BINDURA UNIVERSITY OF SCIENCE EDUCATON

DEPARTMENT OF CROP SCIENCE

THE EEFECTS OF DIFFERENT WATERING FREQUENCIES ON THE EARLY GROWTH STAGES OF SOYABEANS.

FACULTY OF AGRICULTURE AND ENVIRONMENTAL SCIENCE

A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE BACHELOR OF AGRICULTURAL SCIENCE HONOURS DEGREE IN CROP SCIENCE

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CERTIFICATION

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DEDICATION

The dissertation is dedicated to my father, Sebastian Chichetu.

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I express my deep gratitude to Professor Mandumbu, my project supervisor, for his consistent support and guidance during the project. I am appreciative of the moral support and understanding provided by my father and friends throughout my academic journey. Above all, I am thankful for the guidance and support from the Devine Being.

ABSTRACT

Soybean is an important crop cultivated worldwide, providing essential nutrition for both humans and animals. This study examines the influence of different watering frequencies on the early-stage growth of soya bean plants using a Randomised Complete Block Design (RCBD) experiment. The experiment spanned four months and involved subjecting soya bean plants to varied watering schedules, including daily, every three days, weekly, and every ten days. Various growth parameters, including the height of the plants, the area of their leaves, the quantity of dry matter, and the quantity of leaves per plant, were measured and analysed. The results indicate that watering frequency significantly affects the growth and output of soya beans. Crops receiving daily watering exhibited higher growth rates and outperformed those with less frequent watering in all measured parameters. The study also highlights the importance of optimal watering regimes to maximise soya bean production while emphasizing the need for water conservation and sustainable agricultural practices. These findings provide valuable insights for farmers and agricultural practitioners aiming to enhance soya bean production through efficient water management strategies.

TABLE OF CONTENTS

List of figures

List of Tables

List of Appendices.

List of acronyms and abbreviations

Mt	Metric tons
FAO	Food Agricultural Organisation
ICRISAT	International Crops Research Institute for the semi-Arid Tropics
ARC	Agricultural Research Council
CBD	Central Business District
ANOVA	Analysis of Variance
LSD	Least Significant Difference

CHAPTER 1

1 Introduction

1.1 Background

Soya bean *(Glycine max)* is a plant indigenous to Southeast Asia that grows best in subtropical climates, (Sandler, 2017). Soya bean *(Glycine max)* is a leguminous crop and belongs to the family (*Fabaceae)* and sub-family *(Faboideae)*. Soybeans provide oil, protein, and additional nutrients for both human consumption and as a component in animal feed (Ali W. , 2020). According to Cheng, (2016), soya bean is an important crop used in food production, pharmaceuticals, animal feed, and bioenergy.

Soybean is a legume that can be grown in a variety of environments and has a wide range of uses, making it an important crop for global food security and sustainability, (Cheng, 2016). According to Milazzo, (2013), soybean production has seen a rise in recent years owing to the plant's nutritional significance and it's utilization in the production of biofuels. It is categorized primarily as an oilseed crop rather than a pulse (Devi. K. N. & Singh, 2012). Soybeans were first cultivated for their ability to fix nitrogen in the soil, rather than as a food crop. It was only later that they were recognized for their nutritional value and began to be used more widely in food production (Bryant. & Babu, 2016).

National Foods, one of the largest food processing and distribution companies in Zimbabwe, uses soybeans as an ingredient in many of its products, including cooking oil, flour, and livestock feed. According to Zimbabwe National Chamber of Commerce, (2022), National Foods sources soybeans from local farmers and processes them into various products. The company has invested in infrastructure and technology to support soybean processing, making it a key player in the country's soybean industry.

According to Rahman, M. M., (2011), soybean seeds have a composition of approximately 40-45% protein, 20-22% oil, and 20-26% carbohydrates. They are also rich in essential nutrients such as calcium, phosphorus, and vitamins. Additionally, soybean seeds contain around 3% lecithin, which is beneficial for brain development. Soybean is a significant contributor to the global production of oil crops, accounting for about 50% of total output (Prakash & Kumar, 2015). Soybean has become the leading source of edible oils and fats, accounting for around 20% of the global stock. This makes it the largest single source of this essential component in the global food market.

Studies conducted by Malik, M. F. A., (2006) have indicated that soybean oil is predominantly composed of unsaturated fatty acids, making up about 85% of its content. Notably, it is free from cholesterol, making it a healthier alternative to other oils. The protein content of soybean is considered well-balanced, as it contains essential amino acids in adequate proportions. This makes soybean protein a valuable source of high-quality nutrition (Dugje, I. Y., 2009).

In summary, soybean seeds offer a rich nutritional profile with significant protein, oil, and carbohydrate content. They are also abundant in essential nutrients and vitamins. Soybean's dominance in the oil crop market, its cholesterol-free unsaturated fatty acids, and its well-balanced protein composition make it a highly valued food source.

Over the last decade, Zimbabwe has produced an average of 56,000 metric tons of soybeans each year, which falls far short of the country's demand for 240,000 metric tons for food, animal feed, and industrial uses (FAO, 2021). According to the (FAO, 2021), the projected increase in soybean production in the current growing season points to the need for irrigation to boost the production of this strategically important crop. Also the production has increased due to the growing demand for soybean-based protein (Voora, A. 2020).

Currently, commercial farmers on large scale-farms (A1 and A2) account for 70% of soybean production, while small holder farmers produce the remaining 30%. The average national yield per hectare for commercial farmers has been below 1.3 metric tons (mt), while smallholder farmers have had a yield of 0.5 mt per hectare. The United States, Brazil, Argentina, and China stands as the leading soybean production countries, boasting a yield per hectare that exceeds 3.5 mt (FAO, 2021).

Soybean farming in Zimbabwe is influenced by the country's diverse climate, which varies from region to region. According to (ICRISAT, 2021) there is a significant variation in rainfall patterns in Zimbabwe, with the northern region receiving more rainfall than the southern region. This makes water availability a critical factor in agricultural production, including soybean farming (ICRISAT, 2021). Soya beans require a certain amount of water for successful germination, vegetative growth, flowering, and pod development. Farmers in Zimbabwe need to be aware of the water requirements of soybeans in order to achieve optimal yields (ARC, 2020).

In Zimbabwe, where water resources are frequently scarce and unreliable, it becomes particularly crucial to comprehend the implications of various watering frequencies on soybean production. This is because limited or inconsistent water availability can have adverse effects on the growth and yield of soybeans. By gaining insight into the impact of different watering frequencies on soybean production, farmers are now able to make more informed and strategic choices when it comes to managing their irrigation practices, thereby promoting a more sustainable and efficient utilization of water resources. It is imperative for farmers to optimize water use efficiency and identify the most suitable irrigation strategies to attain maximum yields while conserving water resources (Singh, 2012).

1.2 Problem statement

Extensive research on the influence of different watering frequency on the growth and output of soybeans has not been conducted, resulting in a lack of clarity regarding the ideal watering frequency for achieving maximum growth and sustainability. It is crucial to investigate the effects of various watering schedules on soya bean growth, including parameters such as plant development, leaf area index, chlorophyll content, and dry matter accumulation and root development. This experiment aims to fill this informational void, by comparing the growth and physiological responses of soya beans watered at daily, three-day interval, seven-day interval and ten day interval frequencies from the first week of emergence to the 8th week, valuable insights can be gained regarding optimal watering practices for enhancing soya bean production, these findings will aid in the advancement of effective water management tactics and sustainable approaches in the cultivation of soya beans.

