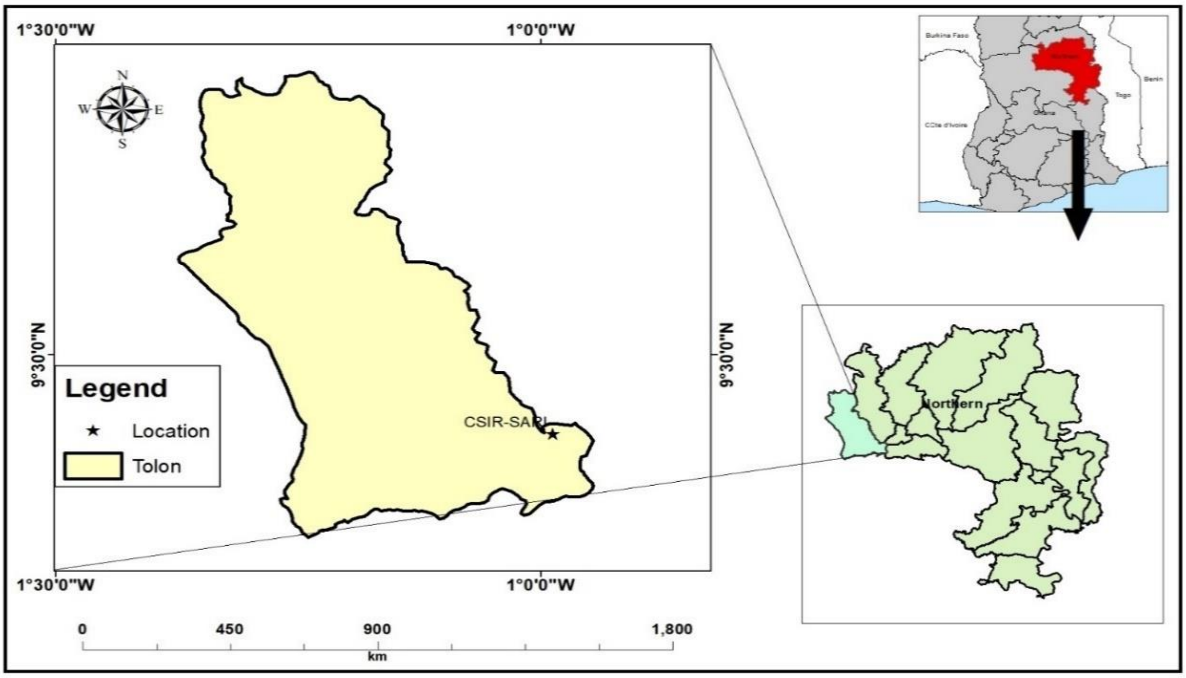

Figure 3.1. Geographical Map of The Study Location
Source: (Greenhouse experiment, 2023)

3.1.2. Climate of Northern Ghana

The Northern Region of Ghana stands as one of the driest area within the country, receiving an annual rainfall of approximately 1,000 mm (Ayitey *et al.,* 2021). This region has one of the highest average daily maximum temperatures within Ghana, reaching up to 34°C (Asante & Amuakwa-Mensah, 2015). The Northern region of Ghana experiences a single rainy season from May to September, with September being the month of highest precipitation. November stands out as the sunniest month, while August receives the least amount of sunshine. Additionally, January has the fewest rainy days. The climate of Nyankpala is tropical savanna and is characterized by distinct dry and wet seasons with consistently warm temperatures throughout the year.

3.1.3. Experimental Treatment Combinations

The experiment consists of 18 treatment combinations, which include three deficit irrigation (DI) techniques, three levels of water regimes (100%, 80%, and 60% ETc), and two levels of nitrogen (N) fertilizer. Among the water regimes, the first level corresponds to full irrigation (control) at 100% ETc, while the other two levels represent deficit irrigation treatments at 80% and 60% of full irrigation, respectively. The deficit irrigation strategies employed are Alternate Partial Rootzone Drying (A-PRD), Fixed Partial Rootzone Drying (F-PRD), and Conventional Deficit Irrigation (C-DI). The two levels of nitrogen (N) fertilizer were; N1 (3.2 g N/plant) and N2 (5.5 g N/plant). N2 represented an additional increase (excess) using urea (N) fertilizer over the standard fertigation recommendation for sweet corn (Bar-Yosef, 2020) , which was represented by N1. The compound fertilizer composition for N1 was equivalent to 3199 mg N/plant, 1221 mg P_2O_5/plant, and 5132 mg K_2O/plant. On the other hand, the composition for N2 was 5511 mg N/plant, 1221 mg P_2O_5/plant, and 5132 mg K_2O/plant.

Table 0.1. Treatment Combinations

		N-FERTILIZER	
DEFICIT STRATEGY	**IRRIGATION REGIME (ETc)**	**N1: Standard**	**N2: Excess**
A-PRD	100	A-PRD_{100}N1	A-PRD_{100}N2
	80	A-PRD_{80}N1	A-PRD_{80}N2
	60	A-PRD_{60}N1	A-PRD_{60}N2
F-PRD	100	F-PRD_{100}N1	F-PRD_{100}N2
	80	F-PRD_{80}N1	F-PRD_{80}N2
	60	F-PRD_{60}N1	F-PRD_{60}N2
C-DI	100	CI_{100}N1	CI_{100}N2
	80	C-DI_{80}N1	C-DI_{80}N2
	60	C-DI_{60}N1	C-DI_{60}N2

Source: (Greenhouse Experiment, 2023)

3.1.4. Study Design

The experiment was a 3 x 3 x 2 split plot design arranged in a randomized complete block design (RCBD) with three replications. A total of fifty-four (54) poly grow bags were used as experimental units. For each water regime, six (6) grow bags filled with soil were set up beneath a single drip line, receiving the same amount of water. The emitter spacing along the drips was 30 cm, while the inter-row drip space was 120 cm.

Figure 0.2. Experimental Study Layout
Source: (Greenhouse Experiment, 2023)

To mimic the partial separation of the rootzone, two (2) poly grow bags were joined together from the sides, and all the holes at the joined sides were sealed with waterproof tape to prevent movement of water across the poly grow bags. Each subpart of the grow bag was filled to the brim with 20 kg of dry soil. For the conventional deficit irrigation treatments, a single grow bag was used and also filled with 20 kg of dry soil. Seeds were planted 2 inches beneath the soil surface at the line of separation for the partial rootzone drying (PRD) and in the middle of the grow bag surface circumference for the conventional deficit irrigation method. The dimension of the grow bag was 28 cm height and a corresponding top and bottom diameter of 25.5 cm respectively.

Figure 0.3. Conjoined Grow Bag for The Partial Rootzone Drying
Source: (Greenhouse Experiment, 2023)

3.1.5. Experimental unit Drip System Testing

The existing drip system set up in the greenhouse encompasses various components, such as a water supply mechanism, a pressure pump for regulation, a system for injecting fertilizers, screen filters, a control head, main and sub-main lines for distribution, lateral lines, and the emitter drippers responsible for dispensing water. Prior to implementation, thorough testing was conducted to ensure the absence of leaks, pressure discrepancies, and to achieve uniform distribution throughout the system. Due to the small sample size of the experiment, irrigation was done through gravity flow, and on-line drippers made it easy to switch irrigation sides for the partial rootzone techniques.

3.2. Assessment of Soil Physiochemical Properties and Fertigation Plan

3.2.1. Soil Physical Characteristics

The physical characteristics of a composite sample of the soil that was used in the experiment were analysed. The sample soil was taken to the Department of Soil Science laboratory at the

University of Development Studies, Nyankpala Campus, Ghana. The following aspects of the soil's physical properties were studied: soil texture, initial moisture content, saturation point, bulk density, total available water, organic matter content, soil pH, porosity, and saturated hydraulic conductivity. Some information on the soil's physical properties was utilized as part of the decision tool to determine the crop water requirement.

3.2.2. Infiltration Test

The rate of infiltration, which reveals how quickly water penetrates the soil, was gauged by assessing the depth to which water seeped into the soil over an hour. This evaluation was carried out on a soil sample within a container using a mini-disc infiltrometer. The testing adhered to the guidelines outlined in the user manual for the miniature infiltrometer (METER Group Inc., 2020).

3.2.3. Soil Texture

The soil texture was determined using the hydrometer method for evaluating soil particle size distribution (Beretta *et al*., 2014). According to the USDA textural triangle (Moreno-Maroto and Alonso-Azcárate, 2022), the textural class was established, and the proper texture was determined based on the particle size distribution.

3.2.4. Bulk Density

The measurement of bulk density involved analysing intact soil samples directly in the field, where the uppermost layers of soil were gathered for examination. A core sampler was employed to collect soil at a depth of 0 - 20 cm. For determining the fraction of dry weight, the soil samples were subjected to a 24-hour period of oven-drying at 105°C until a consistent weight was achieved, after which they were weighed. The calculation of bulk density was performed by dividing the weight of the desiccated soil by the volume of the soil within the core sampler as shown in equation (3.1).

$$B_d(g/cm^3) = \left(\frac{M_S}{V_C}\right) \quad \text{Equation 3.1}$$

Where;

B_d = Bulk density

M_s = Dry weight of the soil (g)

V_c = Total volume of the soil contained within the core sampler (cm^3)

3.2.5. Field Capacity

For the assessment of field capacity, the soil specimen underwent a 24-hour saturation period. Following this, the fully saturated soil was drawn out using a pressure plate apparatus set at 0.33 bars (Parker, 2021).

3.2.6. Permanent Wilting Point

This measurement was established utilizing a specialized membrane apparatus. The procedure involved saturating a partially disturbed soil sample and situating it within a synthetic ring. Following a 24-hour saturation period, an overpressure of 15 bars was applied to the pressure membrane extractor through the compressor. Once equilibrium was attained, the samples were extracted, weighed (W1), and subsequently subjected to oven-drying at 105°C. After drying, the samples were weighed again (W2). The permanent wilting point was calculated as shown in equation (3.2) as;

$$PWP\ (\%) = W_1 - W_2 \quad \text{Equation 3.2}$$

Where;

PWP = Permanent wilting point

W_1 = Initial soil weight (g)

W_2 = Soil after after oven drying at 105 ^oC (g)

3.2.7. Soil Chemical Properties

Chemical analysis of the composite sample of the experimental soil was carried at the Council for Scientific and Industrial Research, Savannah Agricultural Research Institute (CSIRSARI), Nyanpkala's laboratory. The soil was tested for nitrogen (N), phosphorus (P), potassium (K), Calcium (Ca), Magnesium (Mg), Cation Exchange Capacity (CEC), pH, Electrical conductivity (EC), and organic carbon. The chemical characteristics of the soil was taken into account when calculating the fertilizer rate that was applied to the crop.

3.2.8. Irrigation Water Test

Water samples was analyzed for salinity and dissolved solids to determine their suitability for irrigation. The testing was conducted both prior to and following the experiment, utilizing the LAQUA testing device. In this process, collected water samples were carefully measured to 400 ml in a conical flask in the laboratory, after which the LAQUA EC Sensor Cartridge was immersed into the water. Readings were subsequently recorded after few minutes when the emoji sensor stabilized on the screen.

3.2.9. Fertigation Formulation

Soluble fertilizers, such as potassium nitrate, mono ammonium phosphate, and urea, were applied to the plants. The application rate recommended for sweet corn under drip irrigation, as adopted from Bar-Yosef, (2020), was utilized. The fertilizer rate, which was adopted was based on the recommendation for sweet corn, consisted of 240 kg N/ha, 91.61 kg P_2O_5, and 385.47 kg K_2O, was based on a plant density of 75,000 plants. To determine the required quantity of fertilizer (mg/plant) for each plant in a pot experiment, the volume of the grow bag was measured. This was achieved by sealing all the openings and filling it with water, enabling the calculation of the soil volume. Several factors were considered in this determination, including soil bulk density, height of the grow bag (soil depth), soil and water chemical properties, and the crop's salinity tolerance. The fertilizers were applied during irrigation, using a stock solution that was prepared by mixing the soluble fertilizers at a ratio of 1:200. Each plant received the stock solution independently, depending on the designated treatment levels. Phosphorus (P_2O_5) and potassium (K_2O) application remained consistent for all fertilizers, while the application of nitrogen (N) varied depending on the treatment level. The fertilizer solution was manually applied using a 0.75L water bottle, which was perforated once with a pin on the cap and had its base cut open. The bottle was then submerged into the soil with the cap facing downward. The fertilizer treatment commenced four weeks after planting (4 WAP) and continued every 2 to 3 days until the milking stage of the corn crop.

3.3. Determination of Crop Water Demand

To calculate how much water the crop will need throughout the growth season, the following estimates were made.

3.3.1. Crop Water Requirement

The calculation of reference ET_o was based on meteorological data spanning the years 1970 to 2021. This data encompassed variables such as maximum temperature (T_{max}), minimum temperature (T_{min}), relative humidity (RH), wind speed (measured at two meters above ground), and the duration of sunshine hours (hrs). Weather information was obtained from Savannah Agricultural Research Institute (SARI) weather station. This weather data was collected from the weather station at the study location, and was adopted due to lack of macro climatic data for the greenhouse, as suggested by Ilahi (2009). However, during the crop growth period, daily temperature and humidity readings were recorded with an HTC-1 LCD Digital

Thermometer Hygrometer device to monitor the temperature difference with the external environment.

ET_o was determined through the FAO Penman-Monteith method using the CROPWAT program (FAO, version 8.0). For sweet corn, crop coefficient (Kc) values were sourced from FAO Irrigation and Drainage Paper 56 (Allen *et al*., 1998). Essential crop data like root depth, critical depletion, yield response factor, crop height, and harvest index were used for calculating water requirements. An adjustment to the Kc initial value was made considering limited soil surface coverage by drip irrigation (Huanjie and Zhi, 2011), as shown in equation (3.3);

$$K_{c\ ini} = f_w * K_{c\ ini} \qquad \text{Equation 3.3}$$

Where;

fw = the fraction of surfaced wetted by irrigation or rain [0.4 for trickle irrigation],

Kc ini = the value for Kc ini of the crop.

The crop evapotranspiration (ET_c) was calculated as the product of ET_o and Kc, as shown in equation (3.4);

$$ET_c = ET_0 * K_c \qquad \text{Equation 3.4}$$

Where;

ET_c = crop evapotranspiration

ET_o = reference evapotranspiration (mm)

K_c = crop constant

In the context of localized (drip) irrigation, the adaptation of ET_c to ETcrop-loc for systems employing localized irrigation with a ground cover (Pd) of 95% is done following the formular (equation 3.5) presented by Keller & Bliesner (1990). Thus, the modified ET_c value was derived as:

$$T_d = U_d \times [0.1(P_d)^{0.5}] \qquad \text{Equation 3.5}$$

Where;

T_d = ETc-localized

ETc-localized = calculated ETcrop at peak demand for localized irrigation

U_d = conventional peak ETcrop estimate

P_d = percentage of ground cover (%)

3.3.2. Estimation of the Net Irrigation Requirement

The net irrigation water requirement (IRn) represents the amount of water necessary to achieve the maximum yield of an irrigated crop, beyond what is already available in the soil and any received precipitation (Bennett *et al*., 2014). This value excludes any irrigation water that is not utilized by the crops, such as water that percolates below the crop's root zone or runoff from the irrigated area. As shown in equation 3.6, the field balance equation, as described by Savva & Frenken, (2002), was utilized to calculate the net irrigation requirement:

$$IR_n = ET_c - (P_e + G_e + W_b) + LR \qquad \text{Equation 3.6}$$

Where;

IRn = Net irrigation requirement (mm)

ET_c = Crop evapotranspiration (mm)

P_e = Effective dependable rainfall (mm)

G_e = Contribution from groundwater based on the water (mm)

W_b = Initial soil water storage at the beginning of the period (mm)

LR= Amount needed for leaching (mm)

As no effective rainfall (Pe) or leaching (LR) was present, the calculated net irrigation requirement was termed the adjusted crop water requirement (ETc). It is important to mention that the net irrigation requirement (IRn) did not consider any losses that might have happened during water application. The computation of net irrigation was performed using a distinct formula:

$$IR_n = ET_c - P_e \qquad \text{Equation 3.7}$$

Where;

Pe = 0,

IRn = ETc-localized

3.3.3. Estimation of the Gross Irrigation Requirement

Water lost during delivery and application to the field is included in the overall amount required for irrigation (Savva and Frenken, 2002). Water losses that occurred during delivery and application in the field were accounted in the gross irrigation requirements. Because the drip method of application was used, the gross irrigation requirement was calculated using a 95% field application efficiency (Ea). The formula (equation 3.8) for gross irrigation requirement is calculated as;

$$IR_g = \frac{IR_n}{E_a} \qquad \text{Equation 3.8.}$$

Where;

IR_g = Gross irrigation requirement (mm)

IR_n = Net irrigation requirement (mm)

E_a = Field application efficiency (distribution uniformity, %)

3.4. Irrigation Scheduling

The following steps were used to compute the estimates to schedule the irrigation water.

3.4.1. Estimation of Available Water Content

The available water content is the difference between the field capacity (which is the highest amount of water that the soil can hold), and the wilting point, at which a plant can no longer draw water from the soil (Blaschek *et al.*, 2019). The formula (equation 3.9) for available water content is given as;

$$AWC = FC - PWP \qquad \text{Equation 3.9}$$

Where;

FC = Field Capacity

PWP = Permanent Wilting Point

3.4.2. Total Available Water in Soil

The TAW is the difference between the field's maximum water storage and its permanent wilting point. How much of this water is available for growth depends on the distribution of roots in the soil (Parish *et al*., 2017). The formular (equation 3.10) for calculating the TAW according to Halimi & Tefera, (2019) is given as;

$$TAW = \frac{(FC - PWP)}{100} \times BD \times DZ \qquad \text{Equation 3.10}$$

Where;

TAW = Total available water (mm/m)

FC = field capacity (%),

PWP = permanent wilting point (%),

BD = bulk density of the soil (gm cm^{-3})

Dz = maximum effective root zone depth (mm).

3.4.3. Readily Available Water in Soil

RAW is the term used to describe the amount of water that is constantly available to the plant. This is calculated according to the formula (equation 3.11) expressed by Halimi & Tefera, (2019);

$$RAW = p \times TAW \qquad \text{Equation 3.11}$$

Where;

RAW = Readily Available Water (mm/m)

P = critical soil moisture depletion (%),

TAW = total available water (mm/m).

To convert RAW into a volume measurement, it was multiplied by the surface area of the grow bag, calculated as:

$$RAW_{(litres)} = RAW_{(mm)} \times \text{surface area}_{m^2} \times 1000 \qquad \text{Equation 3.12}$$

3.4.4. Estimation of the Maximum Irrigation Interval (days)

This is the lengthiest time frame possible before the next irrigation is required. As shown in equation 3.13, the maximum irrigation interval was computed as;

$$ID = \frac{RAW}{IR_n} \qquad \text{Equation 3.13}$$

ID = Maximum irrigation interval (days)

RAW = The readily available water (litres)

IR_n = The net irrigation requirement in (l/day).

3.4.5. Estimation of the Irrigation Run Time (hours)

This refers to the estimated duration for irrigation, calculated in hours. It considers factors such as the crop water requirements, soil moisture levels, and system efficiency to ensure optimal watering for healthy plant growth. The estimated irrigation run time as shown in equation 3.14 was expressed as;

$$T_a = \frac{IR_g}{Q} \qquad \text{Equation 3.14}$$

Where;

T_a = Irrigation run time (hours),

IR_g = The gross irrigation requirement (l),

Q = Emitter discharge (l/h),

The estimated irrigation run time for deficit irrigation regimes, specifically 80% ETc and 60% ETc, was estimated based on interpolation from the full irrigation requirement (100% ETc).

3.4.6. Distribution Uniformity Test

In order to assess the water flow recorded at specific time intervals, a distribution uniformity test was conducted to evaluate the distribution pattern. Randomly placed catch cans were positioned along the drip lines within the experimental unit, and the collected water volume was measured over time. Each drip line had a catch can placed beneath it, and the flow rate per unit time was recorded. The recorded values were then arranged in descending order. As illustrated in equation 3.15, the distribution uniformity test was performed by calculating the average of the lower quarter of values and all values, using the following formula;

$$DU\ (\%) = 100 \times \left(\frac{\text{Average catch in lower quarter}}{\text{Average catch Total}}\right) \qquad \text{Equation 3.15}$$

A distribution uniformity exceeding 80% is considered excellent, as defined by Prinn (2006).

