BORNEO AKADEMIKA (BA)

Volume 8 (1), June 2024 (85-90)

e-ISSN: 2735-2250

Journal home page:
https://borneoakademika.uitm.edu.my/

EFFECTS OF VARYING WATER CONSUMPTION ON SPINACH *(Spinacia oleracea L.)* SUSTAINABLE CULTIVATION

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ABSTRACT

Water is a raw material used in various biochemical processes inside plants, making it a crucial element for plant development and growth. Understanding the appropriate amount of water consumption is vital to prevent plants from experiencing abiotic stress such as waterlogging and water stress. Leafy vegetables, such as spinach (*Spinacia oleracea*), require more water than other vegetables. Therefore, this study aimed to determine the optimal amount of water necessary for sustainable spinach cultivation and to assess the effects of different irrigation regimes on spinach growth and yield. Four different irrigation treatments with four replications were applied: T0 (600 ml), T1 (700 ml), T2 (800 ml), and T3 (900 ml). Significant differences (p-value < 0.05) were observed for plant height, number of leaves, root length, soil oxygen levels, and the fresh and dry weight of spinach when irrigated with 700 ml of water (T1). The highest spinach yield (fresh weight = 9.64 g) was achieved with adequate water supply (T1), while the yield (fresh weight = 0.78 g) was lower at a higher water consumption level (T3). This suggests sustainable cultivation of spinach due to the optimal yield obtained with lower water consumption.

Keywords: Irrigation regimes; spinach; sustainable cultivation; water consumption

Introduction

Across the globe, individuals rely on food to sustain their livelihoods, seeking proper nutrition from diverse sources, including vegetables. Spinach, for instance, boasts a rich array of vitamins and minerals such as vitamin A, vitamin C, vitamin E, and phenolic compounds, which are purported to offer health benefits including obesity reduction and anti-inflammatory properties (Ribera et al., 2020). However, spinach is highly sensitive to fluctuations in water supply. Inconsistent water consumption can induce abiotic stresses, with both excessive and insufficient irrigation leading to waterlogging and water stress in spinach plants. Over-irrigation can alter spinach's morphology and biochemical properties, while a 50% reduction in irrigation has been shown to significantly decrease spinach growth and yield (Leskovar et al., 2012; Jabeen et al., 2019; Seymen, 2021).

Due to its high-water content, spinach demands relatively higher water requirements throughout its growth cycle (Seymen, 2021; Nasarullah, 2022). Moreover, its shallow root system necessitates frequent irrigation to maintain optimal soil moisture levels for leaf development and growth. However, it is crucial to consider soil texture variations when applying water to prevent waterlogging (Koike et al., 2011; Murcia et al., 2020). Water plays a pivotal role in the growth and development of crops, with each species having distinct water requirements that determine the sustainability of its cultivation. Over-irrigation or inadequate irrigation can both adversely affect spinach growth and development.

Efficient water management in agriculture is critical, particularly in light of impending climate change impacts on water sources. Sustainable water management practices can mitigate the risks of over-irrigation or inadequate irrigation. Climate change has led to rising temperatures in Malaysia, with temperature increases projected to double from the first quarter to the end of the century. These temperature shifts contribute to unpredictable rainfall patterns that affect water sources, particularly in the agricultural sector (Keshminder, 2018). Additionally, water pollution exacerbates water scarcity, reducing the availability of clean water for irrigation in agriculture (Prasanna et al., 2012; Halmi & Ismail, 2017). Hence, it is crucial to ascertain spinach water consumption in alignment with sustainable water management practices.

Appropriate crop water consumption can be facilitated through irrigation, the artificial application of water to crops from groundwater or surface water sources (Serra et al., 2023). Employing various irrigation regimes or frequencies enables determination of the optimal water quantity for crops. Scheduled irrigation regimes help prevent water wastage or deficiencies that may result in over-irrigation or under-irrigation. Excessive irrigation elevates soil moisture levels, inducing waterlogging stress and adversely affecting crop growth and physiology, including reduced yield, compromised crop quality, and diminished chlorophyll content, thereby disrupting photosynthesis (Sensoy, 2007; Liu et al., 2020). Conversely, inadequate irrigation diminishes soil moisture, leading to water stress and substantial reductions in growth and yield (Katsoulas, 2006). The interplay between soil and plant under water stress influences soil oxygen content and root respiration, impeding plant physiological processes, as evidenced by numerous studies (Furtak & Wolinska, 2023; Chen et al., 2011). Thus, this study aimed to quantify the optimal water requirement to enhance sustainable spinach development and assess the impact of varying water consumption via irrigation regimes on soil oxygen levels, spinach growth, and yield.