1.3 Justification

In Zimbabwe, particularly in the regions 2 and 3where soya bean production is concentrated, water is a scarce resource and the available supply is becoming increasingly uncertain due to climate change and growing population. Currently, many small-scale farmers in the region rely on rain-fed agriculture, which is unreliable and often leads to crop failures (Ministry of Lands, 2022). Irrigation systems in the regions are also largely underdeveloped and inefficient, leading to further waste of water resources. According to Hatfield, (2019) in order to increase soybean productivity and ensure food security for a growing population, it is crucial to understand how different irrigation strategies impact soybean growth and water use efficiency, in order to develop strategies that maximize plant growth while minimizing water use. This research will provide information that can be used to develop improved irrigation management strategies, which could result in increased plant's growth and more sustainable water use. Additionally, these findings could inform future policy decisions related to water management and agricultural production in Zimbabwe and other countries facing similar challenges.

1.4 Aim

The aim of this research study is to determine the effects of different watering frequencies on the early growth stages of soya bean.

1.5 Objectives

- To compare the effects of different watering frequencies on the growth, leaf area index, chlorophyll content, dry matter accumulation and root development of soya beans watered at daily interval from the first week of emergence to the 8th week.
- To compare the effects of different watering frequencies on the growth, leaf area index, chlorophyll content, dry matter accumulation and root development of soybeans watered at three days interval from the first week of emergence to the 8th week.
- To compare the effects of different watering frequencies on the growth, leaf area index, chlorophyll content, dry matter accumulation and root development of soybeans watered at seven days interval from the first week of emergence to the 8th week.
- To compare the effects of different watering frequencies on the growth, leaf area index, chlorophyll content, dry matter accumulation and root development of soybeans watered at ten days interval from the first week of emergence to the 8th week.

1.6 Hypothesis

H_1 -Soybeans irrigated daily will have higher biomass accumulation, height, large leaf area index high percentage of chlorophyll content and root system development than those irrigated every 3 days, which in turn will have higher biomass accumulation, height, large leaf area index, high percentage of chlorophyll content and root system development than those irrigated weekly.

CHAPTER 2

2 Literature Review

This literature review aims to explore the effects of different watering frequencies on the early growth stages of soybeans. Adequate water availability is crucial for optimising the growth of soya bean in agriculture. (Souza, 2013). However, understanding the impact of different watering frequencies on soybean plants is essential for efficient water management strategies and sustainable agricultural practices (Johnson & Purcell, 2015). This review synthesizes existing research studies to provide insights into the relationship between watering frequencies and soybean growth.

2.1 Watering Frequency and plant physiology.

2.1.1 Water stress effects on soya bean plants.

Different watering frequencies were said to have effects on the growth of soya beans (Ogunkanmi, 2021). According to Ogunkanmi, L., (2021), water stress can take the form of either a deficit (i.e. the plant does not have enough water) or an excess (i.e. the plant has too much water). A plant that is experiencing water stress due to a deficit may show signs such as wilting, leaf rolling, and reduced growth (Bhattacharya, 2021). A plant that is experiencing water stress due to an excess may show signs such as reduced root growth, root rot, and leaf chlorosis (Ogunkanmi, 2021). Both forms of water stress can adversely impact the growth of the soybean plants.

According to Siamabele, B. (2021), soya beans have relatively small and underdeveloped root systems compared to other crops, and they have high water demand throughout their life cycle. The root system is particularly sensitive to harsh conditions, such as drought, which can cause yield reductions ranging from 25% up-to 50% (Seleiman, et al., 2021). According to Liu, Y., (2021), the symbiotic relationship between soybeans and rhizobia is indeed dependent on sufficient water. When soybeans are water-stressed, the roots of the plant can become damaged, reducing the ability of the rhizobia to attach to the roots and form nodules (Liu, *et al*., 2021). The root tissues transport oxygen from the shoots to the nodules, maintaining an oxygen-rich environment necessary for the activity of nitrogenase enzymes responsible for nitrogen fixation (Gupta, A., 2017). Nodules are small swellings on the roots that contain the rhizobia, where they fix nitrogen from the atmosphere and convert it into a form usable by the plant (Liu, *et al*., 2021). According to Liu, Y., (2021), water stress can limit nodule formation and, as a result, limit the plant's ability to access nitrogen from the soil.

An overabundance of water, such as flooding, can also adversely impact the productivity and output of soybeans. Excess water can disrupt the absorption of oxygen and nutrients by the roots, and can lead to anaerobic conditions that are not suitable for the plant's root system (Afzal, *et al*., 2023). According to Yan, H., (2022), excess water can lead to the development of fungal diseases, such as root rot, which can further affect the plant's ability to grow and produce yield. When soybean plants experience water stress due to a watering frequency of more than 1 week interval, their leaves may wilt or become droopy due to a lack of turgor pressure (Bhattacharya, 2021). Additionally, water stress can cause chlorosis or yellowing of leaves as a result of reduced chlorophyll production (Bhattacharya, 2021).

Different watering frequencies have effects on the early growth stages of soybean plants. According to Oropeza, (2018), under-watering or over-watering can increase the susceptibility of soya bean plants to diseases and pests. Water stress weakens the plant's immune system, making it more vulnerable to attack from pathogens and pests (Oropeza, W.A., 2018). Some of the most common diseases that can affect soybean plants under water stress include stem canker, stem rot, bacterial blight, and soybean rust (Roth, *et al*., 2020).

According to Hodaei, M., (2018), water stress reduces the plant's ability to produce phytochemicals that act as defence compounds, making the plant more vulnerable to attack and it can also weakens the plant's cell walls, allowing pathogens to more easily penetrate the plant tissue. Under-watering or over-watering can reduce the plant's ability to produce new tissue, preventing it from replacing infected or damaged tissue (Hodaei, 2018). Waterlogging can create conditions that are conducive to the growth of fungal pathogens, which can further damage the plant (Huang, B., 2000). Over watering can leads to the promotion of Fusarium root rot in soybean (Afzal, *et al*., 2023).

Water stress, whether due to under-watering or over-watering, can cause premature senescence in soybean plants. Premature senescence is usually caused by an increase in the production of reactive oxygen species, which can damage plant cells and cause death (Djanaguiraman & Prasad, 2010). This premature senescence will then cause the reduction in yield of soya bean. According to Djanaguiraman, (2010), the combination of stunted growth, nutrient deficiencies, disease susceptibility, and poor root development ultimately leads to reduced yield potential in soybean plants.

2.1.2 Physiological Responses to different watering frequencies.

The physiological responses of soybeans to different watering frequencies can have a significant impact on their productivity and output (Wang, *et al*., 2022). According to Bhattacharya, (2021), adequate watering of soybean plants is essential for their survival and growth, as it ensures sufficient water uptake by the roots, allowing the plants to maintain turgidity and carry out physiological processes such as photosynthesis, nutrient uptake, and transpiration.

Watering frequency can have a significant impact on the transpiration rate of soybean plants, which in turn affects their growth and yield (Sadok, 2021). Soybean plants grown under frequent watering have a higher transpiration rate than those grown under less frequent watering, as frequent watering ensures a continuous supply of water to the roots, leading to increased water uptake and transpiration (Sadok, 2021). According to Sadok, W., (2021), Over-frequent watering of soybean plants can lead to excessive transpiration, as the plants may not be able to use all the water being supplied to them. This can result in the water being lost to evaporation, rather than being used by the plants for their physiological processes. On the other hand, infrequent watering can cause water stress, leading to a lower transpiration rate and reduced growth (Puértolas, 2020).

According to Wang, (2021), different watering frequencies have effects on the physiological response of the soya bean plant. Excess watering can cause soybean plants' stomata to close, reducing their gas exchange and photosynthesis, and leading to slow growth and reduced yield (Wang, *et al.*, 2022). This is because the roots of the plants are saturated with water, and as a result, the plants perceive a lack of water and close their stomata to conserve water. This reduces the plants' photosynthetic capacity, as they are not able to take in the necessary carbon dioxide for photosynthesis (Wang, *et al*., 2022).