3.5. Determination of Growth Parameter

3.5.1. Plant Height

Plant growth data collection started at 7 weeks after planting (WAP) and continued weekly until the milking stage at 10 WAP. Measurements were taken at 7, 8. 9 and 10 WAP at vegetative and reproductive stages. Plant height was taken with a measuring tape. The height was determined by measuring from the soil's surface to the top of the arch formed by the topmost leaf, whose tip is pointing downward. The length from the ground to the tassel was measured at tasselling stage.

3.5.2. Leaf Number

Leave number was counted at the point of nodes from the stem to upper part of the plant. The more the number of nodes, the more the number of leaves and consequently, the more photosynthesis activity takes place.

3.5.3. Leaf Area

Determination of leaf area was done with the model developed by Montgomery (1911), which was further modified and suggested as the most appropriate for calculating the whole corn plant's leaf area, using a direct method (Butnan & Toomsan, 2019). The formula as illustrated in equation 3.16 is given as;

$$LA\ (cm^2) = (W_{lat} \times L_{lat} \times 0.75)_n \qquad \text{Equation 3.16}$$

Where;

LA = Leaf area (cm^2)

Wlat = the maximum width of the latest expanded leaf

Llat = the length from base to tip of the latest expanded leaf

0.75 is the correction factor for corn

n = number of all expanded leaves

3.5.4. Leaf area index

The non-destructive direct method used for calculating leaf area was employed for the LAI parameter. The formula for LAI is given as;

$$LAI = \left(\frac{\text{leaf area per plant (cm)}}{\text{ground area (cm)}}\right) = \left(\frac{L \times W \times 0.75}{(\text{intra spacing} \times \text{inter spacing})}\right) \qquad \text{Equation 3.17}$$

Where;

LAI = Leaf area index (cm^2cm^2)

L = the length from base to tip of the latest expanded leaf

W = the maximum width of the latest expanded leaf

0.75 is the correction factor for corn

3.5.5. Chlorophyll content

The chlorophyll content was measured at 7, 9 and 10 weeks after planting (WAP), using a PhotosynQ MultispeQ V 2.0 device. The measurements were taken on the leaves which were marked for identification. and an average value recorded for each plant.

3.6. Determination of Yield Parameter

3.6.1. Kernel Weight

Plants per unit area, ears (cob) per plant, rows per ear, kernels per row, and kernel weight are the five variables that can be measured to determine corn yield (Mark and Zachary, 2023). According to the information on Grain SA article, (2016), the calculation for determining the corn yield as provided in equation 3.18, 3.19, 3.20 and 3.21;

$$\text{Corn yield} = \frac{(\text{plant per unit area})\times(\text{ear per plant})\times(\text{kernal weight})}{1000} \qquad \text{Equation 3.18}$$

$$\text{Plant per unit area} = \text{cob per 10 meter} \times \left(\frac{100\ (\text{m})}{\text{inter row spacing}\ (\text{m}^2)} \times 100\ (\text{m})\right) \qquad \text{Equation 3.19}$$

$$\text{Kernal weight}\ (g) = (\text{rows per ear} \times \text{kernels per row}) \times 0.28\ \text{g} \qquad \text{Equation 3.20}$$

Since the corn was cultivated in pots, the observation of ears per plant and plants per unit area was the same. So, the yield per pot was calculated with the formula;

$$\text{Yield}\ \ (\text{g/plant}) = \text{kernal weight} \qquad \text{Equation 3.21}$$

3.6.2. Fresh and dry biomass

After harvesting and at the end of the experiment, each sampled plant was uprooted and the biomass in terms of fresh and dry weight taken. When the plant was uprooted, the shoot and roots (shaken off from the sand) were separated and weighed to determine the fresh weight. Thereafter, they were taken to the oven and dried initially at 105 °C for 30 min to inactivate plant enzymes, and further dried at 60 °C to achieve constant mass, and obtain the dry weight (Fengbei *et al.*, 2017).

3.6.3. Water productivity (WP)

Water productivity was computed based on the fresh kernel yield and total biomass, as depicted in equations 3.22 and 3.23 below;

$$\text{WP in yield potential}_{\text{WPy}}\ (\text{kg/m}^3) = \frac{\text{yield}}{\text{total water consumption (TWC)}} \qquad \text{Equation 3.22}$$

$$\text{WP in biomass potential}_{\text{WPyp}}(\text{kg/m}^3) = \frac{\text{shoot dry mass} + \text{root dry mass}}{\text{total water consumption (TWC)}} \qquad \text{Equation 3.23}$$

3.7. Determination of Nitrogen Uptake, and Use Efficiency

3.7.1. Nitrogen concentration (on dry mass basis)

After the final dry weight was taken, each dry sample of the root and shoot was grinded and digestated with H_2SO_4/H_2O_2 and analyse using the Kjeldahl method (Sáez-Plaza *et al.*, 2013) to determine the N content. The differences in N absorption from the various root zones was assessed independently for each sub-part. However, to obtain the total value for the sample root, the composite value was added together.

3.7.2. N – uptake

The nitrate (N) uptake was derived from the product of N content and the sample dry weight. As illustrated in equation 3.24, 3.25, 3.26 and 3.27, the following formula was used to calculate the N-uptake parameters;

$$\text{N} - \text{uptake} = \text{N grain concentration (\% N)} \times \text{dry mass (g/plant)} \qquad \text{Equation 3.24}$$

$$\text{Root N uptake (mg/plant)} = \text{root N content} \times \text{root dry mass} \qquad \text{Equation 3.25}$$

$$\text{Shoot N uptake (mg/plant)} = \text{shoot N content} \times \text{shoot dry mass} \qquad \text{Equation 3.26}$$

$$\text{Total N uptake (mg N/plant)} = \text{root N uptake} + \text{shoot N uptake} \qquad \text{Equation 3.27}$$

3.7.3. Nitrogen Use Efficiency

Nitrogen use efficiency parameter (g dry mass per mg N) was derived from the summation of the plant biomass divided by the total N uptake as;

$$\text{NUE (g/mg)} = \left(\frac{\text{shoot dry weight} + \text{root dry weight}}{\text{Total N uptake}}\right) \quad \text{Equation 3.28}$$

3.8. Statistical analyses

General analyses of variance (ANOVA) for split plot design were used to analyse all the data sets. The mean values of the treatments were compared for significant difference at 5% level using the least significant different (LSD) on GENSTAT statistical package. Significant treatments means were further separated using Duncan Multiple Comparison on GENSTAT software.

CHAPTER FOUR

RESULTS AND DISCUSION

4.1. Crop Water Requirement

4.1.1. Long Term Weather Data From CSIR-SARI

In calculating the crop water requirements using the CROPWAT 8.0 model, the process involved utilizing monthly average climate parameters which included minimum and maximum temperatures, relative humidity, wind speed, sunshine hours, radiation, reference evapotranspiration, and rainfall. These parameters spanned a timeframe extending from 1970 to 2021. The meteorological data utilized in this analysis was collected from the Council for Scientific and Industrial Research-Savannah Agriculture Research Institute (CSIR-SARI), situated at the experimental site.

From the meteorological information (Appendix T1), the hottest months are from January to May, with temperatures ranging between 19.3°C and 37.8°C, while the cooler months fall between June and December, with temperatures ranging from 22.7°C to 26.1°C. Additionally, the lowest relative humidity occurs from January to March (24.7% to 33.9%), and the highest relative humidity is observed from June to September (63.9% to 71.5%). Wind speed remains relatively consistent throughout the year, ranging from 1.6 m/s to 2.9 m/s, while solar radiation shows minimal variation, with values between 12.8 MJ/m^2/day and 17.4 MJ/m^2/day. On average, the daily sunshine duration ranges from 3.4 hours to 6.6 hours, and the driest months are January to April (0.1 mm to 2.4 mm) compared to the wetter months between May and October (3.3 mm to 7.0 mm).

4.1.2. Crop Water Requirement

The crop water requirement, calculated using CROPWAT 8.0, indicateded a net irrigation requirement of 325.6mm for the crop growing season (Appendix T2). The table presents crop water requirements for different months and stages of development for the sweet corn production. The information includes crop coefficients (Kc) and crop water requirements (ETc) in millimetres per day. The highest ETc of 5.48 mm/day occurs in June during the mid-stage, while the lowest ETc of 2.15 mm/day is observed in April during the initial stage. The stage with the highest Kc is the mid-stage in June, where it reaches 1.13. Additionally, during May (Decade 3) in the mid-stage, the crop receives the highest water requirement of 57.8 mm/dec. The total water requirement for the entire period covered is 325.6 mm. Depending on the duration of the growing season, the water requirement for sweet corn can fall within the calculated range (Zima, 2023).

4.1.3. Total Crop Water Requirement Applied for Various Water Regime

The total net irrigation water applied for the 100%, 80%, and 60% water regimes are 325.6 mm, 260.5 mm, and 195.4 mm, respectively. When using a 100% water regime, which represents full irrigation, sweet corn receives 325.6 mm of water throughout its growing season. Under the 80% water regime, considered mild stress, the water application is reduced to 260.5 mm, indicating a slightly limited water supply. Lastly, the 60% water regime, representing severe stress, provides the lowest amount of water at 195.4 mm, signifying significant water scarcity and considerable stress on the sweet corn crop.

Table 4.1. Total Net Irrigation Water

Month	Kc Coeff	ETo mm/day	100 % ETc mm/dec	80 % ETc mm/dec	60 % ETc mm/dec
Apr	0.38	5.95	6.8	5.4	4.08
Apr	0.38	5.95	21.5	17.2	12.9
May	0.40	5.07	21.6	17.3	13.0
May	0.70	5.07	35.5	28.4	21.3
May	1.06	5.07	57.8	46.2	34.7
Jun	1.13	4.72	54.8	43.8	32.9
Jun	1.13	4.72	53.5	42.8	32.1
Jun	1.12	4.72	49.1	39.3	29.5
Jul	1.03	3.71	25.0	20.0	15.0
TOTAL			325.6	260.5	195.4

Source: (Greenhouse Experiment, 2023)

4.1.4. Distribution Uniformity Test for the Drip System

To assess Distribution Uniformity (DU), 24 Catch cans were randomly placed along drip lines. Three replications were conducted, resulting in DU values of 87%, 90%, and 88% sequentially. Drip irrigation systems with DU levels of 85% to 95% are deemed suitable (Zellman, 2016).

Table 4.2. Distribution Uniformity Value

Replication	DU (%)	Qa (l/h)
1	87	6.0
2	90	5.7
3	88	4.9

DU = Distribution uniformity, Qa = average discharge rate of all observations.
Source: (Greenhouse experiment, 2023)

Figure 4.1. Performance of Distribution Uniformity Test
Source: (Greenhouse Experiment, 2023)

4.1.5. Greenhouse Temperature and Humidity

During the growing season for sweet corn inside the greenhouse, daily temperature and relative humidity measurements were recorded. The highest mean temperature observed was 39.6°C, and the lowest mean temperature recorded was 28.2°C. Similarly, the highest mean relative humidity observed was 73.4%, while the lowest mean relative humidity was 42%. The ideal temperature range for the optimal growth of sweet corn lies between 30.8°C to 33.8°C (Olsen et al., 1993; Dhaliwal & Williams, 2022). Sweet corn is a warm-season crop, and its growth and development are favoured by higher temperatures (Bullock *et al.*, 2012). However, the highest mean temperature of 39.6°C could potentially create unfavourable conditions for its growth, induce stress on the plants, affecting pollination and kernel development. The higher temperature recorded inside the greenhouse, may have possibly affects the growth and yield of the corn. Therefore, the plant data collected in this experiment reflects a possible distortion of the environmental condition due to the high temperature.

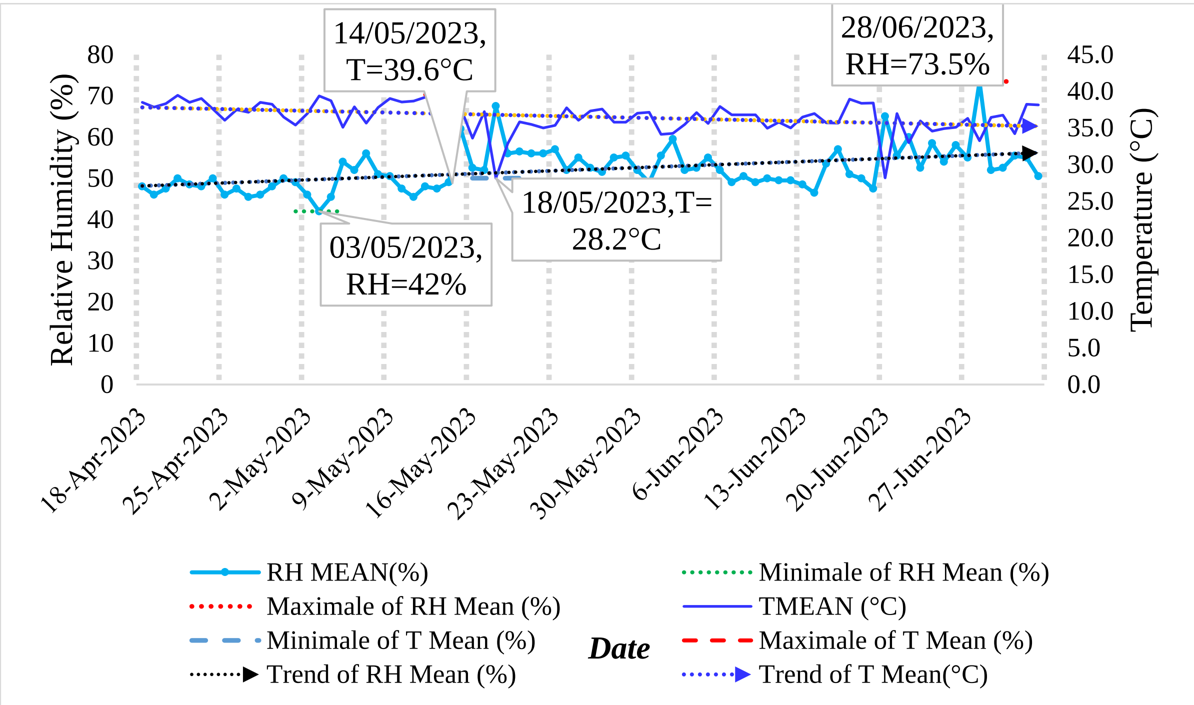

Figure 4.2. Temperature and Relative Humidity During Growth Period
Source: (Greenhouse Experiment, 2023)

4.2. Water and Soil Physiochemical Properties

4.2.1. Soil physical Properties

The study of composite soil samples revealed important physical traits. The experimental soil displayed a sandy loam texture, with a slightly acidic pH. Notably, the soil exhibited high bulk density, indicative of its compactness.

Table 4.3. Soil Physical Properties

SOIL	Sand	Clay	Silt	Texture	Gravel >2mm	PWP	FC	pH	Bd
	%	%	%		%	%	%	(1:2:5 H_20)	(g/cm^3)
	57.64	16.4	25.96	Sandy loam	48	8.4	20.3	5.8	1.63

PWP; Permanent wilting point, FC; Field capacity, pH; Potential of hydrogen, Bd; Bulk density
Source: (Greenhouse Experiment, 2023)

The soil physical properties indicate a favourable environment for cultivation. The soil is classified as Sandy loam, containing 57.64% sand, 16.4% clay, and 25.96% silt. This balanced texture allows for good water drainage while retaining enough moisture for plant growth (Ball, 2013). The presence of 48% gravel with particles larger than 2mm may contribute to enhanced soil structure and improved water movement (Zhang *et al*., 2022). The PWP at 8.4% and FC at 20.3% highlight the soil ability to hold water and provide adequate moisture for plant roots, ensuring favourable growing conditions. The soil pH level (5.8) falls within an acceptable range for sweet corn cultivation, and may influence nutrient availability (Hartemink & Barrow, 2023). With a bulk density of 1.63 g/cm^3, the soil appears to have moderate compaction, promoting proper aeration for root development.

4.2.2. Soil Infiltration Rate

The mini disk infiltrometer results indicate an initial infiltration rate (C1) of 0.052265922 cm/s, highlighting the rapid water entry into dry soil. The saturated hydraulic conductivity (K) is 0.013367539 cm/s, representing the soil's water transmission capacity when saturated. The cumulative infiltration against the square root of time graph shows a quadratic relationship ($y = 0.0373x^2 - 0.0528x$) with a high R-square value of 0.9965, indicating a strong fit. This signifies that cumulative infiltration increases initially but levels off due to soil factors like structure and porosity.

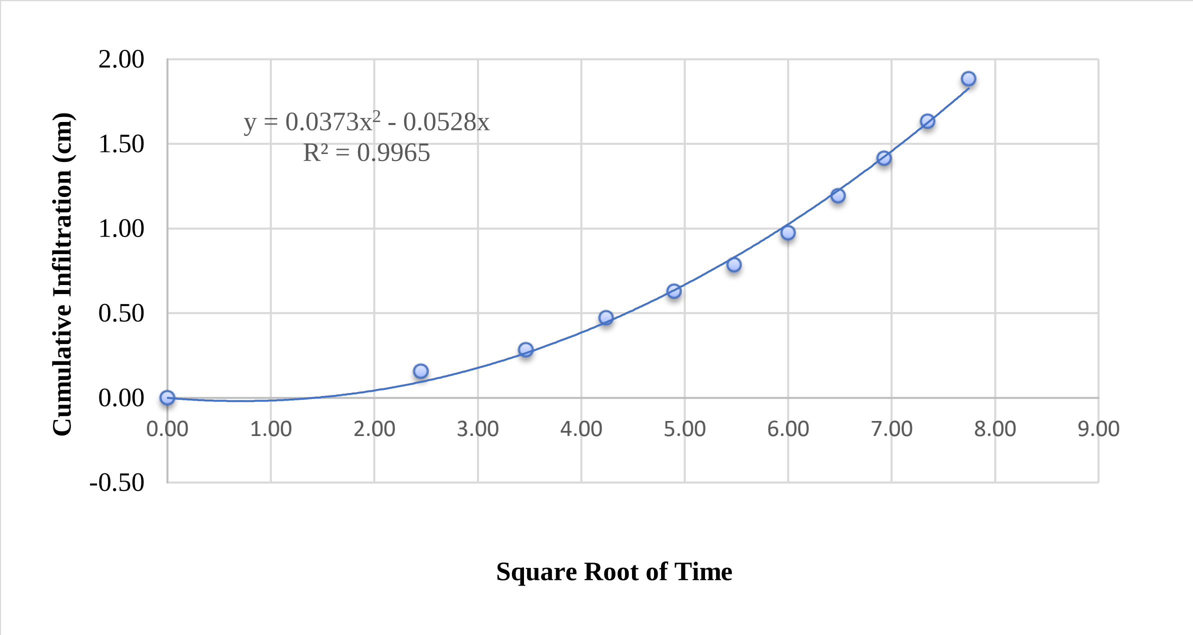

Figure 4.3. Soil Cumulative Infiltration
Source: (Greenhouse Experiment, 2023)

4.2.3. Soil Chemical Properties

The soil pH of 5.9 indicates a slightly acidic (Table 4.5). This falls within an acceptable range for crops. The nitrate nitrogen concentration ($NO^{3-}N$) in the soil is 14.9 mg/kg, indicating a moderate (caution) level for supporting plant growth (Pattison *et al.,* 2010). The ammonium nitrogen ($NH4^{+-}N$) concentration of 27.87 mg/kg falls within a moderate range, providing a usable nitrogen source for plants. The available phosphorus (Bray 1 P) concentration is 47.87 mg/kg, indicating a relatively high phosphorus supply for plant growth (Marx *et al*., 1999). Adequate phosphorus is essential for strong root development and overall plant health (Gupta *et al*., 2014). The level of potassium (0.305 mg/kg) is low. Calcium (7.4 Cmol/kg), and magnesium (4.3 mg/kg) appear to be within a moderate range, providing essential macronutrients for plants. The organic carbon content (0.703%) is also found to be low. The electrical conductivity of the soil is 0.91 µS/cm, which indicates low salinity level.