Materials and Methods

The study was conducted within a greenhouse environment. Spinach seeds were sown in seedling trays and nurtured for two weeks before being transplanted into 8 cm x 9 cm polybags, each containing 2.5 kg of soil. The experimental design followed a Randomized Complete Block Design (RCBD), comprising four treatments with four replications, resulting in a total of 16 polybags subjected to four different irrigation regimes which were set as independent variables. Irrigation regimes for the spinach plants were designated as T0 (600 ml), T1 (700 ml), T2 (800 ml), and T4 (900 ml), with each treatment replicated four times. Treatments commenced one week post-transplanting. All treatments were administered twice daily, in the morning and evening. Data collected from the study were analysed using One-Way Analysis of Variance (ANOVA) via the Statistical Package for the Social Sciences (SPSS) software (Figure 1).

Data Collection

Dependent variables encompassed of various growth and yield parameters, including plant height (PH), number of leaves (NOL), root length (RL), soil oxygen (SO), shoot fresh weight (SFW), shoot dry weight (SDW), root fresh weight (RFW), and root dry weight (RDW) were measured and recorded to study the effects of different irrigation regimes.

Growth parameters

Growth parameters, comprising plant height, number of leaves, and root length, were monitored throughout the study period. Plant height was measured weekly using a measuring tape, while the number of leaves was manually counted for each replicate and treatment. Root lengths were determined post-harvest using a measuring tape, with measurements taken from the upper roots to the root tips. Plant height and root length were recorded in centimetres (cm).

Yield parameters

Upon harvest, shoots and roots were separated from the plants, and their fresh weights were measured using a weighing scale. Subsequently, shoots and roots were oven-dried at 80°C for 48 hours (Seymen, 2021) before their dry weights were recorded in grams (g).

Soil oxygen

Soil oxygen levels were assessed based on soil pore space to determine oxygen availability. This measurement helped evaluate the impact of different irrigation regimes on soil oxygen levels. Oxygen readings were taken post-treatment application by inserting an oxygen meter to a depth of 10 cm in the soil. The recorded values were expressed as a percentage (%).

Statistical analysis

The collected data were subjected to statistical analysis using the Statistical Package for the Social Sciences (SPSS) software, employing One-Way Analysis of Variance (ANOVA). Subsequently, Tukey's b test was employed to further compare the mean data of the treatments.

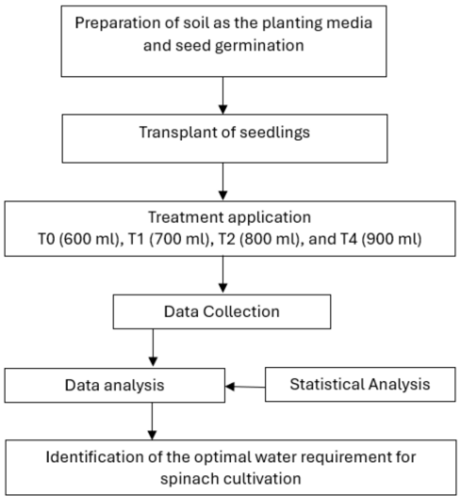

Figure 1: Research framework

Results and Discussion

The results pertaining to growth, yield, and soil oxygen levels demonstrated significant differences at p-value < 0.05. As shown in Table 1, watering spinach with 700 ml (T1) proved to be the most optimal for enhancing growth and yield. Notably, spinach plant height was highest when irrigated with 700 ml (T1) and lowest with 600 ml (T0) of water.

Water plays a pivotal role in regulating plant growth, with even slight decreases in water availability swiftly impeding physiological and metabolic processes in growing plants. Variations in plant height among genotypes may reflect differing water requirements for physiological and biological processes (Yusuf & Hamed, 2021). Similar studies on tomato and onion have reported significant decreases in plant height under conditions of excessive water or waterlogging, closely linked with disruptions in photosynthesis processes (Tareq et al., 2020; Ghodke et al., 2018).

Inappropriate water levels can stifle spinach development, leading to leaf wilting and loss of new leaves, particularly under conditions of excessive water (Palapala & Nyamolo, 2016). Results indicate that T3 (900 ml) exhibited the poorest spinach growth compared to other treatments. Excessive water can induce plant stress, prompting plants to redirect energy to cope with such stressors. Morphological changes in leaves, including leaf withering and reduced inter-nodal length, are attributed to excessive water. A decrease in leaf count due to inappropriate water consumption diminishes the net light-absorbing surface, thereby impacting photosynthesis and subsequently reducing yield production. Furthermore, nutrient imbalances resulting from excess moisture can disrupt plant physiological processes. Regarding soil oxygen levels, T3 (7.25%) recorded the lowest percentage compared to other treatments. This low percentage suggests that soil pore space was saturated with water, hindering oxygen diffusion from the atmosphere into the soil and thereby impeding gas exchange. Consequently, low oxygen levels limit root respiration, diminish root activity and development (Pan et al., 2021; Yamauchi et al., 2017).