Infrequent watering, can also cause the stomata of soybean plants to close. According to Proctor, J., (2022), when soya bean plants are not irrigated enough on a regular basis, the limited water supply causes the plants to conserve water by reducing the amount of water they release through their stomata. This reduction in water loss from the stomata also leads to a decrease in carbon dioxide uptake, which is essential for photosynthesis (Yin, *et al.*, 2020).

According to Yin, Q., (2020), when water is scarce, soybean plants will reduce their leaf area in order to conserve water and minimize water loss through the stomata. When water availability is limited, soya bean plants will respond by decreasing their leaf area in an effort to conserve water and minimize water loss (Bhattacharya, 2021). In contrast, when water availability is abundant, soybean plants will respond by increasing their leaf area to take advantage of the available water and nutrients (Xiong & Considine, 2021).

The root development of soybean plants is also affected by different watering frequencies, and this can have a significant impact on the plants' overall physiological response (Naruse, 2022). According to Naruse, T., (2022), when water is over-abundant, soybean plants may develop shallow roots that are less effective at absorbing water and nutrients. Shallow roots may also be less effective at anchoring the plants, making them more susceptible to uprooting during windy conditions (Ennos, A., 2000).

Overwatering soybean plants can have detrimental effects, including reduced root growth, nutrient uptake, and photosynthesis (Hafeez, *et al*., 2023). This can delay the plants' maturity, reducing their overall yield and potentially leading to crop failure (Hafeez, *et al*., 2023). It has shown that even a single instance of overwatering can have lasting effects, with negative impacts on the plants' yield. When soybean plants experience under-watering, or a lack of sufficient irrigation, it can delay their maturity and negatively impact their growth (Zhaocai, X., 2018). According to Martin *et al*. (2019), under-watered soybean plants had longer root systems and fewer leaves, leading to delayed maturity. Zhaocai, X., (2018) also noted that even a mild level of water stress can cause significant changes in plant growth and photosynthesis. The study also noted that under-watered plants are more susceptible to lodging.

2.2 Growth Parameters.

2.2.1 Plant height

Water plays a vital role in the growth and development of soya beans. Ensuring a sufficient water supply is essential for fostering ideal plant growth and attaining favourable crop yields (Ali & Talukder, 2008). According to Garcia, A. (2010), the watering frequency, also known as the irrigation regime, is a critical factor in determining the water availability for soybean plants. By altering the frequency of watering, we can observe noticeable impacts on different growth characteristics, such as the height of the plants.

According to Sharma, S., (2021), overwatering can cause waterlogged soil, which can lead to reduced plant height. This occurs because waterlogging deprives the roots of oxygen, which causes them to decay (Balakhnina, 2015). Overwatering can cause nutrients to be leached from the soil, resulting in deficiencies that further impact plant height and contribute to stunted growth or plant height (Huang, 2000).

According to Grassini, P., (2021), when soybean plants receive limited water, they adapt by prioritizing vertical growth. This behaviour serves as a survival strategy since taller plants have a better chance of absorbing sunlight and generating flowers and seeds. The plant's energy is primarily allocated to elongating the stem instead of developing lateral branches and leaves (Bhattacharya, 2021). This may lead to the growth of a tall and slender plant with minimal branches and leaves (Grassini, 2021).

According to Wang, X., (2022), when soybean plants are given frequent watering, they respond by focusing their energy on lateral branching and leaf production. The plant exhibits a shorter, denser growth form with increased branching and leaf production. This outcome arises from the plant's ability to allocate more energy towards these growth processes when provided with an adequate water supply, rather than prioritizing survival mechanisms such as elongating the stem (Wang, X., 2022).

Varied watering schedules plays a crucial part in the generation and movement of plant hormones. According to Bhattacharya, A., (2021), water availability influences the production and transport of plant hormones, such as auxins, which play a crucial role in promoting cell elongation. Adequate watering helps maintain proper hormone balance, facilitating vertical growth and contributing to increased plant height (Bhattacharya, 2021).

According to Mazzoni-Putman, S. M., (2021), auxins are a class of plant hormones that regulate various aspects of plant growth and development, including cell elongation. They are synthesized in the growing tips of shoots and roots and then transported throughout the plant (Mazzoni-Putman, 2021). According to Bhattacharya, A., (2021) when water is readily available, plant roots absorb water and minerals from the soil. These minerals serve as essential components for auxin synthesis. Adequate water uptake ensures a sufficient supply of minerals, supporting optimal auxin production (Mazzoni-Putman, 2021). Once synthesized, auxins move through the plant via polar auxin transport, which involves both active and passive processes (Casanova-Sáez, 2021). Water is crucial for maintaining the flow of auxins through the plant's vascular system (Mazzoni-Putman, 2021). The presence of water ensures the proper dissolution and movement of auxins within the plant tissues, allowing them to reach the target sites where they exert their effects (Bhattacharya, 2021).

According to Du, M., (2020), auxins stimulates cell elongation by relaxing the cell wall, allowing it to expand without rupturing. They stimulate the uptake of water by the cells, leading to increased turgor pressure and subsequent elongation (Spalding, 2020). Sufficient water availability provides the necessary water for cell expansion, enabling auxins to effectively stimulate elongation and contribute to vertical growth. According to Bhattacharya, A., (2021), when plants experience water stress or insufficient watering, auxin production and transport may be affected.

Inadequate water availability can disturb auxin synthesis, resulting in decreased hormone levels (Mazzoni-Putman, 2021). Furthermore, insufficient water can impede the transport of auxins within the plant, impacting their distribution to the intended tissues (Bhattacharya, 2021). As a result, inadequate water availability can negatively impact cell elongation and vertical growth (Bhattacharya, 2021). Without sufficient auxins and water for cell expansion, plants may exhibit stunted growth and reduced plant height (Bhattacharya, 2021). Maintaining an appropriate water balance through adequate watering ensures the presence of sufficient auxins, which support their efficient transportation throughout the plant (Bhattacharya, 2021). This, in turn, promotes cell elongation, vertical growth, and ultimately results in an elevation in plant height.

According to Williams, (2022), when soybean plants experience water stress, their vulnerability to diseases and pests increases. Stressed plants tend to allocate their resources towards survival mechanisms instead of vertical growth, leading to a decrease in plant height (Bhattacharya, 2021).

2.2.2 Leaf Area Index

Leaf Area Index is the ratio of the total leaf area of a plant to the area of the ground that the plant covers (Parker, 2020). It is typically expressed as a numerical value or percentage. The higher the leaf area index, the more leaf area the plant has, and the more efficient it is at photosynthesis (Parker, 2020). Watering frequency can influence leaf area index by affecting the overall growth and development of the plant.

Leaf area index is an important metric that evaluates the density and photosynthetic capacity of a plant canopy by measuring the total leaf surface area relative to the ground area (Parker, 2020). Leaf are index is impacted by various environmental elements, such as the availability of water and the methods used for water management, including watering frequency. According to Bhattacharya, A., (2021), water is a fundamental requirement for plant growth, and soybean plants, in particular, rely on sufficient water supply for optimal development. The frequency of watering directly impacts the availability of water to plants, subsequently influencing physiological processes such as leaf growth and ultimately affecting the leaf area index (Wang, X., 2022).

According to Bhattacharya, A. (2021), insufficient watering frequency can result in water stress for soybean plants, which can subsequently have an adverse effect on their leaf area index (LAI). Water stress occurs when plants do not receive a sufficient amount of water to meet their requirements. In the case of soybean plants, this can cause the leaves to wilt and shrink in size, ultimately resulting in a reduction in the overall leaf area. The leaf area index, which represents the ratio of leaf surface area to ground area, may decrease when soybean plants experience water stress due to infrequent watering (Kumar, S., 2022). To promote ideal growth and robust leaf area index in soya bean plants, it is crucial to supply them with adequate and consistent watering (Bhattacharya, 2021).