4.2.4. Water Quality

Results of the water analysis, indicate the mean pH value of 7.84, indicating a slightly alkaline pH. The electrical conductivity (EC) of the water is 14.9 µS/cm, assisting in determining its total dissolved solids (TDS) and salinity level. The water shows a salinity level of 0.01, indicating a low concentration of salts, making it suitable for irrigation purposes. Additionally, the water contains 7.45 mg/l of total dissolved solids (TDS), representing the sum of all inorganic and organic substances dissolved in the water.

Figure 4.4. Water Quality Test in the Laboratory
Source: (Laboratory studies, 2023)

Table 4.4. Soil and Water Chemical Properties

SOIL				
pH (1:2.5 H_2O)	NO^{3-} N (mg/kg)	NH_4^{+-} N (mg/kg)	Bray 1 P	K (mg/kg)
5.83	14.9	27.87	47.87	0.305
Ca (Cmol/kg)	Mg (mg/kg)	O.C	EC (µS/cm/)	
7.4	4.3	0.703	0.91	
WATER				
pH	EC (µS/cm)	Salinity (µS/cm)	TDS (mg/l)	
7.84	14.9	0.01	7.55	

NO^{3-} N; Nitrate nitrogen, NH_4^{+-} N; Ammonium nitrogen, EC; Electrical conductivity, OC; Organic carbon, P; phosphorus, K; Potassium, Ca; Calcium, Mg; Magnesium, TDS; Total dissolvable solids.
Source: (Greenhouse Experiment, 2023)

4.2.5. Fertilizer Application

The fertigation plan was developed by taking into account the soil's chemical properties and the specific nutrient requirements of the crop. This careful process resulted in the determination of the precise amount of net nutrients that need to be applied to the crop (Appendix T3). The fertigation plan incorporated the use of the following soluble fertilizers based on the adopted application: monoammonium phosphate (MAP) (12-61-0) containing 12% nitrogen and 60% phosphorus, potassium nitrate (KNO^3) containing 12% nitrogen and 46% potassium oxide, and urea fertilizer with 46% nitrogen content.

4.3. Plant Growth Parameters

Figure 4.5. Leaf Chlorophyll Measurement with PhotosynQ MultispeQ
Source: (Greenhouse Experiment, 2023)

4.3.1. Plant Height

The results revealed that main effects of irrigation techniques had a significant effect ($p < 0.05$) on plant height throughout these observation periods (Appendix T4). Among the irrigation techniques, C-DI resulted in significantly higher plant height ($p < 0.05$) compared to F-PRD across all observed periods. This suggests that C-DI ability to ensure uniform water supply across the rootzone possibly led to better growth conditions, enhancing water and nutrient uptake. Similar plant height between C-DI and A-PRD during the observed weeks implies comparable growth effects from both techniques. This aligns with previous research on maize by Hakeem *et al.* (2016), who reported that conventional irrigation (CI) resulted in the highest plant height, followed by A-PRD, which exhibited statistically similar effects, while F-PRD significantly led to the lowest plant height when compared to the two aforementioned techniques. Similarly, Gebreigziabher (2020) reported that conventional furrow irrigation produced the highest plant height for maize compared to fixed furrow irrigation.

Furthermore, the plant height of the irrigated crops exhibited significant variation based on the level of water supplied (Appendix T4). Plants irrigated at the full crop water requirement (100% ETc) demonstrated the tallest height in comparison to those subjected to mild (80% ETc) and severe deficit (60% ETc) water conditions. Across all the observed weeks, the plant height recorded under severe deficit irrigation consistently remained the lowest, displaying markedly lower values ($p < 0.05$) compared to the height observed under full irrigation. In a study by Darko *et al*. (2019) on eggplants, significant differences in plant height were observed under mild stress at 80% and 70% ETc compared to full irrigation. Conversely, Cheng *et al*. (2021) reported in their previous research on maize that plant height was highest under full irrigation compared to deficit irrigation, corroborating the findings of the current study. However, their study found no significant difference in maize height under different water regimes, implying that certain crop types may respond differently to varying water availability.

Fertilizer rate at 5.5 g N/plant (N2) resulted in lower plant height compared to the standard nitrogen rate at 3.2 g N/plant (N1). However, the difference in plant height between the two fertilizer treatments was not statistically significant (Appendix T4).

The interaction effects among the treatments showed a significant influence on plant height only at 7 WAP (Figure 4.6). During this stage, interaction of CI+100% ETc +N1 resulted in the tallest plants ($p < 0.05$) compared to the management practice of F-PRD+60% ETc+N1. However, in the other observed periods, the treatment interactions did not significantly influence plant height (Appendix T4). The observed differences only at 7 WAP might be attributed to other growth factors.

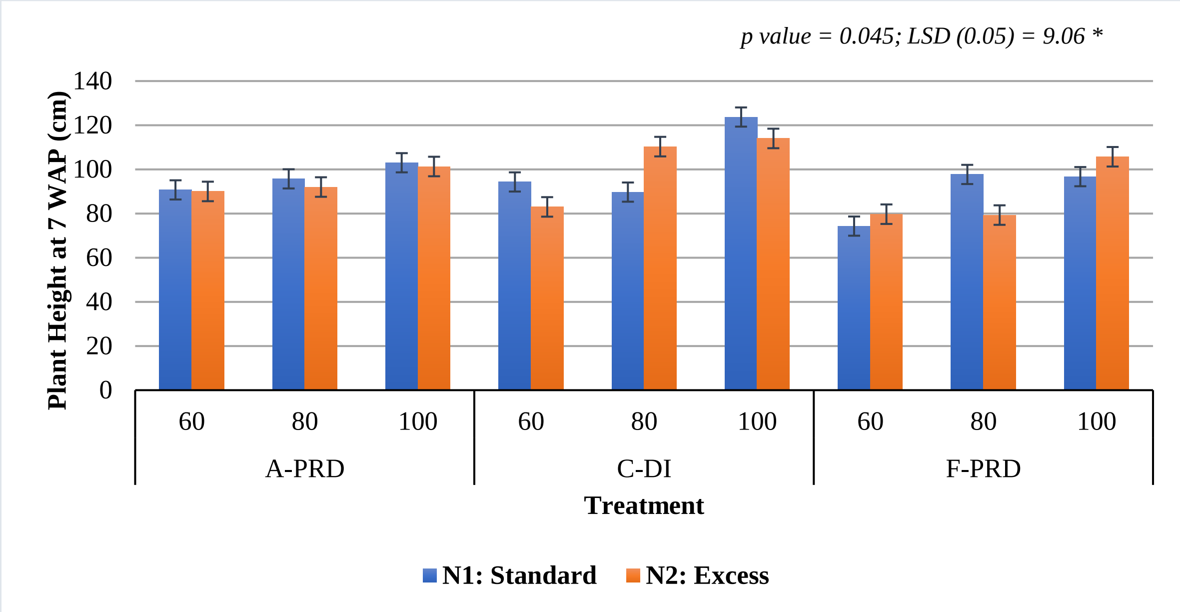

Figure 4.6. Treatment Effect on Plant Height
Source: (Greenhouse Experiment, 2023)

4.3.2. Number of Leaves Per Plant

Leaf count and their strategic placement are vital elements that decisively contribute to shaping the intricate plant architecture observed in corn (Li *et al*., 2016). Plant leaf number remained relatively the same across the main treatments of irrigation techniques (C-DI, A-PRD, F-PRD) during all observed periods (Appendix T5). The lack of significant differences suggests comparable effectiveness in maintaining leaf numbers, possibly due to genetic factors playing a prominent role. Water regime significantly influenced leaf number at 7, 9, and 10 weeks WAP (Figure 4.6). At 7 WAP, crops under mild irrigation (100% ETc) exhibited the highest leaf number ($p < 0.05$) compared to those under severe deficit irrigation (60% ETc). Similarly, at 9 and 10 WAP, leaf number was highest for crops under full irrigation in contrast to sweet corn plants facing severe water deficit.

Water stress exerts an influence over the leaf number per plant (Anjum *et al*., 2011). The observation from the present study aligns with the findings of Enchalew *et al.* (2016) on onion. They emphasized that the number of leaves per plant is significantly affected by deficit irrigation, with an increase in irrigation water supply leading to an increase in the number of leaves. It is crucial to acknowledge that the impact of deficit irrigation on leaf number can differ based on crop type and the severity of the deficit treatment. Abdelmula and Sabiel, (2007) suggested that vegetative characteristics like leaf count are primarily determined by genetic factors rather than drought, implying that environmental conditions might have a limited influence on this trait.

Furthermore, leaf number across all the observed periods was similar for N1 and N2 application rates (Appendix T5). Excess nitrogen application did not significantly increase leaf count, suggesting the plant's nitrogen needs were already met by the standard dose.

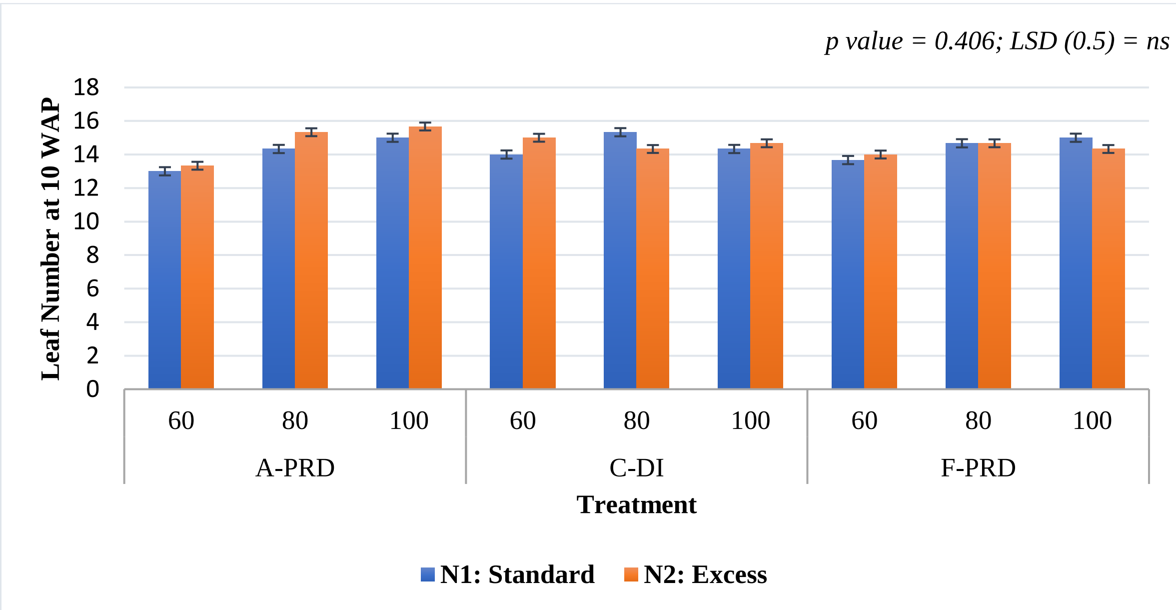

Figure 4.7. Treatment Effect on Leaf Number
Source: (Greenhouse Experiment, 2023)

Among the examined treatment interactions, leaf number was not statistically influenced. At the final observation week (10WAP), leaf number was highest ($p > 0.05$) with the interaction of A-PRD+100% ETc+N1, and lowest with A-PRD+60% ETc+N1 (Figure 4.7).

4.3.3. Leaf Area and Leaf Area Index

Leaf area index (LAI) represents the proportion of leaf area in relation to the ground area, serving as a valuable gauge for gauging crop development and soil circumstances to improve agricultural yield (Anjum *et al*., 2017). This fundamental physiological metric provides insight into the extent of crop assimilation in field conditions. Leaf area and LAI was influenced by irrigation techniques at 7 and 8 WAP across the observation period (Appendix T6 and T7). LA and LAI were highest ($p < 0.05$) under C-DI compared to A-PRD and F-PRD which had the lowest LA and LAI. Both parameters remained statistically the same for all the irrigation techniques at 9 and 10 WAP. This finding aligns with the prior investigation on corn conducted by Barideh *et al.* (2018), who noted that conventional irrigation (CI) yielded the highest leaf area index (LAI), while F-PRD resulted in the lowest, and A-PRD outperformed F-PRD. Similar observation was made for leaf area on maize (Wang *et al*. 2008). On the other hand, Cheng *et al*. (2021) reported non influence of irrigation technique on leaf area in maize.

Furthermore, water regime significantly influenced both LA and LAI in all the observed period (Appendix T6 and T7). Sweet corn plants exhibited the highest LA and LAI when subjected to full (100% ETc) and mild (80% ETc) irrigation at 7 WAP, whereas severe deficit irrigation (60% ETc) gave the lowest value. Additionally, at 8, 9 and 10 WAP, LA and LAI were highest under full irrigation while crops under sever irrigation produced the lowest leaf area index. This aligns with previous studies on maize (Alkhaldi *et al.*, 2012; Abbas *et al.*, 2019;Comas *et al.*, 2019). Contrary with the present study, Cheng *et al.* (2021) found no significant influence of water regimes on corn leaf area. In some studies, deficit irrigation resulted in a non-significant decrease in LAI (Abu-Grab *et al.,* 2019).

Leaf area and index was higher for N2 over N1 across all the observed weeks (Appendix T6 and T7). However, there was no significant different among the 2 levels. Higher nitrogen doses lead to increased leaf area (LA) and leaf area index (LAI) in corn, as nitrogen fosters leaf growth and development, leading to greater leaf coverage. However, excess application of nitrogen fertilizer over standard application does not significantly increases LAI. This aligns with Jaliya and Barwa, (2015), where application of 120 kg N/ha produced significantly higher LAI, but further increase to 180 kg N/ha did not affect the LAI.

The integration of irrigation techniques under various water regimes and nitrogen fertilizer application did not yield a significant effect on the LAI (Figure 4.8). At the crop maturity stage and final observation week (10 WAP), interaction of A-PRD+80% ETc+N2 gave highest LA and LAI. The lowest LA and LAI was observed with A-PRD+80% ETc+N1.

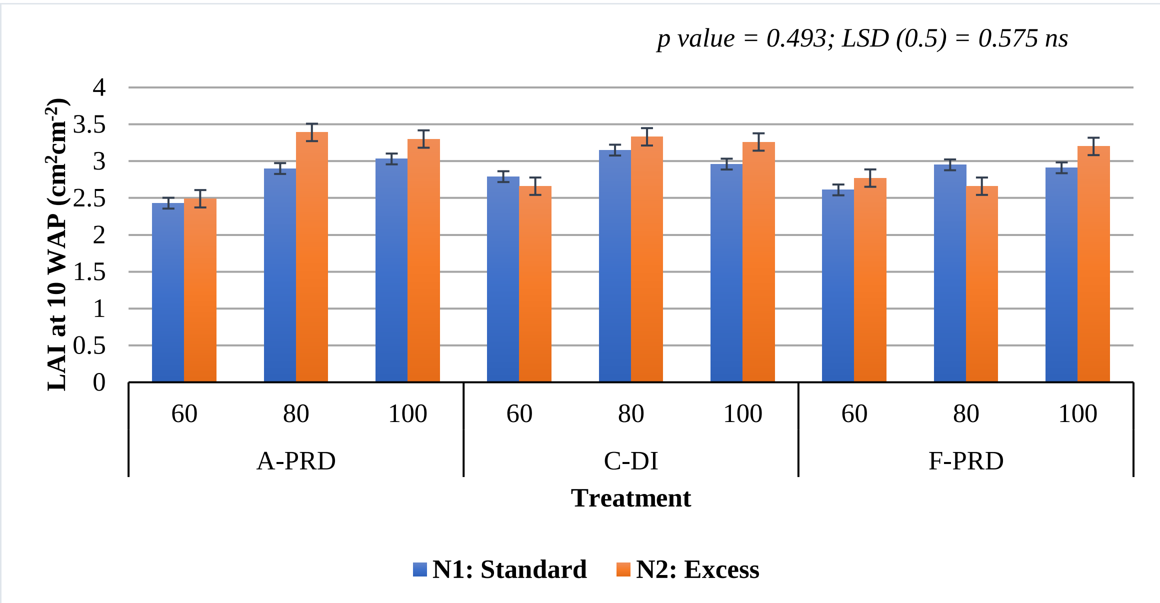

Figure 4.8. Treatment Effect on Leaf Area Index
Source: (Greenhouse Experiment, 2023)

4.3.4. Chlorophyll Content

Chlorophyll constitutes a significant part of the chloroplast elements crucial for photosynthesis, and there is a direct correlation between the amount of chlorophyll present and the rate of photosynthesis (Anjum *et al.*, 2011). The chlorophyll content of the plant was assessed at 7, 9, and 10 WAP (Appendix T8). The main effects of irrigation technique did not have any significant influence on the plant's chlorophyll content across all the observed weeks. This observation aligns with Zin El-Abedin *et al*. (2019), report that the chlorophyl content on potato leaves was similar for C-DI and PRD technique. Contrary to the present findings, Lin (2012) on naked oat, reported that APRI and FPRI, decreased leaf chlorophyll (SPAD) content compared to conventional irrigation (CI), and the leaf SPAD of A-PRD was significantly enhanced compared to that of F-PRD.

Across all the observed weeks, water regime only significantly influences the chlorophyll content at 10 WAP (Appendix T8). Crop ssubjected to mild deficit irrigation (80% ETc) exhibited significantly higher chlorophyll content compared to those under full irrigation (100% ETc) and severe deficit irrigation (60% ETc). Plants reaction to drought has been reported to be influenced by the length and intensity of the drought period, resulting in either a decrease or no change in chlorophyll levels (Anjum *et al*., 2011). In previous studies, (Khayatnezhad & Gholamin, 2012) when examining resistant corn cultivars in contrast to regular ones, a distinct chlorophyll pattern emerged during drought stress. The resistant cultivars exhibited a significant rise in chlorophyll content compared to the normal cultivars. This might explain why the chlorophyll content in this study was significantly higher (42.64 SPAD) for sweetcorn under mild deficit, compared to full irrigation with the lowest chlorophyll content (36.55 SPAD). Contrary to the present study, previous studies have reported that chlorophyll content (SPAD) is significantly reduced by deficit irrigation, as observed in sweet corn (Rou *et al*., 2017); maize (Ghahfarokhi *et al*., 2015).

There was no significant difference between the two nitrogen fertilizer levels on the chlorophyll content (Appendix T8). Despite the known role of nitrogen fertilizer in contributing to overall chlorophyll production in corn (Shashishekhar, *et al*., 2017; Nathan & Maricle, 2018), the application of excess nitrogen did not result in significantly higher chlorophyll content compared to the application of standard nitrogen levels. This suggests that there might be a threshold beyond which additional nitrogen does not continue to enhance chlorophyll production.

The Integration of irrigation and fertilizer management did not significantly influence the chlorophyl content at all the observed periods (Appendix T8). Nevertheless, at 10 WAP, the highest chlorophyll content (42.64 SPAD) was observed with A-PRD+80% Etc+N1 (Figure 4.8). Conversely, in the same observed week, the lowest chlorophyll content (24.41 SPAD) was recorded with treatment interaction of C-DI+60% ETc+N2. This suggests that specific combinations of irrigation techniques and nitrogen application at certain stages of growth can influence chlorophyll content. Although these effects were not statistically significant in the context of this study, it is apparent that the most favourable conditions for chlorophyll production might vary depending on these factors. The chlorophyll content in leaves is directly related to the plant ability to carry out photosynthesis efficiently, and this influence the overall growth and productivity if plant. In the context of leaf number, leaves that possess higher chlorophyll content demonstrate a heightened ability to conduct photosynthesis more effectively. Notably, our study revealed variations in both chlorophyll content and leaf number among all treatment groups at the 10 WAP (Figure 4.9).