Wet conditions pose significant challenges to crop production, resulting in estimated yield losses of 10% and reductions of fresh weight yield ranging from 8% to 49% due to poor root development during wet conditions (Barickman et al., 2019; Ding et al., 2020). Excessive soil moisture alters physicochemical properties in the rhizosphere, affecting oxygen balance, oxygen exchange between soil and atmosphere, and leaching of nitrogen (Zaidi et al., 2003; Manik et al., 2019). Prolonged exposure to wet soil renders plant roots susceptible to extreme oxygen stress, as evidenced by the significant reduction in soil oxygen levels and root length in T2 and T3 compared to T1 (Table 1). Poor root development in wet soil ultimately affects spinach growth and fresh weight. An optimal soil should maintain an oxygen concentration of at least 10% (Pais et al., 2022). In contrast, the oxygen concentration in T2 and T3 fell below 10%, significantly affecting spinach growth.

In terms of yield parameters, both fresh weight and dry weight were highest when spinach was watered with the optimal amount of 700 ml (T1), underscoring the importance of appropriate water management for maximising yield production (Nasarullah et al., 2022). Aldana et al. (2014) noted that excessive water can lead to oxygen deficit or anoxic conditions, impeding root growth and triggering plant responses to reduce shoot growth and overall productivity. Conversely, insufficient water supply results in decreased nutrient intake, transport, and utilization at each growth stage, ultimately reducing root dry weight (Aslanpour et al., 2019). Insufficient water supply, such as below 600 ml (T0), can lead to diminished growth, while excessive watering can result in significant reductions in both fresh and dry weights. Therefore, precise irrigation management is crucial to avoid both overwatering and underwatering.

Table 1: The mean data for spinach growth, yield, and soil oxygen based on different irrigation regimes.

Treatment (ml)	**PH (cm)**	**NOL**	**RL (cm)**	**SO (%)**	**SFW (g)**	**SDW (g)**	**RFW (g)**
600 (T0)	**6.50^{b}**	**6.50^{b}**	**7.98^{ab}**	**11.50^{b}**	**5.53^{b}**	**0.59^{b}**	**1.08^{b}**

700 (T1)	**45.00^{a}**	**8.75^{a}**	**10.77^{a}**	**13.25^{a}**	**9.64^{a}**	**1.09^{a}**	**2.09^{a}**
800 (T2)	**25.58^{c}**	**4.50^{c}**	**5.70^{bc}**	**9.50^{c}**	**3.21^{bc}**	**0.34^{bc}**	**0.54^{bc}**
900 (T3)	**14.11^{d}**	**3.00^{d}**	**3.67^{c}**	**7.25^{d}**	**0.78^{c}**	**0.09^{c}**	**0.06^{c}**
Significance	*	*	*	*	*	*	*

*Plant height (PH), number of leaves (NOL), root length (RL), soil oxygen (SO), shoot fresh weight (SFW), shoot dry weight (SDW), root fresh weight (SDW) and root dry weight (RDW).
*Superscripts letters indicate the statistically significant differences that exist between the groups.
*Significance differences showing results are significant at p-value<0.05 denoted by symbol *

Conclusion

The impact of irrigation water quantity on spinach growth is significant, with excessive water leading to suboptimal development. Our study demonstrated that when spinach receives daily watering—once in the morning and once in the evening—using the appropriate amount for its water needs, it exhibits enhanced plant height, leaf count, root length, fresh weight, and dry weight, with notable differences among all treatments. Hence, it is important to determine and regulate the water supply for each plant to prevent stress and ensure favourable growth conditions. Our findings highlight the detrimental effects of excessive water application, as evidenced by the poor spinach development observed in T3 (900 ml). Therefore, excessive watering practices, as observed in T3, should be avoided. Furthermore, employing different irrigation regimes tailored to spinach water consumption significantly impacts growth and yield.
However, in situations of water excess or scarcity, it is advisable to adopt watering practices akin to T1 (700 ml), which strike a balance between providing sufficient water for optimal spinach growth and yield while mitigating water stress. Embracing such practices not only enhances spinach cultivation but also promotes sustainable irrigation tailored to spinach water requirements.

Acknowledgments

We extend our sincere gratitude to all individuals who contributed to the success of this study, without whom this research would not have been possible.

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