Excessive watering can have detrimental effects on the (LAI) of soya bean plants. According to Ploschuk, R., A., (2022), when soybean plants receive excessive amounts of water, it can lead to waterlogging or saturated soil conditions. This excess water can cause oxygen deprivation in the root zone, creating an unfavourable environment for the roots (Sathi, 2022). When the root zone undergoes oxygen deprivation, it impairs the roots' capacity to absorb essential nutrients from the soil (Bhattacharya, 2021). Proper plant nutrition is a fundamental factor in determining the overall growth, development, and physiological processes of plants, including the formation and maintenance of the plant's leaf canopy. In particular, obtaining crucial nutrients such as nitrogen, phosphorus, and potassium is essential for the growth of leaves (Shrivastav, 2020).

According to Lutts, S., (2019), when nutrient uptake is compromised due to waterlogging, it can result in stunted plant growth, including reduced leaf area. Overwatering can also lead to the development of root diseases and increased susceptibility to fungal infections, which can further impact plant health and leaf area (Lutts, S., 2019). According to Jemo, M., (2023), the presence of excess moisture can create a favourable environment for pathogens to thrive and attack the roots, compromising the overall vigour of the soybean plants.

A consistent and adequate watering schedule is essential for maintaining optimal leaf area index in soya bean plants (Wang, 2022). This ensures that the plants have enough water to support healthy leaf growth and expansion without experiencing water stress or excess moisture (Wang, 2022). According to Amoanimaa-Dede, H., (2022), young soybean seedlings often benefit from frequent watering to facilitate the establishment of robust root systems and encourage leaf growth. On the other hand, mature soybean plants typically require less frequent watering, but with deeper irrigation, as they have larger sizes and higher water demands (Amoanimaa-Dede, 2022).

2.2.3 Biomass Accumulation

Biomass accumulation in soybean plants refers to the process of increasing the total dry weight or mass of plant tissues over time (Toleikiene, 2021). According to Raza, M., (2021), biomass accumulation in soybean plants arises from a combination of physiological processes, including photosynthesis, nutrient uptake, and plant growth. This process holds significant importance for soybean cultivation since it directly impacts the overall productivity and yield of the crop (Raza, 2021).

According to Raza, (2021), during biomass accumulation, soybean plants undergo several stages of growth, including vegetative growth, flowering, and pod development. These stages involve the formation and expansion of leaves, stems, and reproductive structures such as flowers and pods. The primary source of biomass in soybean plants is the photosynthetic activity occurring in the leaves, where carbon dioxide (CO2) is converted into carbohydrates through the process of photosynthesis (Li, 2013).

The biomass accumulated in soybean plants consist of diverse plant parts such as leaves, stems, roots, and reproductive structures. According to Rezaei, (2023), the distribution of biomass among these plant parts can vary due to factors such as genetics, environmental conditions, and management practices, including watering frequencies. According to Jumrani, K., (2018), the presence of water significantly influences the allocation of biomass within soybean plants. Watering frequencies can impact plant growth and influence the allocation of biomass among various plant parts (Rezaei, *et al*., 2023). For example, when soybean plants are subjected to frequent and adequate watering, they are more likely to allocate biomass towards leaf development and expansion. This is because sufficient water availability supports photosynthesis and promotes leaf growth, resulting in a higher biomass allocation to leaves (Souza, 2013). According to Souza, G. M., (2013), when soya bean plants are not watered frequently enough, they may experience water stress, which can hinder their ability to photosynthesize effectively. According to Souza, G., (2013), water stress in soybean plants can diminish biomass accumulation by impairing photosynthetic efficiency through several mechanisms.

According to Murata, Y., (2013), water stress can lower stomatal conductance, which hampers the exchange of gases such as CO_2 and O_2 between the plants and the atmosphere. The reduced availability of CO_2 limits the capacity for photosynthesis (Murata & Mori, 2013). According to Wahab, A., (2022), water stress can decrease the activity of Rubisco, an enzyme crucial for photosynthesis. By inhibiting Rubisco, water stress directly impedes the plant's ability to convert CO_2 into organic compounds, further hampering biomass accumulation (Wahab, *et al*., 2022).

Excessive water in the soil can lead to waterlogged conditions, which restrict the availability of oxygen in the root zone (Akhtar, 2013). Oxygen is essential for proper root respiration and growth. When roots are deprived of oxygen, their growth is impeded, resulting in reduced nutrient uptake and impaired biomass accumulation (Sousa, 2002). Insufficient nutrient uptake in soybean plants hampers their capacity to synthesize organic compounds, which in turn has a direct impact on biomass production.

Overwatering increases the risk of root rot and other diseases that thrive in waterlogged conditions (Carminatti, H., 2020). Pathogens such as fungi and bacteria can proliferate in excessively wet soil, causing root infections and impairing root function. According to Fageria, N. K., (2011), diseased or damaged roots are less efficient in nutrient absorption, leading to reduced nutrient availability for biomass production. Furthermore, compromised root systems are less capable of providing structural support to the plant, potentially resulting in stunted growth and decreased biomass accumulation (Carminatti, H., 2020).

Achieving the optimal balance in watering frequency is essential for maximizing biomass accumulation in soybean plants (Fageria, 2011).

CHAPTER 3

3. Materials and methods

In this chapter, a concise overview is provided regarding the experimental period, location climatic conditions, planting materials, treatments applied, experimental design and layout, cultivation procedures for the crop, watering practices, methods employed for data collection and the statistical analysis conducted.

3.1 Trial site

The research was conducted at Bindura University of science Education, specifically at Astra Campus, situated in Natural region 2b of Zimbabwe. The Astra Campus is located approximately 0.9km from Bindura CBD along Trojan road, with coordinates at -17.30192 latitude and 31.33056 longitude. The experiment took place from February 2024 to April 2024. In natural region 2b, the annual rainfall ranges between 650mm and 1000mm, and the climate is characterised by mid-season dry spells. During summer, temperatures range from 27^0C to 38^0C, while in winter, they range from 10^0C to 25^0C.

3.2 Research Design

3.2.1 Experimental design and treatments

The research was laid out using a Randomised Complete Block Design with one factor, watering frequency. There were four treatments in total, which include daily watering, watering every 3 days, watering every 7 days and watering every 10 days. Each treatment was replicated five times, resulting in a total of 20 pots. The randomisation of the experiment was implemented to ensure statistical validity.

3.3 Soil type used

Organic potting soil collected from the University nursery was used for the experiment. To achieve moisture equilibrium, the soil was sun-dried for 3 days. The soil was placed in black plastic pockets with a diameter of 20cm and a height of 25cm. The weight of the soil in each pocket was measured. Before planting, the pots were uniformly watered with an equal amount of water. To represent a natural open-field conditions, the pot were placed in a secured open area.

3.4 Planting

The seeds were sown in the pots one day after watering. Four seeds were placed in each pot, with one seed positioned at the centre at a depth of 3 cm. After placing the seeds, they were properly covered with soil. Following the planting process, the pots were also evenly watered.

3.5 Thinning

After germination, two soya bean plants were placed in each pot to ensure the normal growth of the soya bean crop.

3.6 Watering

Watering was administered according to the treatment immediately after germination, and the watering intervals were constantly maintained.