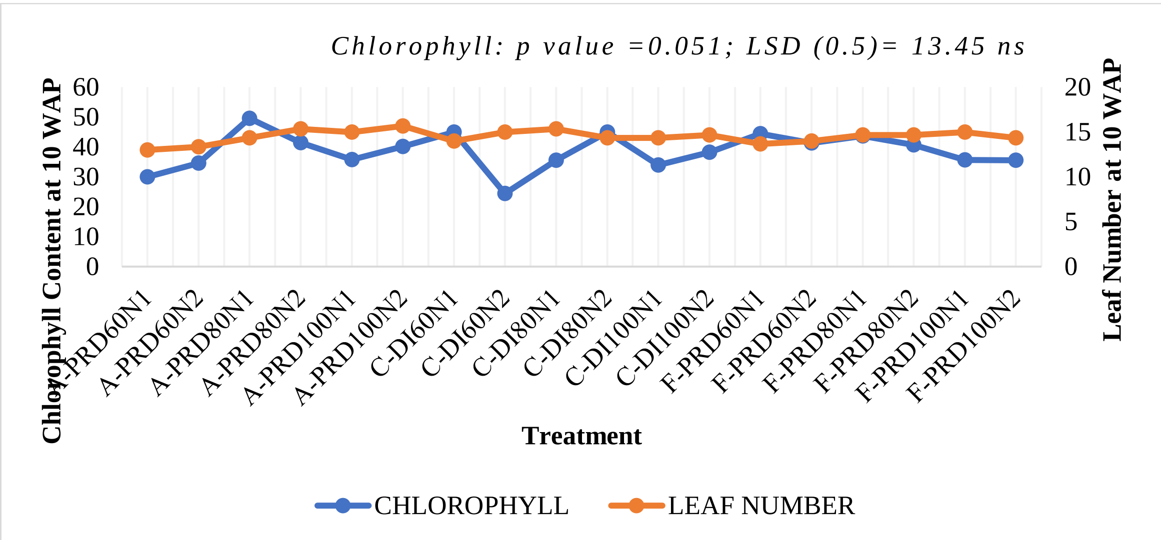

Figure 4.9. Treatment Effect on Leaf Chlorophyl Content
Source: (Greenhouse Experiment, 2023)

Figure 4.10. Fresh Yield at Harvest
(Greenhouse Experiment, 2023)

4.4. Fresh Yield Parameters

4.4.1. Shoot wet mass

The shoot wet mass was significantly influenced by irrigation technique at harvest (Appendix T9). Shoot wet mass was highest ($p < 0.05$) under C-DI (299.0 g/plant), followed by A-PRD (276.7 g/plant), while F-PRD gave the lowest shoot wet mass (239.5 g/plant). The percentage deductions of shoot wet mass for A-PRD and F-PRD in comparison to C-DI were 7.46% and 19.90%, respectively. The shoot wet mass for C-DI and A-PRD were statistically similar, and both irrigation techniques statistically outperformed the F-PRD. This result aligns with a study by Tabatabaei *et al.* (2017) that observed a similar pattern in maize. In that study, it was found that the shoot fresh weights for conventional deficit irrigation and partial rootzone drying were statistically the same. Cheng *et al.* (2021) similarly observed no significant difference between conventional irrigation and alternate partial rootzone drying

Furthermore, the shoot wet mass was significantly influenced by water regime at harvest (Appendix T9). Irrigation at full crop evapotranspiration (100% ETc) gave the highest ($p < 0.001$) shoot fresh mass (332.1 g/plant). Sweet corn plants subjected to severe deficit irrigation (60% ETc) resulted in the lowest shoot wet mass (203.2 g/plant). In comparison to the full irrigation scenario, the application of a water regime at mild stress (80% ETc) resulted in a reduction of the shoot wet mass by approximately 15.70%. Further reduction in water savings to a more severe deficit of 60% ETc led to a more pronounced decrease, causing the shoot wet mass to diminish by around 38.82%. The shoot wet mass recorded for both full irrigation and mild deficit are statistically the same. The present finding agrees with Cheng *et al*. (2021) who reported significant decrease in fresh leaf weight of maize with deficit irrigation. Similarly, Tabatabaei *et al.* (2017) reported that fresh corn shoot under full irrigation was significantly higher to deficit irrigation at 60% ETc. Higher shoot fresh mass in conditions of limited water availability presents a favourable attribute (Anjum *et al.*, 2011).

Excess nitrogen fertilizer (N2) beyond the standard amount (N1) had no significant impact on shoot wet mass, resulting in 279.0 and 264.5 (g/plant) for the respective nitrogen rates (appendix 6). A slight increase of 5.48% in shoot wet mass was observed with excess nitrogen application. The application of nitrogen fertilizer plays a crucial role in sustaining both optimal plant growth and bolstering defence mechanisms against various environmental stresses (Qi & Pan, 2022).

Integration of irrigation and fertilizer management did not significantly influence the shoot wet mass (Figure 4.11). Nevertheless, treatment CI+100% ETc+N2 gave the highest shoot wet mass (402.3 g/plant), while the lowest fresh shoot mass (163.7 g/plant) was obtained with F-

PRD+60% ETc+N2. Evaluating the performance of various deficit irrigation interactions compared to C1 + 100% ETc + N2 which gave the highest shoot wet mass value (402.3 g/plant); under mild stress (80% ETc) with N1 and N2 applications, the shoot wet mass decreased by 32.11% and 22.62% respectively for C-DI, 22.41% and 23.36% for A-PRD, and 41.18% and 40.74% for F-PRD. Furthermore, under severe stress (60% ETc) with N1 and N2 applications, the shoot wet mass reduced by 44.38% and 36.75% respectively for C-DI, 43.34% and 57.02% for A-PRD, and 56.16% and 59.35% for F-PRD. Thus, alternate partial rootzone drying exhibited a good potential in enhancing shoot wet mass under mild stress conditions. This current observation was also reported for maize (Tabatabaei *et al.*, 2017).

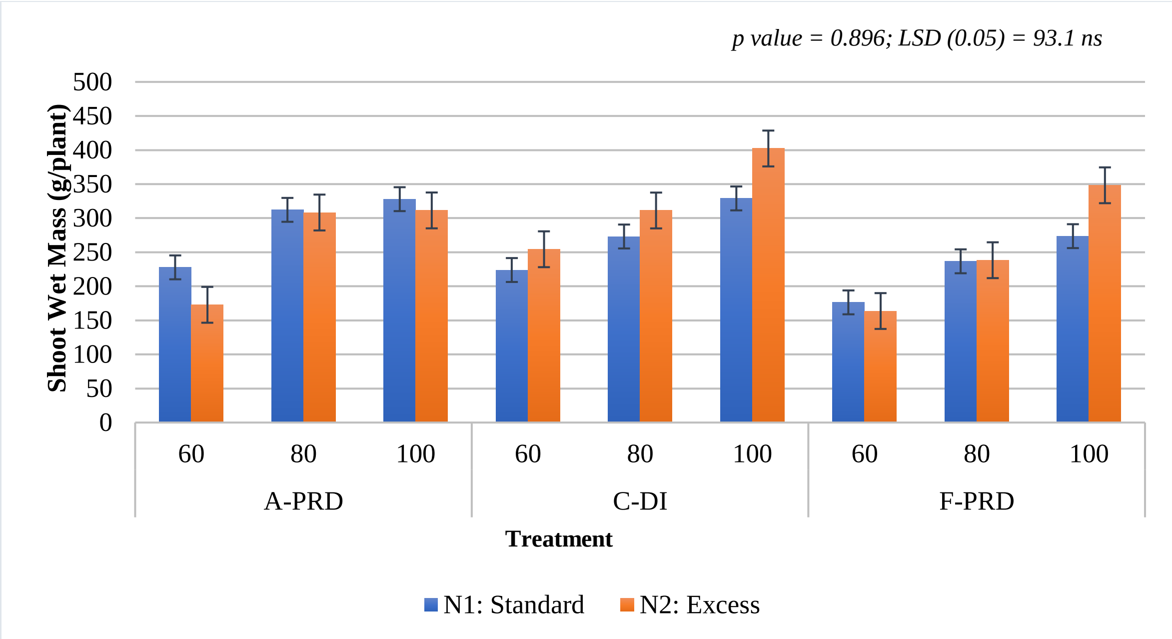

Figure 4.11. Treatment Effect on Shoot Wet Mass
Source: (Greenhouse Experiment, 2023)

4.4.2. Root Wet Mass

Roots serve as the plant's nutrient-absorbing system, responsible for creating and moving important substances. They are crucial for crop growth, influencing shoot development and crop yield (Chen *et al.*, 2020). The root wet mass was influenced by irrigation technique at harvest (appendix T2). Highest ($p < 0.05$) root wet mass was observed with the adoption of C-

DI (44.6 g/plant), and this was statistically the same for what was obtained with the use of A-PRD (42.3 g/plant). The root fresh mass was found to be the lowest using the F-PRD technique (28.2 g/plant). This resulted in a significant reduction of 36.73% and 33.33% in root fresh mass compared value observed under the C-DI and A-PRD techniques, respectively. The present observation aligns with previous report on sugar beet by Topak *et al.* (2016) who reported highest root weight with C-DI, followed by A-PRD and lowest with F-PRD. The development of roots are influenced by the way water is distributed in the soil over space and time (Sepaskhah & Ahmadi, 2010). In the case of C-DI, the uniform water supply across the root zone likely facilitated higher root weight due to consistent access to water. For A-PRD, controlled stress resulting from alternating wetting and drying may have encouraged root exploration, leading to a moderate root weight. Meanwhile, in the context of F-PRD, the lowest root weight could be attributed to continuous stress on the dry side, potentially restricting root elongation.

Additionally, the root fresh mass was influenced by water regime at harvest (Appendix T9). Irrigating at full crop evapotranspiration significantly ($p < 0.001$) gave the highest root fresh mass (55.4 g/plant) as compared to what was obtained under mild (80% ETc) and severe (60% ETc) deficit (29.2 and 30.5 g/plant) respectively. The root fresh mass reduction due to 80% ETc and 60% ETc deficit irrigations, in comparison to full irrigation, amounted to 47.22% and 45.06% respectively. The observation in this present study aligns with some previous report on sugar beet (Topak *et al.*, 2016); and hot pepper (Ahmed *et al.*, 2014); where an increase in deficit irrigation led to a significant decrease in root fresh weight. On the other hand, root growth can be sustained even when exposed to conditions of water scarcity (Kang *et al.*, 2021). Contrary to the present observation where root fresh mass was lowest under mild deficit, Maurel and Nacry (2020) asserted that moderate reduction in water stress promotes the growth of main roots and the development of lateral roots, whereas severe water scarcity has the opposite effect, leading to inhibitory outcomes.

Furthermore, nitrogen fertilizer application did not influence the root fresh weight (appendix T6). Excess nitrogen application increased the root fresh weigh by 15.45% when compared to standard nitrogen fertilizer application. However, there was no significant difference between them. Increasing nitrogen fertilizer improves root yield (Relente & Asio, 2020).

Figure 4.12. Root Development in Conventional DI, Alternate-PRD and Fixed-PRD
Source: (Greenhouse Experiment, 2023)

The treatment interactions had no significant effect on the root wet mass (fig. 4.13). However, the highest root wet mass was recorded under the integration of CI+100% ETc+N2 (78.0 g/plant) while the lowest was observed with F-PRD+60% ETc+N1 (17.7 g/plant). Comparing the performance of various deficit irrigation strategies combined with nitrogen fertilizer to the control (100% ETc) treatment (CI+100% ETc+N1) yielding the highest root fresh mass value (78 g/plant); under mild stress (80% ETc) with N1 and N2 applications, the root fresh mass decreased by 55.26% and 67.69% respectively for C-DI, 63.85% and 44.74% for A-PRD, 66.23% and 77.31% for F-PRD. Also, under severe stress (60% ETc) with N1 and N2 applications, the shoot wet mass reduced by 63.59% and 50.26% respectively for C-DI, 68.85% and 46.15% for A-PRD, and 74.10% and 62.56% for F-PRD. Treatment combination of A-PRD+80% ETc+N2 showed potential in root development. According to Kang *et al*. (2021), the processes that support the continuation of root growth during water stress include osmotic adjustment, reinforcement of cell loosening, and the accumulation of abscisic acid (ABA). These mechanisms collectively enable plants to adapt and optimize their root growth under challenging water stress conditions.

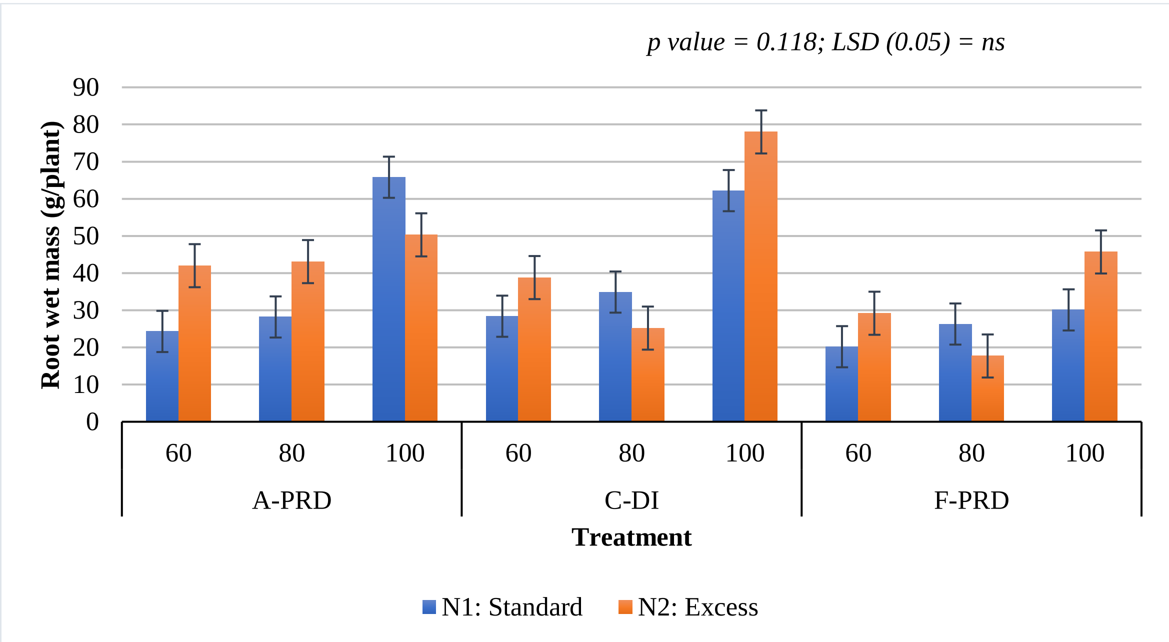

Figure 4.13. Treatment Effect on Root Wet Mass
Source: (Greenhouse Experiment, 2023)

4.4.3. Fresh Kernel Yield

The kernel fresh yield was influenced by main effect of irrigation technique (Appendix T9). Notably, the C-DI method demonstrated the highest yield (96.0 g/plant), while A-PRD and F-PRD techniques which resulted in yields of 76.2 g/plant and 68.3 g/plant respectively. Compared to yield under C-DI, A-PRD and F-PRD significantly reduced fresh kernel mass by 20.31% and 28.65% respectively. Previous studies has shown that partial root-zone drying and conventional deficit irrigation have different effects on kernel yield. In allingment with our study, Hakeem *et al.* (2016) reported highest grain yield with conventional irrigation, follwed by A-PRD and F-PRD respectively. However, contrary to our result, Cheng *et al.* (2021) found that corn kernel yield was higher in A-PRD compared to C-DI, although no significant difference was noted between them. Additionally, Kirda *et al.* (2004) reported that under similar water conditions, the PRD technique yielded higher tomato yields compared to C-DI. Similar observations were made for potatoes, with Shahnazari *et al.* (2007), who reported greater yields under PRD than CI. The inconsistency in yield between conventional irrigation (CI) and partial root-zone drying (PRD) could be attributed to factors such as varying root distribution, controlled stress responses, and crop adaptability, all interacting with environmental conditions and management practices.

Furthermore, the kernel yield was influenced by water regimes (Appendix T9). Application of water at full crop water requirement (100% ETc) significantly produced the highest grain yield (97.6 g/plant) as compared to sever deficit (60 ETc) which gave the lowest yield (49.6 g/plant). The kernel yield under mild stress (93.4 g/plant) was statistically similar with yield obtained in full irrigation. Under 60% ETc, there was a reduction in grain yield by 49.18% compared to 100% ETc, and a reduction of 46.94% compared to 80% ETc. In agreement with this study, previous studies has also demonstrated a decline in corn yield due to deficit irrigation as compared to full irrigation (Yazar *et al*., 2009; Hakeem et al., 2016; Rou *et al.*, 2017; Cheng *et al.,* 2021). Likewise, in the case of cucumber, severe stress led to a significant reduction in yield, whereas mild and full irrigation resulted in comparable yields (Alordzinu *et al.,* 2022).

In the study, sweet corn which received the standard nitrogen requirement (N1), produced a kernel yield of 86.9 (g/plant). On the other hand, the application of excess nitrogen (N2) led to a lower yield of 73.5 (g/plant) (Appendix T9). The reduction of 15.35% in kernel yield associated with the excess fertilizer application did not exhibit statistical significance. Excessive nitrogen fertilizer application can decrease crop yield and result to nitrogen loss

(Gao *et al.*, 2020). Studies have shown that the increase in nitrogen loss is much higher than that in production gain caused by excessive application of nitrogen fertilizer (Zhao *et al.*, 2019).

There was no significant difference in kernel yield recorded for all the treatment interactions (Figure 4.14). Treatment interaction of C-DI+80% ETc+N1 gave the highest kernel fresh mass (139.5 g/plant). However, this was not statistically different from the lowest yield (35.6 g/plant) observed with F-PRD+60% ETc+N2. Both C-DI and A-PRD techniques demonstrated promising grain yield potential under mild stress and nitrogen fertilization. According to Dong-liang *et al.* (2020) combining irrigation and nitrogen fertilizer effectively enhances corn growth and yield. Under A-PRD, two successful approaches are suggested: 60-65% field capacity with 200-300 kg N/ha, or 75-80% field capacity with 300 kg N/ha, both positively affecting corn yield. However, Ertek and Kara, (2013) asserted that corn yield is impacted by various environmental elements, including factors like climatic conditions during the growing season, the availability of water, and the quality of the soil.

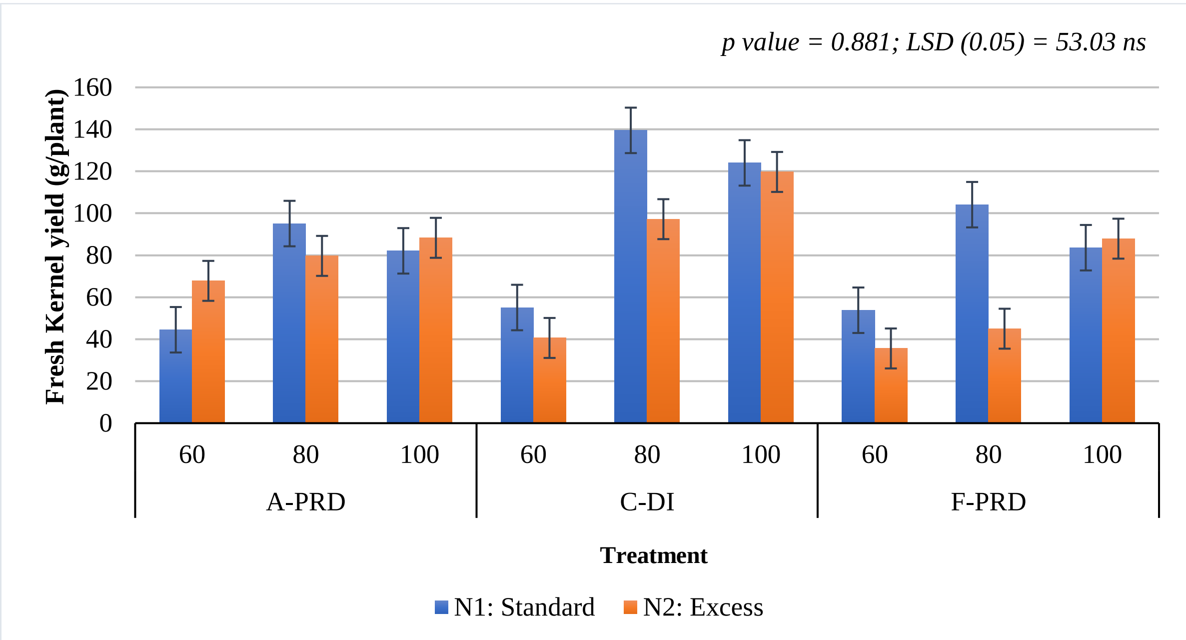

Figure 4.14. Treatment Effect on Fresh Kernel Weight
Source: (Greenhouse Experiment, 2023)

4.4.4. Fresh Whole Yield

Fresh whole yield encompasses the combined mass of both the above-ground components (shoot and grain) as well as the below-ground component (root). The irrigation technique chosen significantly impacted the observed fresh whole yield of the sweet corn plants (Appendix T9). Specifically, the C-DI irrigation method yielded the highest fresh whole yield (439.6 g/plant), showing a statistically significant difference ($p < 0.05$) when compared to the F-PRD method (336.1 g/plant). The A-PRD method resulted in a fresh whole yield of 359.2 g/plant, and this yield was statistically similar to that of C-DI, indicating a comparable performance level between the two techniques. Both methods outperformed the F-PRD method. Implementing the F-PRD technique led to a reduction in fresh whole yield by 23.59% and 14.95% in comparison to the C-DI and A-PRD methods, respectively. The pattern of fresh biomass yield observed in this study was consistent with the outcomes of Kannan & Mulugeta, (2015) in relation to maize. However, in the current study, a significant difference was found between C-DI and A-PRD. In contrast, the study by Kannan & Mulugeta, (2015) reported no significant variation in biomass between conventional furrow irrigation (CFI) and alternate furrow irrigation (AFI). Despite this, there was a noticeable reduction in yield for fixed furrow irrigation (FFI) compared to AFI in their study, with AFI demonstrating a comparatively smaller decrease in yield.

Furthermore, water regime exerted a significant influence on the fresh whole yield (Appendix T9). The highest yield, at 485.0 g/plant, was achieved under full irrigation, closely followed by a yield of 402.6 g/plant under mild stress conditions. In contrast, the lowest yield was observed in crops subjected to severe stress, resulting in a yield of 283.2 g/plant. Notably, the application of 100% ETc irrigation produced the highest fresh whole yield, exhibiting a statistically significant difference ($p < 0.001$) when compared to the yields recorded under 80% ETc and 60% ETc, respectively. Compared to full irrigation, the adoption of a mild deficit approach resulting in a water saving of 19.96% was associated with a 16.97% reduction in fresh whole yield, while a more pronounced water-saving of 39.98% through severe deficit conditions correspondingly lowered the yield by 41.81%. Previous research has demonstrated that when subjected to deficit irrigation, corn's fresh biomass tends to decrease compared to standard irrigation levels. This aligns with the current study, which is in agreement with previous findings that indicate a decrease in maize yield due to deficit irrigation (Liang *et al.* 2013; Kannan & Mulugeta, 2015; Amir *et al.*, 2019; Gadédjisso-Tossou *et al.,* 2020).

Additional application of nitrogen fertilizer (N2) only marginally increased the fresh whole yield by 1.71% over standard nitrogen application (N1), and this was not significant (Appendix T9). The increase in total fresh biomass through increasing nitrogen fertilizer application has been evidenced in maize (Dong-liang *et al*. 2020; Su *et al.* 2020; Qi and Pan, 2022). On other hand, crop yield increases up to a certain limit and declines if applied in an excess amount of nitrogen (Shrestha *et al.,* 2018).

There was no significant difference in fresh whole yield recorded for all the treatment interactions (Figure 4.15). Sweet corn grown with conventional irrigation under full irrigation (100% ETc) and excess nitrogen fertilizer (N2) produced the highest fresh whole yield (600 g/plant). However, this was not statistically different from the yield (228.5 g/plant) recorded with F-PRD under sever water deficit (60% ETc) and standard application of nitrogen fertilizer (N1).

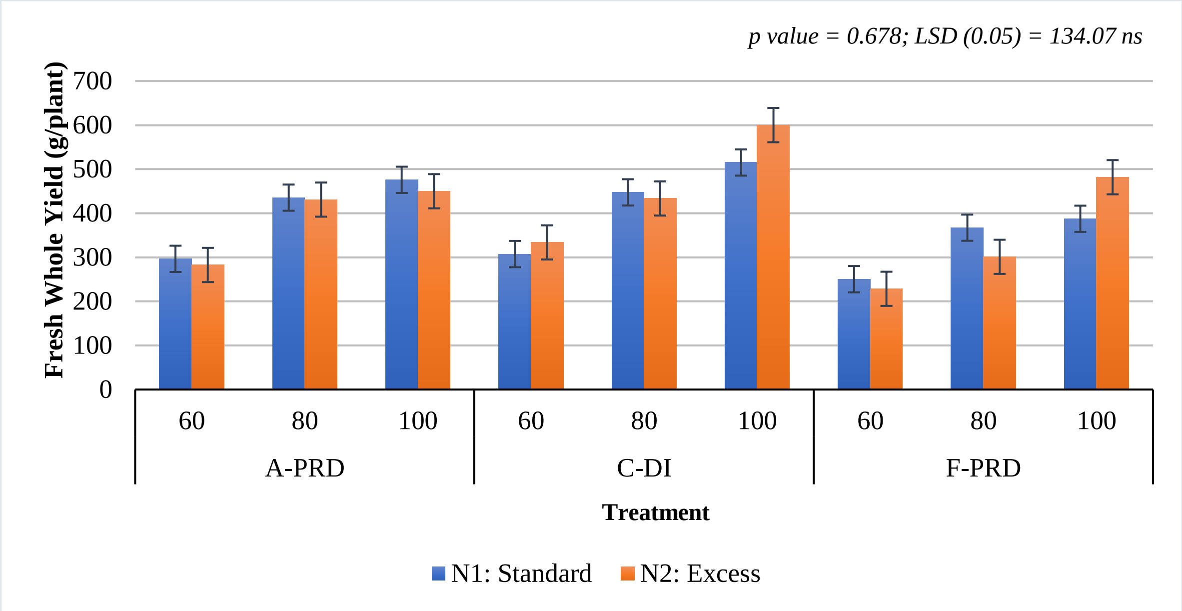

Figure 4.15. Treatment Effect on Fresh Whole Yield
Source: (Greenhouse Experiment, 2023)

Comparing the performance of various deficit water regime interaction with CI+100% ETc+N_2 which gave the highest fresh yield value (600 g/plant); it was observe that under mild stress (80% ETc) with standard (N1) and excess (N2) applications, the fresh whole yield decreased by 24.46% and 27.27% respectively for C-DI, 27.50% and 28.17% for A-PRD, and 38.80% and 49.82% for F-PRD. Furthermore, under severe stress (60% ETc) with N1 and N2 applications, the fresh whole yield reduced by 49.47% and 44.35% respectively for C-DI, 49.25% and 52.90% for A-PRD, and 58.25% and 62.83% for F-PRD. So, the management of irrigation and fertilizer, specifically through the implementation of C-DI and A-PRD techniques, demonstrated potential in enhancing fresh whole yield.

4.5. Dry Biomass Yield

Figure 4.16. Sample Plant Shoots and Roots in the Oven for Drying
(Greenhouse Experiment, 2023)

4.5.1. Shoot dry mass

The adoption of conventional deficit irrigation, or the partial rootzone drying methods, had no significant effect on the shoot dry mass (Appendix T10). Shoot dry mass was highest under C-DI (68.59 g/plant), followed by A-PRD (68.14 g/plant) and lowest with F-PRD (58.19 g/plant). In the previous studies, Barideh *et al.* (2018) reported significant differences in shoot dry mass influenced by irrigation technique in corn. Their findings indicated that shoot dry mass was highest with conventional irrigation (CI), followed by alternate partial rootzone drying (A-PRD), and lowest with fixed partial rootzone drying (F-PRD). Similarly, Liang *et al.* (2013) examined sticky maize and identified significant differences in shoot dry mass among C-DI, A-PRD, and F-PRD at the booting stage, while finding no significant differences at the jointing and maturity stages. On the other hand, some studies have reported that partial rootzone drying outperformed conventional irrigation with respect to shoot dry mass in corn (Yazar *et al*., 2009; Fengbei *et al*., 2017;Cheng *et al*., 2021).

The shoot dry mass was significantly influenced by water regime (Appendix T10). Shoot dry mass was highest ($p < 0.001$) under full irrigation (74.84 g/plant), followed by mild deficit (65.63 g/plant), and lowest with sweet corn subjected to severe deficit (54.45). Compared to full irrigation, shoot dry mass decreased by 12.33% ($p < 0.05$) at mild irrigation, and a further 27.27% at severe deficit (p <.001). The findings of this study are consistent with previous research, which has reported a significant decrease in the shoot dry mass of corn under deficit (Wei *et al.*, 2010; Guo *et al.*, 2011; Wang *et al.* 2017; Cheng *et al*. 2021). Water scarcity has a notable impact on crop yield characteristics, likely stemming from its disruption of gas exchange in leaves. This disruption affects not only the size of source and sink tissues, but also impairs processes like phloem loading, movement of nutrients, and distribution of dry matter (Anjum *et al*., 2011).

Furthermore, nitrogen application at 5.5 g N/plant resulted in a higher shoot dry mas (67.78 g/plant) but this was not significant to the shoot dry mass (62.1 g/plant) obtained from plants that received 3.2 g N/plant. (Appendix T10). This result is in line with the findings of Wang *et al.* (2017), who reported increase in dry biomass of corn with increasing nitrogen fertilizer. Similarly, the shoot dry mass of corn has been observed to increase with increasing nitrogen fertilizer level, up to a certain limit, beyond which further addition do not significantly increase the shoot dry mass (Fengbei *et al.*, 2017). Non-significant different in shoot dry mass with increasing level of nitrogen fertilizer has also been reported for tomato (Zotarelli *et al.,* 2009).

There was no significant difference in shoot dry mass recorded for all the treatment interactions. Sweet corn under treatment interaction of C-DI+100% ETc+N2 produced the highest shoot dry mass yield (Figure 4.17). However, this was not statistically different from the lowest shoot dry mass recorded with F-PRD+60% ETc+N1.

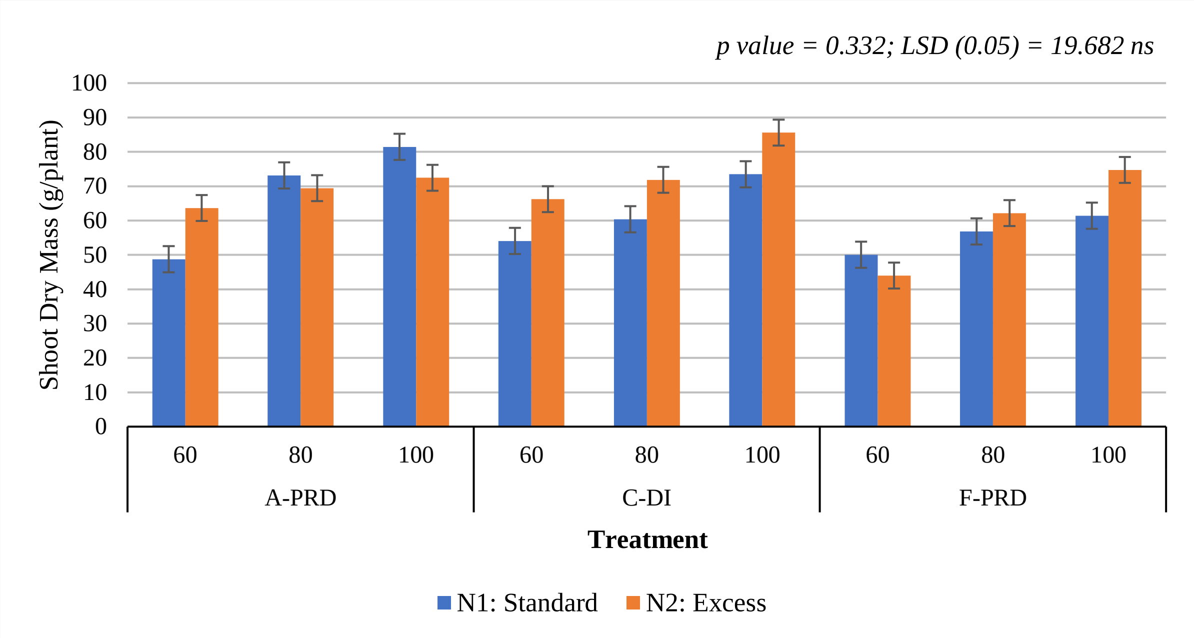

Figure 4.17. Treatment Effect on Shoot Dry Mass
Source: (Greenhouse Experiment, 2023)

Comparing the performance of various deficit water regime interaction to CI+100% ETc+N2 which gave the highest shoot dry mass (85.59 g/plant); it was observe that under mild stress (80% ETc) with standard (N1) and excess (N2) applications, the fresh whole yield decreased by 29.41% and 15.91% respectively for C-DI, 14.54% and 18.79% for A-PRD, and 33.40% and 27.37% for F-PRD. Furthermore, under severe stress (60% ETc) with N1 and N2 applications, the fresh whole yield reduced by 36.85% and 22.45% respectively for C-DI, 43.18% and 25.73% for A-PRD, and 41.49% and 48.58% for F-PRD. The findings of this study suggest that carefully managing irrigation and fertilizer, especially by adopting A-PRD under mild stress conditions and using standard nitrogen fertilizer, holds great potential for increasing dry shoot mass. Previous research has also shown that when combining nitrogen treatments and irrigation methods, corn shoot dry mass can be improved (Liang *et al*. 2013; Fengbei e*t al.*, 2017). Similarly, this study's results align with Wang *et al*. (2017) findings, which indicated that among various deficit irrigation interactions involving irrigation methods and nitrogen fertilizer, using A-PRD techniques resulted in better shoot biomass compared to interactions using C-DI and F-PRD.

4.5.2. Root Dry Mass

Irrigation technique had a significant effect on the root dry mass (Appendix T10). The highest root dry mass (19.99 g/plant) was observed among crops utilizing the C-DI method, and this difference was statistically significant ($p < 0.001$), while the lowest root dry mass (14.1 g/plant) was recorded for F-PRD. The root dry mass attained through A-PRD was statistically comparable to that of C-DI. Various studies have explored the influence of irrigation methods on the root dry mass of corn. According to Liang *et al.* (2013), when assessing root dry mass at the jointing, booting, and maturity stages, a significant different was observed at the maturity stage, with conventional irrigation (CI) demonstrating superior performance over F-PRD.

Conversely, Fengbei *et al.* (2017) noted a significant impact on root dry mass, where alternate partial rootzone drip irrigation (ADI) led to an increase in root dry mass, while fixed partial rootzone drip irrigation (FDI) caused a minor reduction in comparison to conventional partial rootzone drip irrigation (CDI). Furthermore, according to Barideh *et al.* (2018), there was no significant effect on root dry mass; nevertheless, the observed trend suggested that root dry mass tended to be greater with conventional irrigation (CI), followed by A-PRD, and was at its lowest with F-PRD. This is also similar to the findings reported for hot pepper (Dorji *et al.,* 2005).

Furthermore, sweet corn plants exposed to full irrigation yielded the highest root dry mass (24.15 g/plant), which is significant ($p < 0.001$) to root dry mass observed under mild stress (14.94 g/plant) and severe stress (14.72 g/plant). The accumulation of root dry mass reduced by 38.25% and 40.99% under mild and severe stress conditions, respectively. This observation in the present study is aligned with the findings Ahmed *et al.* (2014), who observed a significant decrease in root dry mass due to increased deficit irrigation in hot pepper. More so, Sampathkumar *et al.* (2012) reported significant differences in root dry mass attributable to deficit irrigation across two years of research on maize and cotton. Previous studies have also reported decreases in root biomass due to water stress in corn (Fengbei *et al.*, 2017; Barideh *et al.*, 2018).

Excess application of N fertilizer (N2) marginally increased the root dry mass by 1.79% and this was not significant to dry mass obtained with standard nitrogen application (N1) (Appendix T10). Root dry mass has been reported to increase with increasing nitrogen fertilizer (Fengbei *et al.*, 2017). Significant difference in root dry mass has also been reported for corn at maturity stage (Liang *et al.*, 2013). However, the non-significant different observed in this study could be attributed to the rate of nitrogen fertilizer used.

Interaction of irrigation and fertilizer management practice did not significantly influence the root dry mass of sweet corn (Figure 4.18). Root dry mass highest with treatment interaction of CI+100%ETc+N2. Sweet corn grown under the management practice of F-PRD+60%ETc+N2 produced the lowest root dry mass.

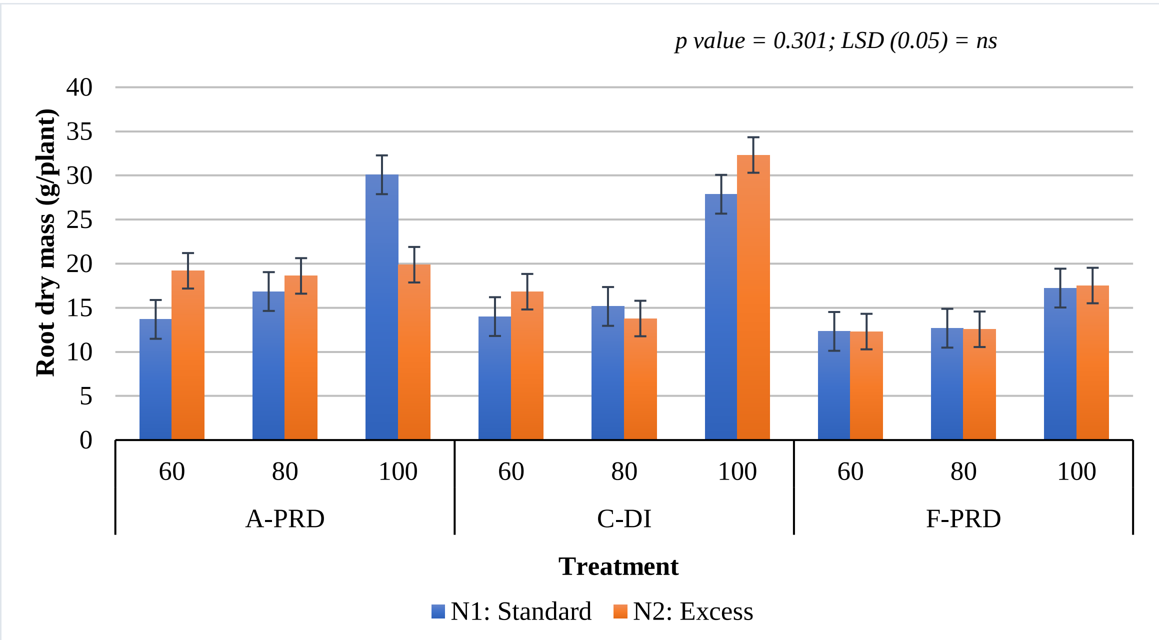

Figure 4.18. Effect on Root Dry Mass
Source: (Greenhouse Experiment, 2023)

Comparing the performance of various deficit water regime interactions to the highest shoot dry mass recorded under CI+100%ETc+N2 (32.32 g/plant), it was observed that under mild stress (80% ETc) with standard (N1) and excess (N2) applications, the root dry mass decreased by 59.11% and 56.95% respectively for A-PRD, 59.19% and 57.34% for C-DI, and 65.48% and 56.60% for F-PRD. Further subjecting the sweet corn to severe stress (60% ETc) with N1 and N2 applications, the root dry mass decreased by 57.07% and 54.25% respectively for A-PRD, 56.65% and 48.39% for C-DI, and 60.68% and 59.78% for F-PRD. Though there was no significant different among all the treatment interactions, C-DI and A-PRD exhibited similar potential under water stress and nitrogen fertilizer. As observed in the present study, Fengbei *et al.* (2017) also reported a non-significant difference with the interaction of irrigation method and nitrogen fertilizer on the root dry mass of sweet corn (Fengbei *et al.*, 2017).

4.5.3. Total Dry Mass

The total dry mass was influenced by irrigation technique. Conventional deficit irrigation (C-DI) and alternate partial rootzone drying (A-PRD) methods significantly performed better than fixed partial rootzone drying (F-PRD), which resulted in lowest total dry mass (Appendix T10). F-PRD reduced ($p < 0.05$) the total dry mass by 18.36 and 17.69 compared to C-DI and A-PRD respectively. This aligns with Liang *et al.* (2013) study, which highlighted a significant difference among C-DI, A-PRD and F-PRD on the total dry biomass of corn at the booting and maturity stage. On the contrary, Fengbei *et al*. (2017) reported a non significant different among the irrigation techniques.