3.7 General observation of the experimental Pots

Daily observations were made to monitor the growth stages of the soybean crops. Generally, the soybean plants in the daily watered treatment exhibited a higher growth rate compared to other treatments. Weeding was performed whenever weeds were observed in the pots. Disease symptoms were more noticeable in the treatments that were watered at intervals of 7 and 10 days. Some of the disease symptoms included damping off and wilting of the soybean plants.

3.8 Data collection

Data were collected on 2 weeks interval. Data collected include plant height, leaf area index, chlorophyll content, leaf length and width and number of leaves per plant. A ruler was used to measure dimensions and then a chlorometer was used to measure chlorophyll content. Leaf area index was calculated using the formula below:

Leaf Area Index = $\quad$ ***length × width × 0.7***

3.8.1 Leaf, Stem and Root dry weight

At the end of the trials, soya bean plant from each pot were harvested and the leaves, stems and roots were separated with a scalpel. The roots were thoroughly cleaned with running water to remove all of the soil. They were then packed in clearly labelled separate envelops and then baked in an oven at 70 degrees Celsius for 24 hours. Subsequently, a digital balance scale was utilized to measure the dry weight of the samples.

3.9 Data Analysis

3.9.1 Statistical analysis

Data was statistically analysed by analysis of variance (ANOVA) appropriate for Randomised Complete Block Design using Genstat. Means were compared using LSD test at 5% level of probability.

CHAPTER 4

4.1 Effects of different watering frequencies on the leaf area of soya beans.

There was a significant ($P<0.05$) difference in the leaf area for all four watering frequencies (1, 3, 7, and 10 days) in weeks 1, 3, and 4 (Figure 4.1). The highest mean leaf area was observed and found to be in plants whose watering frequency was after every 1 day. These were followed by 3 days, 7 days, and 10 days. In week 2 there was no significant ($P>0.05$) difference in the leaf area for all four watering frequencies.

Watering Frequency (days)	Leaf Area 1WAP (cm^2)	Leaf Area 2WAP (cm^2)	Leaf Area 3WAP (cm^2)	Leaf Area 4WAP (cm^2)
1	3.13^{a}	9.14	13.23^{a}	19.35^{a}
3	1.74^{b}	7.39	9.19^{b}	14.64^{b}
7	1.19^{b}	6.04	7.42^{b}	11.24^{c}
10	0.85^{b}	6.05	6.44^{b}	9.17^{c}
P-Value	<0.001	0.146	<0.001	<0.001
SED	0.392	NS	1.347	1.372
cv%	39.3	34.9	25.7	17.5

NB: Means followed by different letters are significantly different at P<0.05. NS means there is no significant difference.

Table 1 Effects of different watering frequencies on the leaf area of soya beans

4.2 Effects of different watering frequencies on the chlorophyll content of soya bean leaves.

There was a significant ($P<0.05$) difference in the chlorophyll content for all four watering frequencies (1, 3, 7, and 10 days) (Figure 4.2). The highest chlorophyll content was observed and found to be in plants whose watering frequency was after every 1 day.

Watering Frequency (days)	Chlorophyll ($mmolcm^{-2}$) 1WAP	Chlorophyll ($mmolcm^{-2}$) 2WAP	Chlorophyll ($mmolcm^{-2}$) 3WAP	Chlorophyll ($mmolcm^{-2}$) 4WAP
1	15.75^{a}	20.15^{a}	13.85^{a}	27.33^{a}
3	13.43^{a}	16.75^{b}	14.92^{a}	22.75^{a}
7	9.88^{a}	13.20^{b}	19.72^{a}	18.90^{a}
10	12.75^{a}	14.27^{b}	18.70^{a}	15.75^{a}
P-Value	0.025	0.002	0.025	<0.001
SED	1.677	1.527	1.975	2.312
cv%	22.4	16.4	20.4	18.9

NB: Means followed by different letters are significantly different at $P<0.05$

Table 2 Effects of different watering frequencies on the chlorophyll content of soya bean leaves.

4.3 Effects of different watering frequencies on the plant height of soya beans.

There was a significant ($P<0.05$) difference in the plant height for all four watering frequencies (1, 3, 7, and 10 days) (Figure 4.3). Plants that were watered after every 1 day exhibited a higher length as compared to those watered after ever 3, 7, and 10 days respectively.

Watering Frequency (days)	Plant height (cm) 1WAP	Plant height (cm) 2WAP	Plant height (cm) 3WAP	Plant height (cm) 4WAP
1	8.42^{a}	14.67^{a}	23.47^{a}	29.75^{a}
3	6.42^{b}	13.67^{a}	20.17^{a}	28.07^{a}
7	4.58^{c}	11.83^{a}	16.33^{b}	24.28^{b}
10	3.17^{d}	9.75^{a}	13.67^{b}	20.00^{c}
P-Value	<0.001	0.002	<0.001	<0.001
SED	0.646	1.068	1.753	1.663
cv%	19.8	14.8	16.5	11.3

NB: Means followed by different letters are significantly different at $P<0.05$

Table 3 Effects of different watering frequencies on the plant height of soya beans.

4.4 Effects of different watering frequencies on the number of leaves of soya beans.

There was a significant ($P<0.05$) difference in the number of leaves for all four watering frequencies (1, 3, 7, and 10 days) in weeks 1, 3, and 4 (Figure 4.4). The highest mean number of leaves was observed and found to be in plants whose watering frequency was after every 1 day. These were followed by 3 days, 7 days, and 10 days. However, there was no significant ($P>0.05$) difference in the number of leaves among all four watering frequencies in week 2.

Watering Frequency (days)	Number of Leaves 1WAP	Number of Leaves 2WAP	Number of Leaves 3WAP	Number of Leaves 4WAP
1	3.50^a	5.50^a	14.00^a	16.50^a
3	2.00^b	5.50^a	11.00^b	15.50^a
7	2.00^b	5.00^a	8.50^c	13.00^b
10	1.33^b	4.50^a	7.50^c	12.00^b
P-Value	0.010	0.317	<0.001	0.003
SED	0.560	1.276	1.111	1.111
cv%	43.9	20.2	18.8	13.5

NB: Means followed by different letters are significantly different at $P<0.05$

Table 4 Effects of different watering frequencies on the number of leaves of soya beans.

4.5 Effects of different watering frequencies on leaf dry matter.

There was a significant ($P<0.05$) difference in the leaf dry matter for all four watering frequencies (1, 3, 7, and 10 days) (Figure 4.5). The highest mean leaf dry matter was observed and found to be in plants whose watering frequency was after every 3 days. These were followed by 1 day, 7 days, and 10 days. The positive R^2 value implies that the more frequently watered the plants, the more dry matter accumulates.

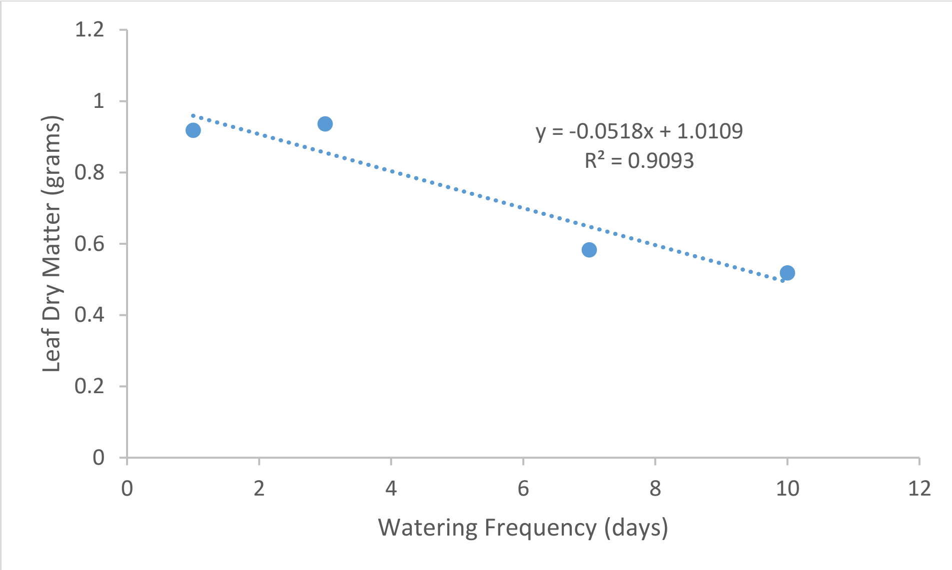

Figure 1 Effects of different watering frequencies on leaf dry matter.