Additionaly, the total dry mass was influenced by water regimes (Appendix T10). Application of water at full crop water requirement (100% ETc) signififcantly yielded the highest total dry mass (99 g/plant) as compared to total dry biomass (69.17 g/plant) obtained for sever deficit (60 ETc) irrigation. Compard to full irrigation, mild deficit reduced the total dry mass by 18.27%, whereas further deficit at 60% ETc reduced the total dry mass by 30.44%. During periods of drought stress, a plant's ability to grow and produce depends on important factors like how it distributes its biomass over time and allocates dry matter (Anjum *et al.*, 2017). The reduction of biomass due to water has been observed across various crop species including tomato (Zotarelli *et al*., 2009), hot pepper (Ahmed *et al.*, 2014), corn (Kang *et al.* 2000; Liang *et al*. 2013; Fengbei *et al*. 2017; Wang *et al*., 2017). Different genotypes exhibit varying degrees of stress tolerance, with some plants being more tolerant to moderate water stress in terms of total dry weight. However, even though certain plants might endure moderate stress, the total dry biomass of sweet corn was significantly reduced under mild stress conditions.

Additionally, the total dry mass increased by 3.59% with the application of excess nitrogen compared to standard nitrogen fertilizer (Appendix T10). Nevertheless, no significant effects on the total dry mass were observed between the different nitrogen application levels. The application of nitrogen fertilizer has been reported to lead to an increase in plant biomass (Wang *et al*., 2017).

The integration of irrigation and fertilizer management had no significant influence on the total dry mass observed for all the treatment interactions (Figure 4.19). Sweet corn grown with conventional irrigation approach under full crop water requirement (100% ETc) and excess nitrogen fertilizer (N2) produced the highest total dry mass. However, this was not statistically different from the yield recorded with F-PRD under sever water deficit (60% ETc) and excess nitrogen fertilizer application (N2). The non-significant different with interaction of irrigation method and nitrogen fertilizer on the total dry mass of corn was also reported by Liang *et al.* (2013).

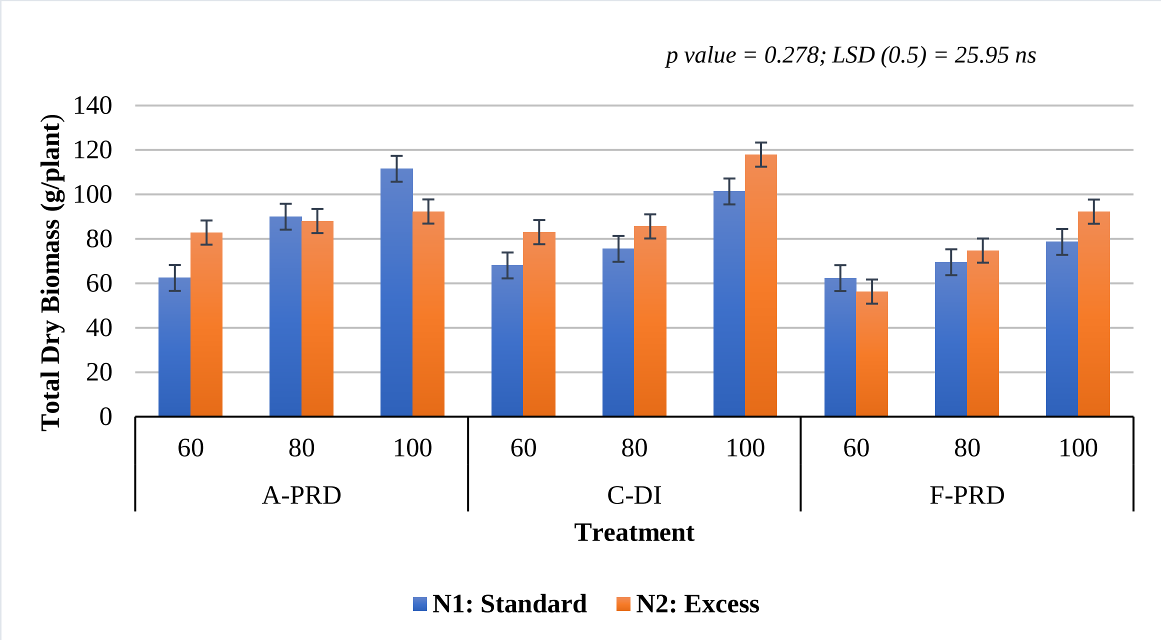

Figure 4.19. Effect on Root Dry Mass
Source: (Field Experiment)

4.6. Water Productivity (WP) in Yield

4.6.1. Water Productivity in Kernel Yield (WP_{ky})

Water productivity is one of the best metric for characterizing agricultural irrigation practices, embodying a widely agreed upon measure of crop productivity and influencing the choice of optimal approaches in agricultural resource management (Barideh *et al*., 2018b). Water productivity was influenced by irrigation technique (Appendix T11). Water productivity in kernel yield WP_{ky} was highest ($p < 0.05$) under C-DI (0.36 kg/m^3), followed by A-PRD (0.29 kg/m^3) and lowest with F-PRD (0.26 kg/m^3). Compared to C-DI, WP_{ky} decreased ($p < 0.05$) by 19.44% and 27.78% for A-PRD and F-PRD respectively. This suggests an enhancement in water productivity through the utilization of the conventional irrigation method. However, in contrast to these findings, Chandra *et al.* (2018) reported on rabi maize that the PRD technique yielded the highest water productivity in terms of yield, showcasing significant superiority over the conventional irrigation method.

Additionally, WP_{ky} was not significantly influence by water regime (Appendix T11). At full irrigation, WP_{ky} was 0.3 kg/m^3, at mild stress, 0.36 kg/m^3 while at sever stress it was 0.25

kg/m^3. WP_{ky} was increased by 20% at mild stress, while further subjecting the crop to severe stress decreased the WP_{ky} by 16.67%. This aligns with Al-Ghobari and Dewidar, (2018) in their study on tomato. They asserted that deficit irrigation can improve the WP of tomato plant. However, when the when crop water requirement is drastically reduced, WP decrease due to decline in productivity. Similar observation was made for maize (Tafrishi *et al*., 2013). Also, in cucumber water productivity in yield was increased by deficit irrigation but this was not significant (Mao *et al.,* 2003; Kirnak and Demirtas, 2006). Improving water productivity (WP) involves increasing yield or reducing water use and irrigation. This benefits growers aiming to maintain yield and quality while saving water (Kirnak and Demirtas, 2006). However, this study's data revealed that yield was only maintained with mild water stress. Contrary to the present study, WP in yield have been demonstrated to be lowest under full irrigation, such as in tomato (Topcu *et al*., 2007), and cucumber *(Abdelraouf et al.,* 2023). Meanwhile, the lack of significant improvement across all water levels from this study suggests that saving water did not increased the yield or compensate for the yield reductions.

Nitrogen application levels had no significant influence on the WP_{ky} (Appendix T11). Water productivity in fresh kernel yield was 0.33 kg/m^3 with N1. However, for N2, the WP_{ky} reduced by 15.15% at 0.28 kg/m^3. In contrast Fengbei *et al.* (2017) on sweet corn reported a significant increase in WP_{ky} with increasing nitrogen application.

Furthermore, none of the interactions among the irrigation and fertilizer management exerted a significant influence on the WP_{ky}. (Figure 4.20). Despite this, it was observed that the highest WP_{ky} was achieved when sweet corn under the treatment interaction of C-DI+80% ETc+N1. On the other hand, the lowest WP_{ky} was observed with interaction of F-PRD+60% ETc+N2. The lack of significant difference across all treatment interactions indicates that none of the irrigation and fertilizer management strategies exhibited a clear advantage in terms of sustaining or increasing yield through water conservation and nutrient utilization. This might be attributed to other factors such as the higher temperature condition the corn faced inside the greenhouse during growing stage. Temperature affects several physiological processes in plants, including photosynthesis, transpiration, and respiration, all of which contribute to overall crop growth and water use (Moore *et al.*, 2021). Warmer temperatures can accelerate these processes, leading to higher water loss through transpiration, which might reduce water productivity if not compensated by increased yield.

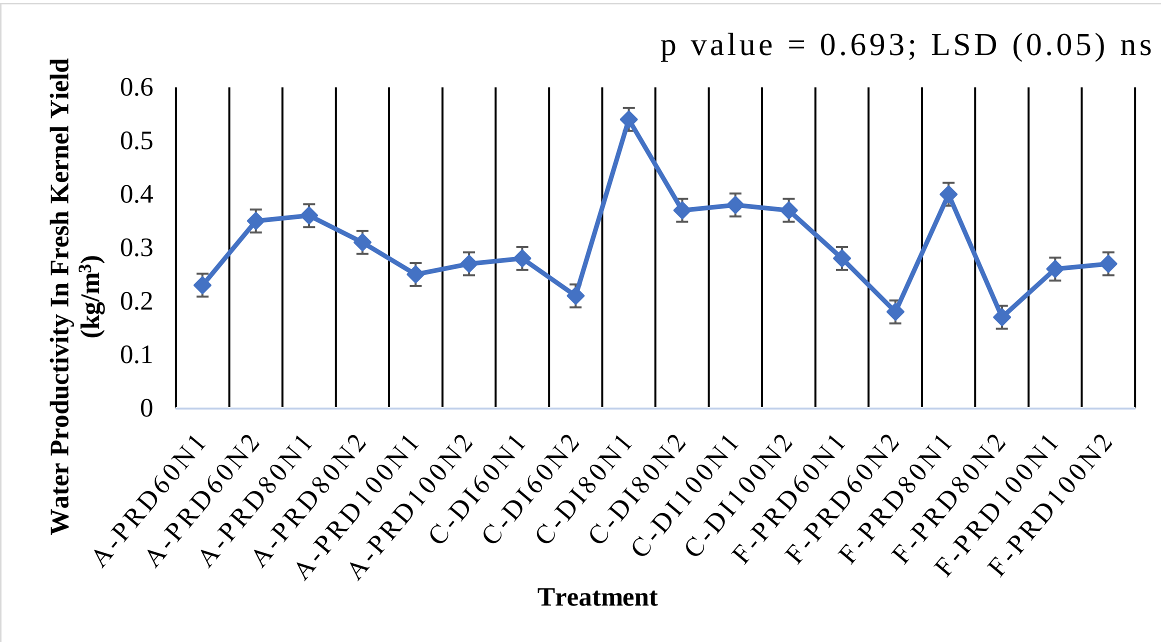

Figure 4.20. Effect on WP in Kernel Fresh Yield (WP_{ky})
Source: (Greenhouse Experiment, 2023)

4.6.2. Water Productivity in Total Dry Biomass Yield (WP_{dy})

Water productivity in total dry mass biomass refers to the amount of biomass (shoot and root) produced per unit of water consumed. Water productivity in total dry biomass yield (WP_{dy}) was influenced by the choice of irrigation technique (Appendix T11). Among the method employed, WP_{dy} was highest and the same for both C-DI and A-PRD (0.34 kg/m^3 respectively), while the lowest WP_{dy} was observed under F-PRD (0.28 kg/m^3). Compared to C-DI and A-PRD which had similar WP_{dy} value, a significant reduction of 17.65% in WP_{dy} was observed with F-PRD. Previous studies have reported that A-PRD and F-PRD yielded highest WP_{dy} than C-DI in maize (Hu *et al.*, 2009; Barideh *et al*. 2018). According to Al-Kayssi (2023), on maize, water productivity in dry mass was highest with A-PRD, followed by F-PRD when compared to C-DI in jointing and tasseling stages, while F-PRD was highest in maturity stage. In other studies where only C-DI and A-PRD was employed WP was reported to be highest with A-PRD, compared to C-DI (Shahnazari *et al*., 2007; Cheng *et al*., 2021). The advantage of A-PRD over C-DI is that although the moist side of the root system consumes water to maintain the plant's water status, the dry side of the root system promotes an increase in ABA production, that reduces stomatal conductance and enhance WP (Sepaskhah and Ahmadi, 2010; Abdelraouf *et al,* 2023). The lowest WP observed for F-PRD can be attributed to the compromised ability of roots to adjust their metabolism and produce chemical signals, particularly abscisic acid (ABA), when experiencing reduced water absorption from the dry section of the root system.

Additionally, decreasing the level of water applied to the crop, inversely increased the WP_{dy} as was observed with the water regimes (Appendix T11). However, there was no statistical difference in WP_{dy} observed for the three water regimes. At full irrigation the WP_{dy} was 0.3 kg/m^3 and a marginal increase by 3.33% was observed when the crops were irrigated at 80% ETc, whereas at 60% ETc, WP_{dy} increased by 16.67%. The observation from this study aligns with Ahmed *et al.* (2014) on hot pepper. According to their report, increasing deficit irrigation resulted in a non-significant increase WP. The highest WP_{dy} observed in the treatment that received the lowest water (60% ETc) was not significant. Contrary to this observation, Chandra *et al*. (2018) on rabi maize, reported a significant difference on WP_{dy} with the treatment that received the lowest water.

Furthermore, water productivity in total dry biomass yield was statistically similar for N1 and N2 fertilizer levels (Appendix T11). With N1 level, the WP_{dy} value was 0.31 kg/m^3, while N2 increased WP_{dy} by 9.68%. Fengbei *et al.* (2017) reported a non-significant effect of nitrogen fertilizer levels on the WP_{dy} of sweet corn, with significant difference only observed with the treatment that received no fertilizer.

Among the treatment interactions, irrigation and fertilizer management did not significantly ($p > 0.05$) influence the water productivity in total dry biomass yield (Figure 4.21). Nevertheless, WP_{dy} was highest with treatment interaction of C-DI+60% ETc+N2. The lowest WP_{dy} was obtained when the crop was under the management of F-PRD+100% ETc+N2. Evaluating the performance of irrigation technique and nitrogen fertilizer under the same water regime, at full irrigation (100% ETc), WP_{dy} was highest with A-PRD and N2 (0.34 kg/m^3) and lowest with F-PRD and N1 (0.24 kg/m^3). At mild stress (80% ETc), WP_{dy} was highest with A-PRD and N2 (0.34 kg/m^3) and lowest with F-PRD and N1 (0.27 kg/m^3). While at severe stress (60% ETc), WP_{dy} was highest with A-PRD/C-DI and N2 (0.42 kg/m^3) and lowest with F-PRD and N2 (0.29 kg/m^3). The non-significant different observed for all the treatments indicate than none of the treatment interaction enhanced the WP_{dy} either by saving water or improving the yield.

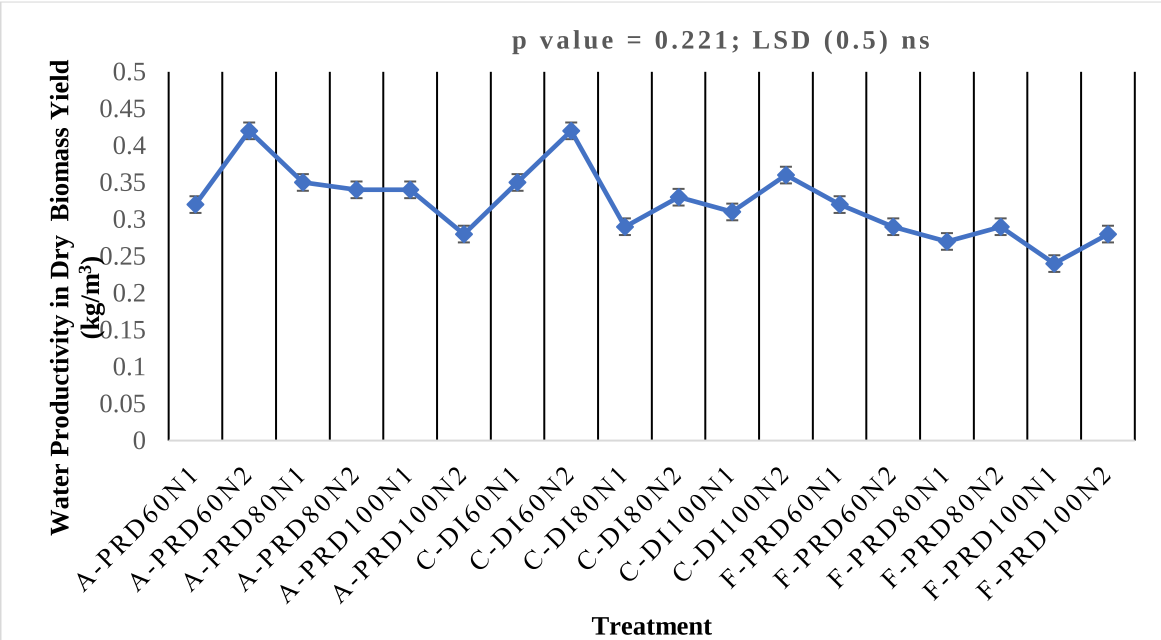

Figure 4.21. Effect on the WP on Dry Biomass Yield (WP_{dy})
Source: (Greenhouse Experiment, 2023)

4.7. Nitrogen Uptake and Nitrogen Use Efficiency

Figure 4.22. Milling of Dry Shoot and Root Samples for Kjeldahl Analysis
(Greenhouse Experiment, 2023)

4.7.1. Shoot Nitrogen Uptake

The irrigation techniques employed in the study significantly affected shoot nitrogen uptake (Appendix T12). The highest uptake occurred with C-DI (1450.33 mg /plant), followed by A-PRD (1012.91 mg/plant) and F-PRD (912.6 mg/plant). Compared to C-DI, nitrogen uptake decreased significantly ($p < .001$) by 30.12% with A-PRD and by 37.08% with F-PRD. In line with the present study, Barideh *et al*. (2018) also reported a significant difference in the shoot nitrogen uptake of corn among irrigation techniques. Their investigation revealed that the highest uptake occurred under CI and APRI methodologies, both of which exhibited a marked contrast to FPRI. Conversely, various other studies diverge from these observations. They contend that the A-PRD technique prompts greater nitrogen accumulation in plants compared to those subjected to C-DI. This outcome was evident in maize (Hu *et al*., 2009), and tomato

(Wang *et al*., 2010) studies. More so, contrary to the present study, Fengbei *et al.*, (2017) on sweet corn reported a non significant variation among C-DI, A-PRD, and F-PRD, although shoot N uptake was highest with A-PRD.

Furthermore, the impact of water regimes on shoot nitrogen uptake was highly significant (Appendix T12). Among the water regimes, highest shoot nitrogen uptake was observed under full irrigation (100% ETc), measuring at 1648.58 mg/plant. This was followed by mild deficit (80% ETc), resulting in 1036.63 mg/plant, and the lowest uptake was recorded under severe deficit condition (60% ETc), amounting to 690.09 mg/plant. Relative to the water regime at 100% ETc, the shoot nitrogen uptake demonstrated a significant ($p <.001$) reduction of 37.08% under 80% ETc regime and a further decrease of 58.14% under the 60% ETc regime. The observation from this study indicated that the crops nitrogen uptake was higher with increase in irrigation water. This aligns with the finding of Eltarabily *et al.,* (2019) on sunflower. They reported that under deficit irrigation conditions, the reduction in N uptake was 17.1% compared to fully irrigated conditions. Furthermore, Hammad *et al.*, (2017) although asserted that higher N uptake can not necessarily be achieved with higher water regimes, they observed highest N uptake on maize shoot under full irrigation. Increasing irrigation water regimes has also been reported to increase the N uptake of maize shoot (Wang *et al.,* 2017b).

Additionally, the excessive utilization of nitrogen fertilizer (N2) resulted in a shoot nitrogen uptake of 1219.62 mg/plant, marking a 15.51% significant ($p <0.005$) increase compared to the standard nitrogen application (N1) with a shoot N uptake of 1030.59 mg/plant (Appendix T12). Previous studies has reported increase in shoot N uptake of corn with increasing fertilizer (Hammad *et al.* 2017; Wang *et al.* 2017b). The significant difference between the two fertilizer levels indicated that additional urea (N) fertilizer showed a remarkable advantage with shoot N uptake over standard nitrogen fertilizer.

The shoot N uptake was significantly influenced among the treatment interactions (Figure 4.23). The shoot N uptake was highest (p <.001) with the management practice of CI+100+N2 (3008 mg/plant), and the lowest shoot N uptake was obtained with F-PRD+60%ETc+N1 (532 mg/plant). This suggests that a combination of conventional deficit irrigation (C-DI) along with higher nitrogen application (N2) and irrigating at full crop water requirement yields substantial nitrogen accumulation in the plant tissues. Contrary to this findings, Fengbei *et al*., (2017) reported a non-significant difference for irrigation and nitrogen fertilizer interactions on the shoot nitrogen uptake of sweet corn.