4.6 Effects of different watering frequencies on stem dry matter.

There was a significant ($P<0.05$) difference in the stem dry matter for all four watering frequencies (1, 3, 7, and 10 days) (Figure 4.6). The highest mean leaf dry matter was observed and found to be in plants whose watering frequency was after every 1 day. These were followed by 3 days, 7 days, and 10 days respectively. Plants watered after 7 days and 10 days yielded the same dry matter accumulated in the stem.

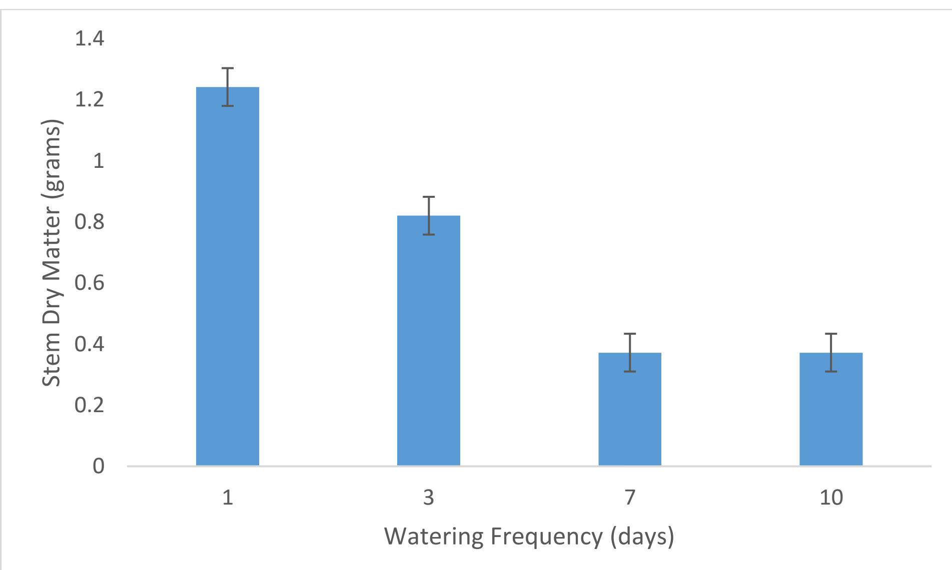

Figure 2Effects of different watering frequencies on stem dry matter.

4.7 Effects of different watering frequencies on roots dry matter.

There was a significant ($P<0.05$) difference in the roots dry matter for all four watering frequencies (1, 3, 7, and 10 days) (Figure 4.7). The highest mean root dry matter was observed and found to be in plants whose watering frequency was after every 1 day. These were followed by 3 days, 10 days, and 7 days respectively. The lowest root dry matter accumulation was in the roots of plants which were watered after every 7 days.

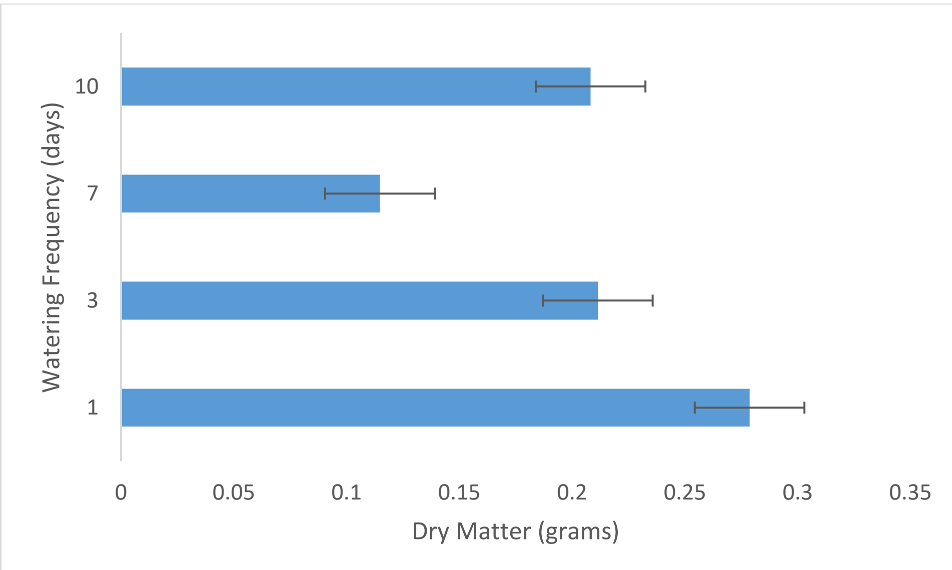

Figure 3 Effects of different watering frequencies on roots dry matter.

4.8 Effects of watering frequency on the total dry matter of soya beans.

There was a significant ($P<0.05$) difference in the total dry matter for all four watering frequencies (1, 3, 7, and 10 days) (Figure 4.8). The highest mean total dry matter was observed and found to be in plants whose watering frequency was after every 1 day. These were followed by 3 days, 10 days, and 7 days respectively.

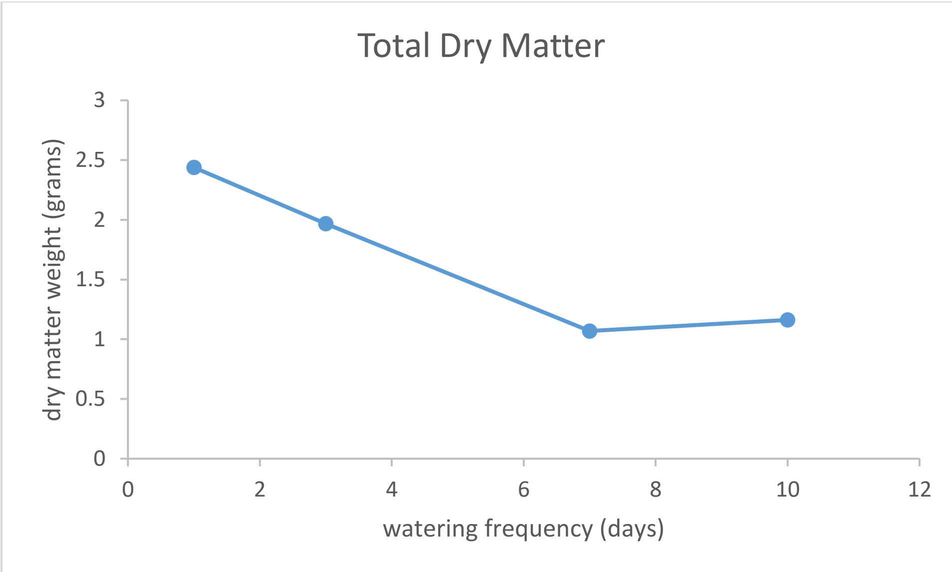

Figure 4 Effects of watering frequency on the total dry matter of soya beans.