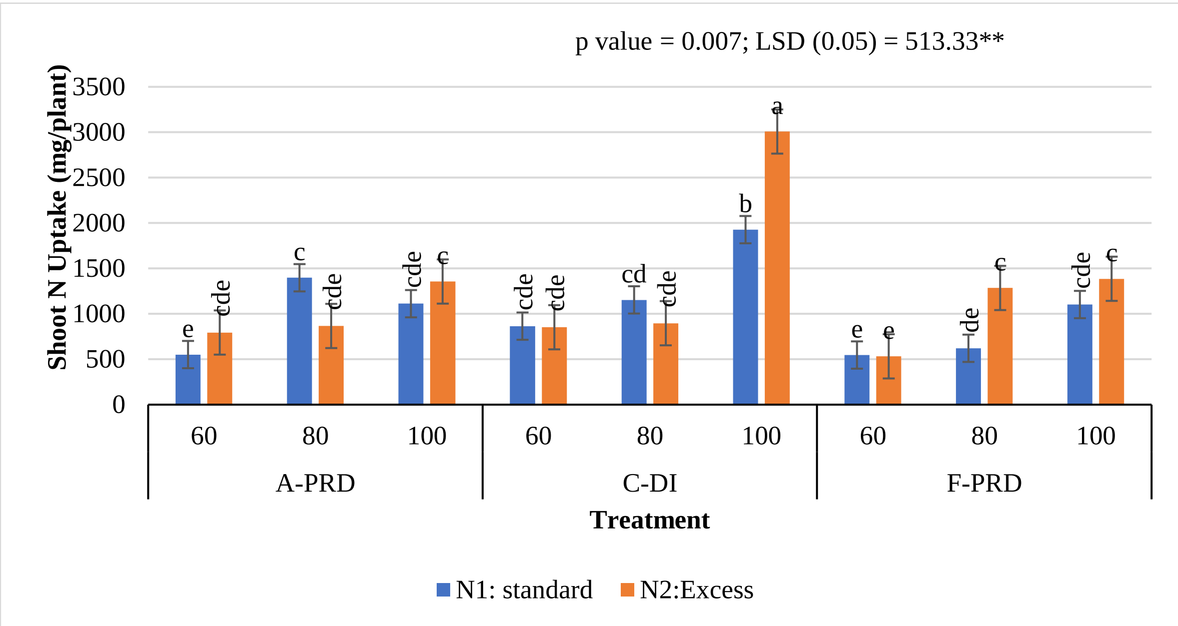

Figure 4.23. Effect on Shoot Nitrogen Uptake
Source: (Greenhouse Experiment, 2023)

4.7.2. Root Nitrogen Uptake

The root N uptake was influenced by irrigation techniques (Appendix T12). The highest root N uptake occurred with C-DI (151.46 mg /plant), followed by A-PRD (113.13 mg/plant) and F-PRD (113.13 mg/plant) respectively. Compared to C-DI, root nitrogen uptake decreased significantly (p < .001) by 25.30% with A-PRD and F-PRD respectively. In previous studies on maize, Hu *et al*., (2009) reported a significant different on the root nitrogen content, with F-PRD and CI higher than A-PRD. Contrary to the present study, Fengbei *et al.* (2017) reported a non-significant difference for C-DI, A-PRD, and F-PRD on the root nitrogen uptake for sweetcorn. More so, root nitrogen uptake was highest with A-PRD, followed by C-DI and lastly F-PRD.

Furthermore, the impact of water regimes on root nitrogen uptake was highly significant (Appendix T12). Among the water regimes, highest root nitrogen uptake was observed under full irrigation (100% ETc), measuring at 160.95 mg/plant. This was followed by mild deficit (80% ETc), resulting in 108.63 mg/plant, and the lowest uptake was recorded under severe deficit condition (60% ETc), amounting to 108.34 mg/plant. Relative to the water regime at 100% ETc, the root nitrogen uptake demonstrated a significant ($p < .001$) reduction of 32.70% under 80% ETc regime and 32.73% under the 60% ETc regime. Conversely, according to the study of Hammad *et al.*, (2017) on maize, the highest root N uptake was observed under full irrigation.

Additionally, the N2 fertilizer level resulted in a root nitrogen uptake of 131.53 mg/plant, marking a 8.55% non-significant ($p > 0.005$) increase compared to the N1 fertilizer level with a root N uptake of 120.29 mg/plant (Appendix T12). In previous findings, Fengbei *et al.*, (2017) reported a significant difference in root nitrogen uptake for sweet corn among these fertilizer rates; 0, 0.2, 0.18, 0.16 and 0.14 g N per kg soil. However, the higher fertilizer rates of 0.2 and 0.8 g N per kg soil were statistically similar, as both were only significant to the lower rates and no fertilizer.

The root N uptake was not significantly influenced among the treatment interactions (Figure 4.24). However, the root N uptake was highest with the management practice of CI+100+N2 (250.2 mg/plant), and the lowest root N uptake was obtained with F-PRD+80%ETc+N2 (76.5 mg/plant). This suggests that a combination of conventional deficit irrigation (C-DI) along with higher nitrogen application (N2) and irrigating at full crop water requirement yields substantial nitrogen accumulation in the plant root tissues.

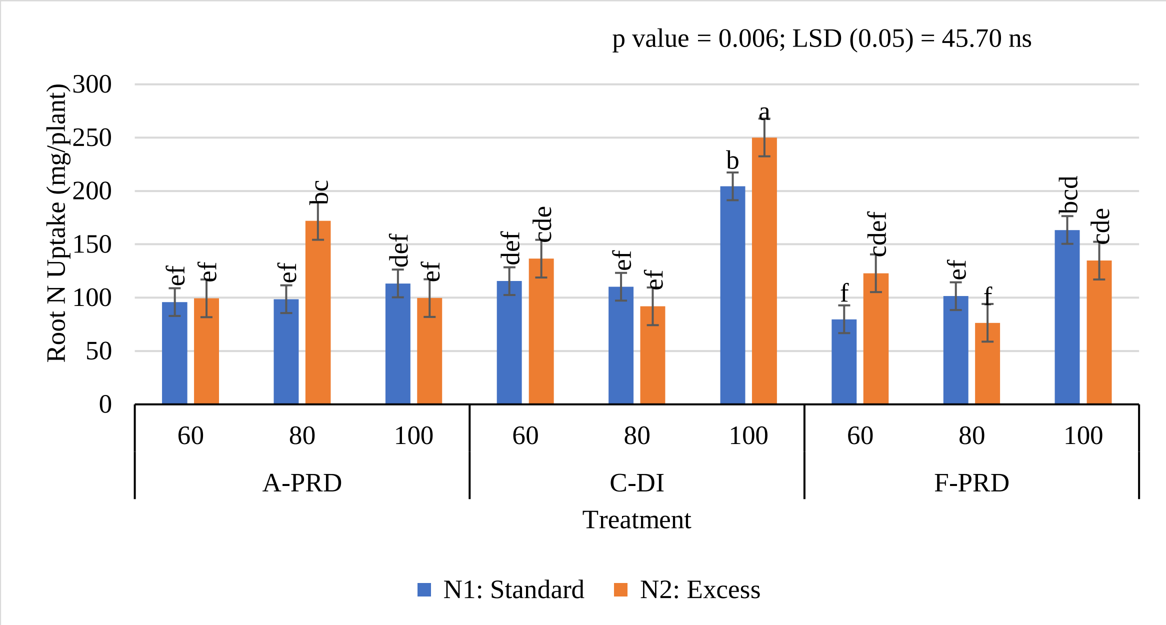

Figure 4.24. Effect on Root Nitrogen Uptake
Source: (Greenhouse Experiment, 2023)

4.7.3. Total Nitrogen Uptake

The total N uptake was influenced by irrigation techniques (Appendix T12). The total N uptake was highest with C-DI (1601.8 mg /plant), followed by A-PRD (1126.04 mg/plant) and F-PRD (1025.9 mg/plant) respectively. Compared to C-DI, total nitrogen uptake decreased significantly ($p < .001$) by 29.7% with A-PRD, and 36% for F-PRD. (Fengbei *et al.*, 2017) reported a non-significant difference for C-DI, A-PRD, and F-PRD on the total nitrogen uptake for sweetcorn. However, total nitrogen uptake was highest with A-PRD, followed by C-DI and lastly F-PRD.

Furthermore, the impact of water regimes on total nitrogen uptake was highly significant (Appendix T12). Among the water regimes, highest total nitrogen uptake was observed under full irrigation (100% ETc), at 1809.54 mg/plant. This was followed by mild deficit (80% ETc), resulting in 1145.06 mg/plant, and the lowest uptake was recorded under severe deficit condition (60% ETc), amounting to 798.43 mg/plant. Relative to the water regime at 100%

ETc, the total nitrogen uptake demonstrated a significant ($p < .001$) reduction of 36.76% under 80% ETc regime and a further decrease of 55.82% under the 60% ETc regime. The findings of this study reveal a direct relationship between increased irrigation water and higher total nitrogen uptake in the crops. This corroborates with the results of Gheysari *et al*. (2009) in their study on maize, where significant variations in total nitrogen uptake were observed across different irrigation regimes, with full irrigation demonstrating greater total nitrogen uptake compared to deficit irrigation levels.

With regards to nitrogen fertilizer main treatment, additional nitrogen fertilizer (N2) resulted in a total nitrogen uptake of 1351.14 mg/plant, marking a 17.34% significant ($p < 0.005$) increase compared to the standard nitrogen application (N1) with a shoot N uptake of 1150.88 mg/plant (Appendix T12). Previous studies has reported increase in total N uptake of corn with increasing fertilizer (Gheysari *et al*., 2009; Fengbei *et al*. 2017). Overall, the application of nitrogen fertilizer plays a crucial role in increasing the total nitrogen uptake of corn, which can have a positive impact on crop yield and productivity.

The total N uptake was significantly influenced among the treatment interactions (Figure 4.25). The total N uptake was highest ($p < .001$) with the management practice of CI+100+N2 (3258 mg/plant), and the lowest shoot N uptake was obtained with F-PRD+60%ETc+N1 (626 mg/plant). This suggests that a combination of conventional deficit irrigation (C-DI) along with higher nitrogen application (N2) and irrigating at full crop water requirement yields substantial nitrogen accumulation in the plant tissues. Contrary to this finding, (Gheysari *et al*., 2009) reported a non-significant difference for irrigation and nitrogen fertilizer interactions on the total nitrogen uptake of sweet corn.

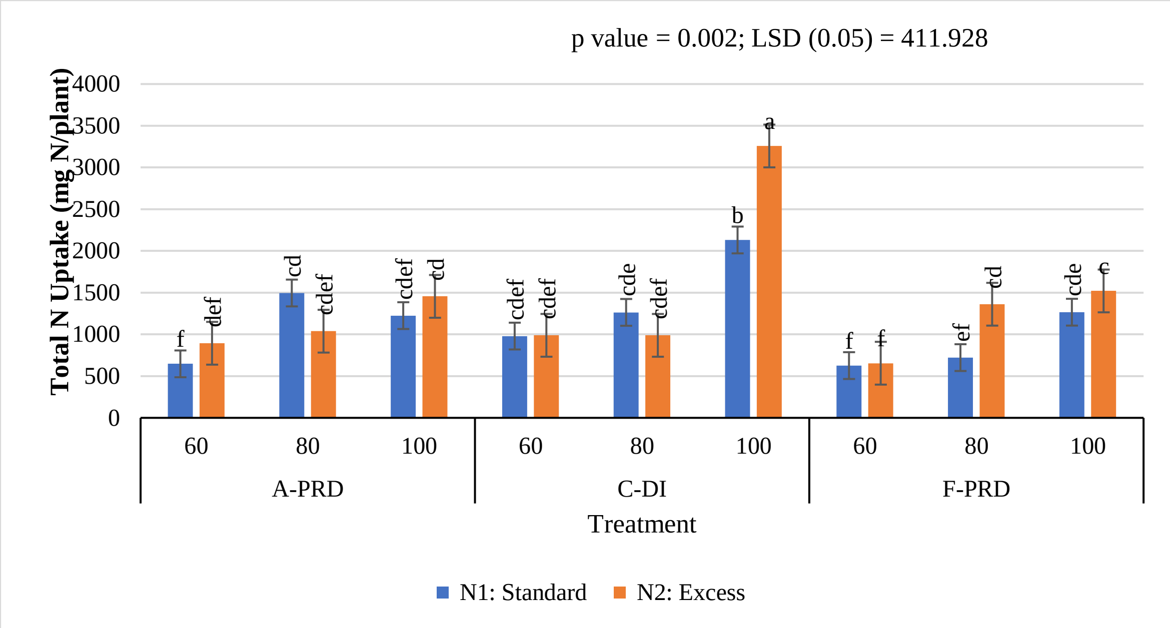

Figure 4.25. Treatment Interaction Effect on Total Nitrogen Uptake
Source (Greenhouse Experiment, 2023)

4.7.4. Nitrogen Use Efficiency

Nitrogen use efficiency (NUE) refers to the ability of a plant to efficiently utilize nitrogen for growth and development. This was significantly influenced by irrigation technique (Appendix T12). NUE was highest (p <.001) with A-PRD (0.08 g/mg) and F-PRD (0.08) and lowest with C-DI (0.06 g/mg). In previous reports, varying conclusions have been made on the effect of irrigation technique on the NUE. Hu *et al*., (2009) reported a significant difference among irrigation technique for NUE of maize, and F-PRD and A-PRD performed better than CI technique. Conversely, Fengbei *et al.* (2017) reported a non-significant difference for C-DI, A-PRD, and F-PRD on the NUE for sweetcorn. However, NUE was highest with F-PRD, followed by C-DI and lastly A-PRD. In another study by Barideh *et al.* (2018) on maize, the CI method had the greatest NUE, while APRI also had relatively good performance, but the FPRI treatment, due to the lack of water content in half of the pot failed to take advantage of the sources of nitrates in the soil.

Furthermore, water regime had a significant effect on the nitrogen use efficiency (Appendix T12). Nitrogen use efficiency was highest under 60% ETc regime (0.09 g/mg), followed by 80% ETc (0.07 g/mg) and lowest with 100% ETc (0.06). This suggests that increasing water regimes reduces the in NUE. This aligns with the findings of Gheysari et al., (2009) who reported higher NUE at deficit irrigation levels as compared to full and over irrigation levels. Similarly, Shoukat *et al*. (2021) on bread wheat reported significant NUE for under mild irrigation, compared to full irrigation and severe deficit. Overall, the effect of deficit irrigation on NUE depends on the crop and the specific conditions of the study.

Additionally, the influence of the 2 nitrogen levels on the NUE was significant (Appendix T12). When the crops were applied with the standard nitrogen fertilizer rate (N1), the NUE was significantly enhanced compared to excess nitrogen application. Despite the increased plant nitrogen uptake with N2, N1 exhibited the highest NUE and this could stem from crops under N1 optimizing the conversion of absorbed nitrogen into plant biomass. As highlighted by (Zotarelli *et al.* (2009), there was an observable decline nitrogen use efficiency (NUE) values as nitrogen rates increase and this may be related to limitation in uptake and sink capacities resulting in a saturation response. In their three-year study on tomato, they reported a significant different on NUE, for three fertilizer rates of 170, 220 and 330 kg/ha, as the lower fertilizer rates of 170 and 220 kg/ha significantly increase the NUE compared to 330 kg/ha. Similarly, Hartmann *et al.* (2015) on a maize-wheat cropping system reported that NUE declines with the increase of N rates.

Treatment interactions across all level significantly influenced the NUE (Appendix 12). In this study, the NUE was highest under F-PRD+60%ETc+NI and this was significant compared to the lowest NUE observed with CI+100% ETc+N2 (Figure 4.26). This suggests that higher nitrogen use efficiency does not necessarily result in higher yield. Nevertheless, improving nitrogen use efficiency can contribute to higher yield.

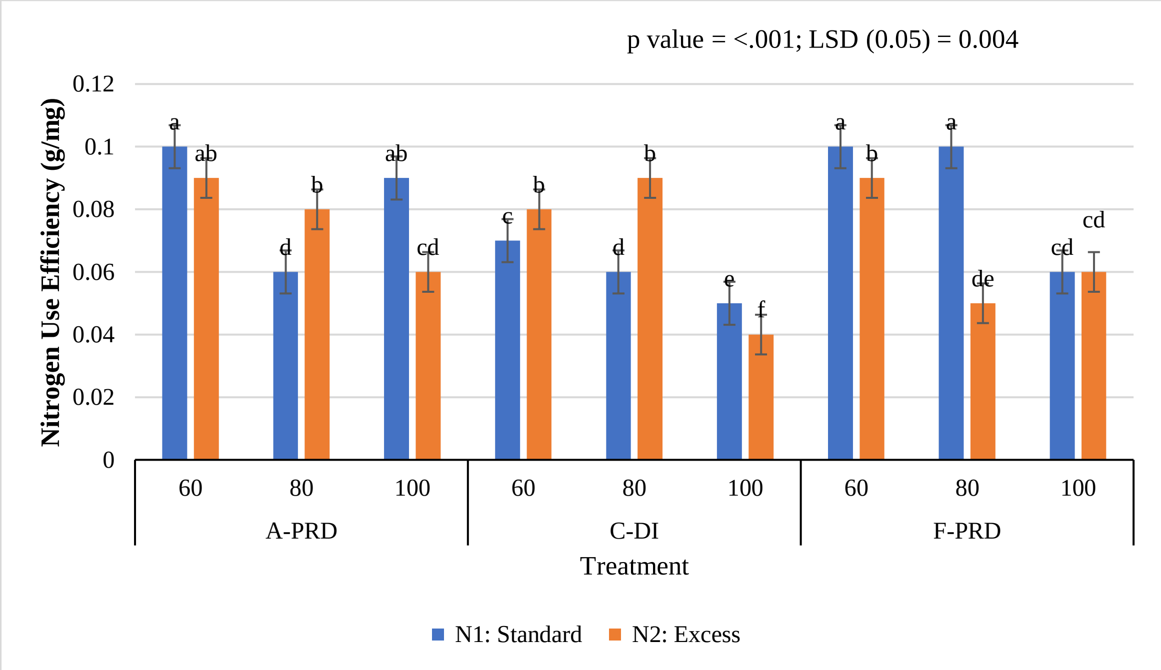

Figure 4.26. Effect on Nitrogen Use Efficiency
Source (Greenhouse Experiment, 2023)

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

This study investigated conventional irrigation and partial rootzone drying effects, coupled with different water regimes and nitrogen fertilization, on sweet corn growth, yield, water productivity, and nitrogen efficiency in greenhouse set up in Northern Ghana. Key findings include:

a. Conventional irrigation significantly improved parameters: plant height, leaf area, leaf area index, shoot and root mass (both wet and dry), kernel weight, fresh yield, total dry mass, water productivity (kernel yield), and shoot and root nitrogen uptake.

b. Alternate partial rootzone drying significantly resulted in highest water productivity (total biomass) and nitrogen use efficiency.

c. Irrigating at 100% ETc yielded significant outcomes in plant height, leaf area, leaf area index, shoot and root mass (both wet and dry), kernel weight, fresh yield, total dry mass, water productivity (kernel yield), and shoot and root nitrogen uptake. Water productivity (total biomass) peaked at 80% Etc, while 60% ETc irrigation enhanced nitrogen efficiency.

d. N1 fertilizer (3.2 gN/plant) promoted plant height and kernel yield, with significant outcome in nitrogen use efficiency.

e. N2 fertilizer (5.5 gN/plant) enhanced leaf area, leaf area index, shoot and root mass (both wet and dry), kernel weight, fresh yield, total dry mass, water productivity (total biomass), root nitrogen uptake, and shoot nitrogen uptake.

f. CI+100% ETc+N2 interaction elevated shoot and root mass (both wet and dry), total dry mass, and root nitrogen uptake; significant shoot nitrogen uptake increase.

g. C1+100% ETc+N1 interaction significantly raised plant height, with non-significant kernel yield increase.

h. C-DI+80% ETc+N1 interaction showed non-significant water productivity (kernel yield) increase; while C-DI+60% ETc+N2 exhibited non-significantly superior water productivity (total biomass).

i. F-PRD+60% ETc+N1 interaction significantly improved nitrogen use efficiency.

5.2. Recommendation

a. Irrigation at crop full water requirement using convention irrigation approach and optimum nitrogen fertilizer is recommended.

b. Subsequent research should consider conducting the experiments within an open field setting, considering the predominant cultivation practices in the Northern region of Ghana.

c. Given the temperature disparities observed between open field and greenhouse conditions, microclimatic data from the local greenhouse should be used for accurately determining the crops water requirements using the CROPWAT model.

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APPENDIXES

Appendix Table 1. Monthly Average Weather Dataset From CSIR-SARI Weather Station

MONTH	TMIN (°C)	TMAX (°C)	RHMIN (%)	RHMAX (%)	WIND (m/s)	RAD (MJ/m^2/day)	SUN (hr)	RAIN (mm)
JAN	19.3	35.5	24.7	47.3	2.3	16.5	5.6	0.1
FEB	22.0	37.5	25.4	51.5	2.4	17.4	5.9	0.4
MAR	26.1	37.8	33.9	64.4	2.6	17.3	6.0	1.0
APR	26.1	36.2	48.1	79.5	2.9	17.1	6.1	2.4
MAY	24.8	34.6	57.2	86.8	2.7	16.3	5.7	3.3
JUN	24.0	32.4	63.9	90.1	2.7	14.7	6.6	4.9
JUL	23.5	30.4	70.2	93.5	2.5	13.4	4.1	5.7
AUG	23.0	29.9	71.5	93.8	2.2	12.8	3.4	6.7
SEP	23.2	31.5	71.4	91.8	1.7	13.9	4.4	7.0
OCT	23.3	32.5	63.6	92.1	1.7	15.6	6.2	3.3
NOV	22.7	35.3	44.4	83.8	1.6	16.3	6.4	0.2
DEC	19.9	35.6	31.3	63.6	1.9	16.0	4.9	0.1

Appendix Table 2. CROPWAT Data Output

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff. Rain mm/dec	Irr. Req. mm/dec
Apr	2	Init	0.38	2.26	6.80	0	6.80
Apr	3	Init	0.38	2.15	21.5	0	21.5
May	1	Deve	0.40	2.16	21.6	0	21.6
May	2	Deve	0.70	3.55	35.5	0	35.5
May	3	Mid	1.06	5.26	57.8	0	57.8
Jun	1	Mid	1.13	5.48	54.8	0	54.8
Jun	2	Mid	1.13	5.35	53.5	0	53.5
Jun	3	Late	1.12	4.91	49.1	0	49.1
Jul	1	Late	1.03	4.17	25.0	0	25.0
TOTAL				325.6			325.6

Appendix Table 3. Fertilizer Amount (mg/plant) Applied to The Crops

WEEK	UREA N1(Standard)	N2 (Excess)	MAP P_2O_5	KNO^3 K_2O
4	4.62	381.34	121.28	1718.41
5	481.99	858.70	296.10	2170.47
6	631.23	1007.95	446.88	2657.31
7	1368.97	1774.67	595.48	1472.10
8	245.15	650.84	420.66	2309.57
9	715.59	1092.31	121.28	843.27
TOTAL	3447.55	5765.81	2001.69	11171.12

Appendix Table 4. Mean Value of The Treatments Effect on Plant Height

TREATMENTS	PLANT HEIGHT (cm)			
	7WAP	**8WAP**	**9WAP**	**10WAP**
IRRIGATION TECHNIQUE				
C-DI	102.5	138.6	148.7	150.1
A-PRD	95.4	127.3	145.5	146.1
F-PRD	88.9	111.8	125.2	129.2
Grand mean	95.6	125.9	139.8	141.8
p value	0.035	0.014	0.005	0.02
LSD (0.05)	9.06 *	13.57 *	9.98 *	12.45 *
WATER REGIME (% ETc)				
100	107.4	147.7	160.1	161.9
80	94.1	123.4	139.1	140.7
60	85.3	106.5	120.2	122.8
Grand mean	95.6	129.9	139.8	141.8
p value	0.001	$<.001$	$<.001$	$<.001$
LSD (0.05)	9.79 **	11.43 ***	15.12 ***	14.84 ***
NITROGEN LEVEL				
N1	96.2	128.6	143.0	144.6
N2	95.0	123.2	136.6	139.0
Grand mean	95.6	125.9	139.8	141.8
p value	0.721	0.237	0.161	0.265
LSD (0.05)	6.66 ^{ns}	9.16 ^{ns}	9.25 ^{ns}	10.35 ^{ns}
Interaction Effects				
IT * WR *(LSD 0.05)*	15.16 ^{ns}	18.85 ^{ns}	22.32 ^{ns}	22.57 ^{ns}
p value	0.577	0.251	0.161	0.592
IT * NL *(LSD 0.05)*	10.74 ^{ns}	15.47 ^{ns}	13.52 ^{ns}	15.78 ^{ns}
p value	0.97	0.114	0.071	0.124
WR * NL *(LSD 0.05)*	12.19 ^{ns}	15.31 ^{ns}	18.1 ^{ns}	18.67 ^{ns}
p value	0.971	0.964	0.259	0.185
IT * WR * NL *(LSD 0.05)*	19.95 *	26.07 ^{ns}	28.58 ^{ns}	30.31 ^{ns}
p value	0.046	0.082	0.111	0.152

Appendix Table 5. Mean Value of The Treatments Effect on Leaf Number

	LEAF NUMBER			
TREATMENT	**7WAP**	**8WAP**	**9WAP**	**10WAP**
IRRIGATION TECHNIQUE				
C-DI	13.44	14.61	14.61	14.61
A-PRD	12.83	14.22	14.44	14.44
F-PRD	13.39	14.39	14.39	14.39
Grand mean	13.22	14.41	14.48	14.48
p value	0.341	0.712	0.837	0.837
LSD (0.05)	1.112 ^{ns}	1.259 ^{ns}	1.054 ^{ns}	1.054 ^{ns}
WATER REGIME (% ETc)				
100	13.5	14.72	14.83	14.83
80	13.72	14.67	14.78	14.78
60	12.44	13.83	13.83	13.83
Grand mean	13.22	14.41	14.48	14.48
p value	0.016	0.073	0.02	0.02
LSD (0.05)	0.859 *	0.847 ^{ns}	0.736 *	0.736 *
NITROGEN LEVEL				
N1	13.30	14.30	14.37	14.37
N2	13.15	14.52	14.59	14.59
Grand mean	13.22	14.41	14.48	14.48
p value	0.612	0.47	0.378	0.378
LSD (0.05)	0.603 ^{ns}	0.632 ^{ns}	0.516 ^{ns}	0.516 ^{ns}
Interaction effects				
IT * WR *(LSD 0.05)*	1.46 ^{ns}	1.527 ^{ns}	1.304 ^{ns}	1.304 ^{ns}
p value	0.261	0.478	0.199	0.199
IT * NL *(LSD 0.05)*	1.172 ^{ns}	1.301 ^{ns}	1.083 ^{ns}	1.083
p value	0.293	0.564	0.429	0.429 ^{ns}
WR * NL *(LSD 0.05)*	1.083 ^{ns}	1.097 ^{ns}	0.928 ^{ns}	0.928
p value	0.246	0.564	0.628	0.628 ^{ns}
IT * WR * NL *(LSD 0.05)*	1.869 ^{ns}	1.953 ^{ns}	1.638 ^{ns}	1.638 ^{ns}
p value	0.863	0.599	0.406	0.406

Appendix Table 6. Mean Value of The Treatments Effects on Leaf Area

TREATMENT	**LEAF AREA (cm^2)**			
	7WAP	**8WAP**	**9WAP**	**10WAP**
IRRIGATION TECHNIQUE				
C-DI	8998.86	10843.66	10530.35	10887.87
A-PRD	8274.00	10265.19	10530.35	10530.35
F-PRD	8662.07	10128.48	10259.99	10259.99
Grand mean	8644.97	10412.44	10559.40	10559.40
p value	0.031	0.039	0.053	0.053
LSD (0.05)	464.96 *	523.95 *	477.27 ^{ns}	477.27 ^{ns}
WATER REGIME (% ETc)				
100	9182.40	10874.79	11200.18	11200.18
80	9189.54	10914.44	11029.94	11029.94
60	7562.98	9448.09	9448.09	9448.09
Grand mean	8644.97	10412.44	10559.40	10559.40
p value	0.003	0.018	0.008	0.008
LSD (0.05)	936.72 *	1076.68 *	1085.40 *	1085.40 *
NITROGEN LEVEL				
N1	8606.93	10158.23	10293.54	10293.54
N2	8683.02	10666.65	10825.26	10825.26
Grand mean	8644.97	10412.44	10559.40	10559.40
p value	0.789	0.139	0.129	0.129
LSD (0.05)	589.661 ^{ns}	690.567 ^{ns}	702.114 ^{ns}	702.114 ^{ns}
Interaction effects				
IT * WR *(LSD 0.05)*	1355.83 ^{ns}	1556.89 ^{ns}	1562.71 ^{ns}	1562.711^{ns}
p value	0.633	0.628	0.496	0.496
IT * NL *(LSD 0.05)*	793.02 ^{ns}	922.07 ^{ns}	921.03 ^{ns}	921.03 n^{s}
p value	0.295	0.630	0.610	0.610
WR * NL *(LSD 0.05)*	1132.99 ^{ns}	1310.97 ^{ns}	1325.72 ^{ns}	1325.72 ^{ns}
p value	0.150	0.345	0.524	0.524
IT * WR * NL *(LSD 0.05)*	1770.09 ^{ns}	2050.91 ^{ns}	2069.95 ^{ns}	2069.95 ^{ns}
p value	0.334	0.673	0.493	0.493

Appendix Table 7. Mean Value Treatments Effect on Leaf Area Index (LAI)

TREATMENT	**LEAF AREA INDEX (cm^2cm^{-2})**			
	7WAP	**8WAP**	**9WAP**	**10WAP**
IRRIGATION TECHNIQUE				
C-DI	2.50	3.01	3.02	3.02
A-PRD	2.30	2.85	2.93	2.93
F-PRD	2.41	2.81	2.85	2.85
Grand mean	2.40	2.89	2.93	2.93
p value	0.031	0.039	0.053	0.053
LSD (0.05)	0.129 *	0.146 *	0.133^{ns}	0.133^{ns}
WATER REGIME (% ETc)				
100	2.55	3.02	3.11	3.11
80	2.55	3.03	3.06	3.06
60	2.10	2.62	2.62	2.62
Grand mean	2.40	2.89	2.93	2.93
p value	0.003	0.018	0.008	0.008
LSD (0.05)	0.260 *	0.299 *	0.301 *	0.301 *
NITROGEN LEVEL				
N1	2.39	2.82	2.86	2.86
N2	2.41	2.96	3.01	3.01
Grand mean	2.40	2.89	2.93	2.93
p value	0.789	0.139	0.129	0.129
LSD (0.05)	0.164^{ns}	0.192^{ns}	0.195^{ns}	0.195^{ns}
Interaction effects				
IT * WR *(LSD 0.05)*	0.377^{ns}	0.432^{ns}	0.434^{ns}	0.434^{ns}
p value	0.633	0.628	0.496	0.496
IT * NL *(LSD 0.05)*	0.22^{ns}	0.256^{ns}	0.256^{ns}	0.256^{ns}
p value	0.295	0.63	0.61	0.61
WR * NL *(LSD 0.05)*	0.315^{ns}	0.364^{ns}	0.368^{ns}	0.368^{ns}
p value	0.15	0.345	0.524	0.524
IT * WR * NL *(LSD 0.05)*	0.492^{ns}	0.57^{ns}	0.575^{ns}	0.575^{ns}
p value	0.334	0.673	0.493	0.493

Appendix Table 8. Mean Value of The Treatments Effect on Leaf Chlorophyl Content

TREATMENT	CHLOROPHL CONTENT (SPAD)		
	7 WAP	9 WAP	10 WAP
IRRIGATION TECHNIQUE			
C-DI	31.29	43.47	37.02
A-PRD	32.42	43.36	38.58
F-PRD	29.57	47.33	40.2
Grand mean	31.09	44.72	38.6
p value	0.586	0.484	0.643
LSD (0.05)	7.216 ns	9.486 ns	8.905 ns
WATER REGIME (% ETc)			
100	30.13	41.87	36.55
80	30.64	45.62	42.64
60	32.51	46.68	36.60
Grand mean	31.09	44.72	38.60
p value	0.523	0.31	0.042
LSD (0.05)	4.669 ns	6.849 ns	5.282 *
NITROGEN LEVEL			
N1	30.71	43.57	39.28
N2	31.47	45.87	37.92
Grand mean	31.09	44.72	38.6
p value	0.748	0.302	0.54
LSD (0.05)	4.875 ns	4.539 ns	4.571 ns
Interaction effects			
IT * WR *(LSD 0.05)*	8.576 ns	11.962 ns	10.159 ns
p value	0.972	0.649	0.193
IT * NL *(LSD 0.05)*	8.227 ns	9.701 ns	9.251 ns
p value	0.815	0.877	0.864
WR * NL *(LSD 0.05)*	7.271 ns	8.442 ns	7.36 ns
p value	0.178	0.33	0.246
IT * WR * NL *(LSD 0.05)*	12.917 ns	14.785 ns	13.45 ns
p value	0.77	0.534	0.051

Appendix Table 9. Mean Value of The Treatments Effect on The Fresh Yield of Sweet Corn

TREATMENT	FRESH YIELD PARAMETERS (g/plant)			
	SHOOT WET MASS	ROOT WET MASS	KERNEL YIELD	WHOLE YIELD
IRRIGATION TECHNIQUE				
C-DI	299.0	44.6	96.0	439.6
A-PRD	276.7	42.3	76.2	395.2
F-PRD	239.5	28.2	68.3	336.1
Grand mean	271.7	38.4	80.2	390.3
p value	0.016	0.044	0.024	0.011
LSD (0.05)	31.77 *	12.63 *	16.99 *	48.89 *
WATER REGIME (% ETc)				
100	332.1	55.4	97.6	485.0
80	280.0	29.2	93.4	402.6
60	203.2	30.5	49.6	283.2
Grand mean	271.7	38.4	80.2	390.3
p value	<.001	<.001	0.008	<.001
LSD (0.05)	48.28 ***	12.19 ***	29.82 *	70.27 ***
NITROGEN LEVEL				
N1	264.5	35.6	86.9	387.0
N2	279.0	41.1	73.5	393.6
Grand mean	271.7	38.4	80.2	390.3
p value	0.339	0.158	0.096	0.753
LSD (0.05)	30.92 ^{ns}	7.86 ^{ns}	15.94 ^{ns}	43.59 ^{ns}
Interaction effects				
IT * WR *(LSD 0.05)*	71.26 ^{ns}	19.34 ^{ns}	43.51 ^{ns}	104.29 ^{ns}
p value	0.713	0.41	0.63	0.801
IT * NL *(LSD 0.05)*	44.47 ^{ns}	13.93 ^{ns}	23.21 ^{ns}	64.63 ^{ns}
p value	0.155	0.999	0.264	0.649
WR * NL *(LSD 0.05)*	58.75 ^{ns}	14.87 ^{ns}	34.27 ^{ns}	84.55 ^{ns}
p value	0.318	0.359	0.082	0.305
IT * WR * NL *(LSD 0.05)*	93.1 ^{ns}	24.62 ^{ns}	53.03 ^{ns}	134.07 ^{ns}
p value	0.896	0.118	0.881	0.678

Appendix Table 10. Mean Value of The Treatments Effect on Dry Matter Yield of Sweet Corn.

TREATMENT	DRY MATTER (DM) YIELD		
	SHOOT DM	ROOT DM	TOTAL DM
IRRIGATION TECHNIQUE			
C-DI	68.59	19.99	88.58
A-PRD	68.14	19.71	87.85
F-PRD	58.19	14.1	72.29
Grand mean	64.97	17.93	82.91
p value	0.069	0.009	0.034
LSD (0.05)	9.722 ^{ns}	2.948 *	12.115 *
WATER REGIME (% ETc)			
100	74.84	24.15	99.0
80	65.63	14.94	80.56
60	54.45	14.72	69.17
Grand mean	64.97	17.93	82.91
p value	<.001	<.001	<.001
LSD (0.05)	8.629 ***	4.509 ***	11.85 ***
NITROGEN LEVEL			
N1	62.16	17.76	79.92
N2	67.78	18.11	85.89
Grand mean	64.97	17.93	82.91
p value	0.11	0.83	0.186
LSD (0.05)	7.013 ^{ns}	3.357 ^{ns}	9.123 ^{ns}
Interaction effects			
IT * WR *(LSD 0.05)*	14.009 ^{ns}	6.651 ^{ns}	18.747 ^{ns}
p value	0.891	0.266	0.733
IT * NL *(LSD 0.05)*	11.423 ^{ns}	4.621 ^{ns}	14.542 ^{ns}
p value	0.394	0.752	0.416
WR * NL *(LSD 0.05)*	11.639 ^{ns}	5.833 ^{ns}	15.569 ^{ns}
p value	0.949	0.512	0.825
IT * WR * NL *(LSD 0.05)*	19.682 ^{ns}	9.368 ^{ns}	25.95 ^{ns}
p value	0.332	0.301	0.278

Appendix Table 11. Mean Value Summary of The Treatments Effect on The Water Productivity (WP) in Yield of Sweet Corn

TREATMENT	WATER PRODUCTIVITY (kg/m^3)	
	KERNEL WEIGHT	DRY BIOMASS
IRRIGATION TECHNIQUE		
C-DI	0.36	0.34
A-PRD	0.29	0.34
F-PRD	0.26	0.28
Grand mean	0.3	0.32
p value	0.025	0.014
LSD (0.05)	0.06 *	0.036 *
WATER REGIME (% ETc)		
100	0.3	0.3
80	0.36	0.31
60	0.25	0.35
Grand mean	0.3	0.32
p value	0.139	0.071
LSD (0.05)	0.106 ^{ns}	0.046 ^{ns}
NITROGEN LEVEL		
N1	0.33	0.31
N2	0.28	0.34
Grand mean	0.3	0.32
p value	0.055	0.123
LSD (0.05)	0.054 ^{ns}	0.034 ^{ns}
Interaction effects		
IT * WR *(LSD 0.05)*	0.155 ^{ns}	0.07 ^{ns}
p value	0.599	0.786
IT * NL *(LSD 0.05)*	0.08 ^{ns}	0.05 ^{ns}
p value	0.119	0.454
WR * NL *(LSD 0.05)*	0.121 ^{ns}	0.059 ^{ns}
p value	0.051	0.582
IT * WR * NL *(LSD 0.05)*	0.186 ^{ns}	0.096 ^{ns}
p value	0.693	0.221

Appendix Table. 12. Mean Value of The Treatments Effect on The Nitrogen Uptake and Nitrogen Use Efficiency

TREATMENT	NITROGEN (N) UPTAKE AND NUE			
	SHOOT N UPTAKE	ROOT N UPTAKE	TOTAL N UPTAKE	NUE
IRRIGATION TECHNIQUE				
C-DI	1450.33	151.46	1601.8	0.06
A-PRD	1012.91	113.13	1126.04	0.08
F-PRD	912.06	113.13	1025.19	0.08
Grand mean	1125.1	125.91	1251.01	0.07
p value	<.001	<.001	<.001	<.001
LSD (0.05)	209.566***	18.659***	212.528***	0.003***
WATER REGIME (% ETc)				
100	1648.58	160.95	1809.54	0.06
80	1036.63	108.43	1145.06	0.07
60	690.09	108.34	798.43	0.09
Grand mean	1125.1	18.659	1251.01	0.07
p value	<.001	<.001	<.001	<.001
LSD (0.05)	209.566***	125.91***	212.528***	0.003***
NITROGEN LEVEL				
N1	1030.59	120.29	1150.88	0.08
N2	1219.62	131.53	1351.14	0.07
Grand mean	1125.1	125.91	1251.01	0.07
p value	0.031	0.143	0.025	0.019
LSD (0.05)	171.11**	15.235*	173.529**	0.003**
Interaction effects				
IT * WR *(LSD 0.05)*	362.979	32.318	368.11	0.006
p value	<.001***	<.001***	<.001***	<.001***
IT * NL *(LSD 0.05)*	296.371	26.387	300.561	0.005
p value	0.242 ns	0.377 ns	0.288 ns	<.001***
WR * NL *(LSD 0.05)*	296.371	26.387	300.561	0.005
p value	0.02*	0.509 ns	0.026*	<.001***
IT * WR * NL *(LSD 0.05)*	513.33	45.704	520.586	0.008
p value	0.007**	0.006**	0.008**	<.001***