CHAPTER 5

5. Discussion

When soybean plants are watered daily, they experience several physiological responses that contribute to their height development. Water is crucial for the process of photosynthesis, wherein plants transform sunlight into energy. When soybean plants are watered daily, they have a consistent supply of water to support photosynthesis, leading to increased plant and productivity. Water aids in conveying nutrients from the soil to the plant’s roots, facilitating their absorption and utilization for growth. When soybean plants are watered daily, they are better able to take up essential nutrients like nitrogen, phosphorus, and potassium, thereby facilitating plant height more as compared to the soya bean that watered after 3 days, 7 days and 10 days. These findings were also observed by (Gavrilescu, 2021).

Due to the high temperatures experienced this year, daily watering of soya beans assist in controlling the plant’s temperature by cooling it through the process of transpiration, therefore helps soya bean plants watered daily to grow rapid than soybean watered after 3 days, 7 days and 10 days. Transpiration is important for maintaining optimal conditions for growth and preventing heat stress. When soybean plants are watered daily, they have sufficient water to maintain turgor pressure, which is important for cell expansion and overall plant health. Turgor pressure refers to the pressure exerted by water contained within plant cells, which aids in upholding their shape and structural integrity.

The primary mechanism driving plant growth involve cell division, enlargement, and differentiation. Shortages of water impairs mitosis and cell elongation which results in poor growth of soya bean plants watered after 7 days and 10 days. Water limiting conditions, i.e. the 7 day interval and the 10 days interval results in impaired cell elongation mainly because of poor water flow from xylem to the nearby cell. Grassini, P., (2021), observed that when soybean plants receive limited water, they adapt by prioritizing vertical growth, which contradicts to my findings.

Daily watered soya bean grow taller than the other watering frequencies of 3 days interval, 7 days interval and 10 days because water availability influences the production and transport of plant hormones, such as auxins, which play a crucial role in promoting cell elongation. Adequate watering helps maintain proper hormone balance, facilitating vertical growth and contributing to increased plant height. My findings were also similar to the observations of (Bhattacharya, 2021).

Infrequent watering of soybean plants, such as watering once a week or every 10 days, can lead to less height growth compared to plants that receive daily or more frequent watering. The inconsistent moisture levels, limited nutrient availability, compromised root development, and physiological stress associated with infrequent watering can all contribute to slower growth and shorter plant height.

The different watering frequency of soya bean plants can have significant impact on the production of chlorophyll content, which is essential for photosynthesis and overall plant healthy. Daily watering of soybean plants helps to ensure that the plants have a consistence supply of water, which is necessary for optimal nutrient uptake and photosynthesis. This can lead to higher chlorophyll content in the plants, as they are able to efficiently produce energy from the sunlight. Daily watering of soybean plants stimulates the synthesis of chlorophyll a and b by improving efficiency of photosynthetic activity, facilitating nutrient uptake, preventing water stress, and regulating temperature. These factors work together to support optimal chlorophyll synthesis which results in higher chlorophyll content to plants watered daily than pants watered after 3days, 7 days and plants watered after 10 days. My findings were similar to the observations made by Jannatual Ferdous, M. A., (2018).

Soybean watered after 7 days have higher chlorophyll content than soya bean plants watered after 3 days which contradicts with the findings observed by (Kulundžić, A. M., 2022). The soya bean plants that were watered after 1 week may have had more time to absorb nutrients from the soil, leading to increased chlorophyll production than plants watered after 3 days and 10 days. The plants that were watered after 1 week may have been at a different growth stage compared to those compared to those watered after 3 days, which could impact their chlorophyll content. There may be genetic variations between the two groups of plants that influence their ability to produce chlorophyll in response to different watering frequencies.

Soybean plants watered after 10 days also have higher chlorophyll content than those watered after 3 days which also contradicts with the findings by (Kulundzic, A. M., 2022), who concluded that water availability support optimal chlorophyll synthesis which results in high chlorophyll content to plants watered frequently. Soya bean watered after 10 days may have been at a different growth stage with those watered after 3 days or the pots were plants watered after 3 days quickly loses soil moisture which will then leads to plant stress and reduces chlorophyll production.

Daily watering of soybean plants ensures a steady and ideal moisture level in the soil, creating a favorable environment for their growth. Adequate moisture availability supports essential processes such as nutrient uptake, photosynthesis, and overall metabolic activities, which in turn promote robust growth and the formation of abundant leaves and branches which is similar to my findings. Consistent watering maintains proper hydration and turgidity in plant cells, facilitating the opening of stomata and the absorption of carbon dioxide. This results in efficient photosynthesis and increased production of carbohydrates. The surplus carbohydrates are then directed towards the growth of leaves and branches, contributing to a fuller and lusher plant structure. On the other hand, infrequent watering, such as once a week or longer intervals, can lead to water shortages in soybean plants. This can cause physiological changes, including restricted cell expansion and altered hormone levels, which adversely affect leaf development. Soybean plants thrive best when the soil moisture level is consistently maintained, as irregular watering can induce stress and disrupt important processes like photosynthesis, cell division, and nutrient uptake, ultimately resulting in a decrease in the quantity of leaves produced.

Soybean plants that receive frequent watering exhibit a higher leaf area index in comparison to those that are watered at longer intervals because regular watering ensures a continuous and sufficient water supply, which is vital for the plants' growth and development. Daily watering has been found to influence hormone regulation, which plays a crucial role in cell expansion. This allows the cells within the leaves to elongate and increase in size. Wang (2022) also observed that frequent watering helps maintain turgor pressure in plant cells, facilitating efficient photosynthesis and the production of new leaves. Consequently, the overall leaf area of the plant increases, resulting in a higher leaf area index.

Frequent watering provides an optimal growth environment for soybean plants, allowing them to allocate more resources and biomass towards leaf production. Adequate water availability supports the efficient utilization of nutrients and energy resources necessary for leaf growth. With daily watering, the plants can direct more resources towards leaf expansion, leading to a higher leaf area index compared to plants that are watered after longer intervals. Conversely, as the watering period increases and plants are watered infrequently or after longer intervals, they may experience periods of water stress. Water stress can cause wilting, reduce photosynthetic efficiency, and ultimately decrease leaf area, resulting in a lower leaf area index.

The allocation of biomass among different parts of soybean plants can vary due to factors such as genetics, environmental conditions, and management practices, including watering frequencies. Rezaei, E. (2023) observed that soybean plants subjected to infrequent watering were more sensitive to water stress, resulting in reduced accumulation of total dry matter which was also similar to my findings. Frequent watering of soybean plants leads to a substantial increase in the accumulation of dry matter. Adequate water availability is important for soya bean plants as it facilitates the process of photosynthesis, aids tin the uptake of nutrients, which are vital for the growth and development of the plant, and contributes to accumulation of biomass. Adequate water availability promotes branching and the production of numerous leaves, contributing to overall biomass accumulation. Water is also important in maintaining turgor pressure within plant cells, allowing them to elongate and enlarge. With a continuous supply of water, soybean plants can sustain optimal cell expansion, leading to increased biomass accumulation and higher levels of dry matter.

CHAPTER 6

6 Conclusion and Recommendation

6.1 Conclusion

Results showed that frequent watering is necessary in the cultivation of soya beans. The research findings indicate that increasing the frequency of daily watering in the early stages of soya bean cultivation has several beneficial effects. It has been noted that increased watering frequency results in a higher quantity of leaves produced per plant. The expanded leaf are provides benefits for the plant's photosynthesis activities.

The data shows that soya bean plants that receive more frequent watering are able to accumulate more dry matter compared to those that are water less frequently, such as once a week. The regular watering appears to initiate important physiological processes within the soya bean plants that support their normal growth and development.

In general, the results indicate that increased watering frequency in soya bean cultivation is correlated with more rapid overall plant growth. The treatments involving watering intervals of one week or ten days produced lower values for the measured parameters compared to the more frequently watered soya bean plants. As a result, we reject the null hypothesis. Varied watering frequencies have an effect on the height of soybean plants, the quantity of leaves, the accumulation of dry matter, and the overall leaf count.

6.2 Recommendations

According to the experimental results, it is advisable for farmers in region 2 of Zimbabwe to elevate the frequency of watering for their soybean crops to promote growth and improve their yield. This recommendation is particularly crucial considering the issue of irrigation, which is often hindered by limited water availability due to the prevailing climate conditions. Through more frequent watering, farmers have the ability to lessen the negative impacts of water scarcity and potentially enhance the performance of different measured parameters in soya bean plants.

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APPENDICES

Appendix 1 Analysis of variance for number of leaves 1

```
Analysis of variance
====================
Variate: LeafNo
Source of variation     d.f.        s.s.        m.s.    v.r.  F pr.
BLOCK stratum              5      4.7083      0.9417    1.00
BLOCK.*Units* stratum
WATERING_FR                3     15.1250      5.0417    5.35  0.010
Residual                  15     14.1250      0.9417
Total                     23     33.9583
```

Appendix 2 Analysis of variance for number of leaves 2

```
Analysis of variance
====================
Variate: Leaf_No2
Source of variation     d.f.        s.s.        m.s.    v.r.  F pr.
BLOCK stratum              5       6.375       1.275    1.19
BLOCK.*Units* stratum
WATERING_FR                3       4.125       1.375    1.28  0.317
Residual                  15      16.125       1.075
Total                     23      26.625
```

Appendix 3 Analysis of variance for number of leaves 3

```
Analysis of variance
====================
Variate: Leaf_No3
Source of variation     d.f.        s.s.        m.s.    v.r.  F pr.
BLOCK stratum              5      49.500       9.900    2.68
BLOCK.*Units* stratum
WATERING_FR                3     151.500      50.500   13.65  <.001
Residual                  15      55.500       3.700
Total                     23     256.500
```

Appendix 4 Analysis of variance for number of leaves 4

```
Analysis of variance
====================
Variate: LeafNo4
Source of variation     d.f.        s.s.        m.s.    v.r.  F pr.
BLOCK stratum              5      43.500       8.700    2.35
BLOCK.*Units* stratum
WATERING_FR                3      79.500      26.500    7.16  0.003
Residual                  15      55.500       3.700
Total                     23     178.500
```

Appendix 5 Analysis of variance for plant height 1

Analysis of variance
====================

Variate: Height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	5	11.677	2.335	1.87	
BLOCK.*Units* stratum					
WATERING_FR	3	93.281	31.094	24.83	<.001
Residual	15	18.781	1.252		
Total	23	123.740			

Appendix 6 Analysis of variance for plant height 2

Analysis of variance
====================

Variate: Height2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	5	25.552	5.110	1.49	
BLOCK.*Units* stratum					
WATERING_FR	3	84.365	28.122	8.22	0.002
Residual	15	51.323	3.422		
Total	23	161.240			

Appendix 7 Analysis of variance for plant height 3

Analysis of variance
====================

Variate: Height3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	5	32.683	6.537	0.71	
BLOCK.*Units* stratum					
WATERING_FR	3	332.805	110.935	12.04	<.001
Residual	15	138.250	9.217		
Total	23	503.738			

Appendix 8 Analysis of variance for plant height 4.

Analysis of variance
====================

Variate: Height4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	5	81.295	16.259	1.96	
BLOCK.*Units* stratum					
WATERING_FR	3	338.268	112.756	13.59	<.001
Residual	15	124.422	8.295		

Total	23	543.985

Appendix 9 Analysis of variance for chlorophyll 1

Analysis of variance
====================
Variate: Chlor

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	5	194.317	38.863	4.61	
BLOCK.*Units* stratum					
WATERING_FR	3	105.108	35.036	4.15	0.025
Residual	15	126.575	8.438		
Total	23	426.000			

Appendix 10 Analysis of variance for chlorophyll 2

Analysis of variance
====================
Variate: Chlor2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	5	181.838	36.368	5.20	
BLOCK.*Units* stratum					
WATERING_FR	3	171.575	57.192	8.18	0.002
Residual	15	104.885	6.992		
Total	23	458.298			

Appendix 11 Analysis of variance for chlorophyll 3

Analysis of variance
====================
Variate: Chlor3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	5	39.06	7.81	0.67	
BLOCK.*Units* stratum					
WATERING_FR	3	146.20	48.73	4.16	0.025
Residual	15	175.53	11.70		
Total	23	360.79			

Appendix 12 Analysis of variance for chlorophyll 4

Analysis of variance
====================
Variate: Chlor4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	5	232.10	46.42	2.90	
BLOCK.*Units* stratum					
WATERING_FR	3	450.07	150.02	9.36	<.001
Residual	15	240.48	16.03		
Total	23	922.65			

Appendix 13 Analysis of variance for leaf area 1

Analysis of variance
====================

Variate: Area

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	5	6.4441	1.2888	2.80	
BLOCK.*Units* stratum					
WATERING_FR	3	18.1132	6.0377	13.13	<.001
Residual	15	6.8996	0.4600		
Total	23	31.4570			

Appendix 14 Analysis of variance for leaf area index 2

Analysis of variance
====================

Variate: Area2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	5	21.414	4.283	0.69	
BLOCK.*Units* stratum					
WATERING_FR	3	38.821	12.940	2.08	0.146
Residual	15	93.291	6.219		
Total	23	153.526			

Appendix 15 Analysis of variance for leaf area index 3

Analysis of variance
====================

Variate: Area3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	5	62.254	12.451	2.29	
BLOCK.*Units* stratum					
WATERING_FR	3	161.960	53.987	9.92	<.001
Residual	15	81.613	5.441		
Total	23	305.827			

Appendix 16 Analysis of variance for leaf area index 4

Analysis of variance
====================

Variate: Area4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	5	40.709	8.142	1.44	
BLOCK.*Units* stratum					
WATERING_FR	3	356.235	118.745	21.02	<.001
Residual	15	84.729	5.649		
Total	23	481.674			

Appendix 17 Analysis of variance for dry matter accumulation of leaves

```
Analysis of variance
====================
Variate: Leaves
Source of variation     d.f.        s.s.        m.s.    v.r.  F pr.
BLOCK stratum              5     0.30486     0.06097    0.92
BLOCK.*Units* stratum
WATERING_FR                3     0.71685     0.23895    3.61  0.038
Residual                  15     0.99386     0.06626
Total                     23     2.01557
```

Appendix 18 Analysis of variance for dry matter accumulation of stems

```
Analysis of variance
====================
Variate: Stem
Source of variation     d.f.        s.s.        m.s.    v.r.  F pr.
BLOCK stratum              5     0.05550     0.01110    0.97
BLOCK.*Units* stratum
WATERING_FR                3     3.13433     1.04478   91.25  <.001
Residual                  15     0.17175     0.01145
Total                     23     3.36158
```

Appendix 19 Analysis of variance for dry matter accumulation of roots

```
Analysis of variance
====================
Variate: Roots
Source of variation     d.f.        s.s.        m.s.    v.r.  F pr.
BLOCK stratum              5    0.024157    0.004831    2.72
BLOCK.*Units* stratum
WATERING_FR                3    0.081637    0.027212   15.33  <.001
Residual                  15    0.026624    0.001775
Total                     23    0.132418
```

Appendix 20 Analysis of variance for total dry matter accumulation.

```
Analysis of variance
====================
Variate: Total
Source of variation     d.f.        s.s.        m.s.    v.r.  F pr.
BLOCK stratum              5     0.22027     0.04405    0.70
BLOCK.*Units* stratum
WATERING_FR                3     7.78634     2.59545   41.43  <.001
Residual                  15     0.93962     0.06264
Total                     23     8.94623
```