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Original research article

Application of Moringa Leaves (Moringa oleifera) in Liquid Organic Fertilizer for Red Spinach (Amaranthus tricolor L) Plant Growth as a Solution for Acidic Soil

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Abstract

Industrial and social activities have a significant impact on environmental degradation, one of which is altering the soil pH to become acidic. Consequently, plants are unable to achieve proper growth. One viable solution lies in the application of liquid organic fertilizer. Liquid organic fertilizer derived from naturally fermented Moringa leaves presents a potential remedy to this issue. Moringa leaf liquid organic fertilizer contains essential macronutrients (N, Ca, P, Mg, K, and Na), micronutrients (Zn, Fe, and Cu), and growth hormones (zeatin and cytokinin), making it highly suitable for use as a liquid organic fertilizer. The study encompassed two variables, namely the impact of soil pH and the effect of liquid organic fertilizer derived from Moringa leaves, over a span of 30 days. The findings revealed that red spinach plants failed to thrive in soil with a pH ranging from 3.5 to 4. However, when cultivated in soil with a pH of 4.5, they exhibited a lifespan of 7 days, while in soil with a pH of 5, growth could be sustained for 9 days. Red spinach demonstrated favorable growth rates at pH levels of 5.5, 6, 6.5, and 7, albeit at different rates. Red spinach plants that are watered with liquid organic fertilizer from Moringa leaves can grow 1.4 times taller and have 1,375 times greater leaf width than without the addition of liquid organic fertilizer.

1. INTRODUCTION

Industrial progress does not invariably yield positive environmental consequences, and one of the adverse outcomes pertains to land pollution. Soil pollution is a direct result of improper disposal of untreated industrial waste, leading to soil contamination. This waste stream comprises an array of toxic and perilous chemicals, which, when deposited into the soil, undermine its structural integrity, ultimately diminishing soil fertility and biological vitality [1]. This disruption not only upsets ecological equilibrium but also imposes impediments on crop production.

Furthermore, the contamination of soil and vegetation with toxic substances and hazardous compounds can impart substantial health risks to individuals who ingest these plants [2]. This contamination can be promptly discerned through alterations in soil pH, resulting in either increased acidity or alkalinity. Soil pH levels that veer towards excessive acidity not only degrade the soil but also present a corrosive threat to all nearby life forms. Consequently, initiatives aimed at mitigating this issue assume paramount significance.

Organic fertilizers present a promising solution for addressing soil pollution. They not only satisfy the nutritional needs of plants but also contribute to the regulation of pest populations [3]. Furthermore, organic fertilizers enhance various soil parameters, including microbial activity, anion and cation exchange capacity, organic matter content, and soil carbon levels [4]. The utilization of organic fertilizers results in enhanced crop quality and yield, comparable to their synthetic counterparts, while avoiding the adverse environmental consequences of pollution [1]. These fertilizers offer additional benefits, including soil texture improvement, increased water retention capacity, and the reinforcement of resistance against erosion [5]. By delivering nitrogen to plants in an easily assimilable form, organic fertilizers support optimal growth without compromising root health or the well-being of beneficial soil microorganisms [6]. Moreover, they play a critical role in disease prevention by meeting plant nutritional needs, effectively mitigating a significant source of stress. The utilization of plant residues such as wood ash, spent grains, rice bran, and sawdust has proven highly efficacious in the production of organic fertilizers [7].

Moringa plants are widely recognized for their attributes that render them well-suited for use as organic fertilizers. The liquid organic fertilizer sourced from Moringa leaves represents a refined product resulting from the extraction of Moringa leaves [8]. Moringa oleifera, commonly known as the drumstick tree, exhibits remarkable versatility, as it is not only a nutritional vegetable but also serves various purposes due to its rich nutritional content [9]. This tree is believed to have its origins in India and has since disseminated globally, including its presence in Indonesia [10].

One of the key components found in Moringa leaves, which can be utilized as liquid organic fertilizer, is zeatin. The leaves contain zeatin in the range of 5-200 mcg/g [11, 12]. Additionally, other substances such as cytokinins, ascorbate, calcium, potassium, and iron contribute to mineral growth [13, 14]. With these constituents, liquid organic fertilizer derived from Moringa leaves can be effectively applied or sprayed on a wide variety of plants. This organic fertilizer enhances plant vigor, increases resistance against pests and diseases, and promotes weight gain [15]. The aim of this study was to investigate the influence of soil acidity on the development of red spinach plants. Furthermore, the research also examined the impact of using liquid organic fertilizer derived from Moringa leaves on the growth of plant height and leaf width in red spinach plants.

2. MATERIALS AND METHODS

Tools and Materials

The materials employed in this investigation encompassed red spinach seeds, approximately one liter of water, five individual Moringa leaves, and soil specimens characterized by pH values ranging from 3.5 to 7. The instruments utilized in this research comprised soil pH measuring devices, knives, spoons, blenders, fabric materials, containers for soil media, rulers, and one-liter spray dispensers.

Production of Liquid Organic Fertilizer for Moringa Leaves

The preparation of liquid organic fertilizer for Moringa leaves involves harnessing the nutritive attributes of Moringa leaves and their stems. Initially, the Moringa leaves are meticulously cleansed and subsequently fragmented into smaller fragments using scissors. Subsequently, the fragmented Moringa leaves are introduced into a blender, where they are combined with 200 mL of water and processed into a homogeneous mixture over a few minutes. Following the attainment of a uniform consistency, the resulting blend is sieved through a fabric material to segregate the filtrate from any residual solid components. This sieving process aims to yield a vivid green Moringa leaf filtrate solution. Subsequently, 800 mL of water is incrementally incorporated into the filtrate solution, with a final volume of 1 liter being the target for the Moringa leaf filtrate solution. The resultant solution is then securely transferred into a sealed container. The solution maintains its distinctive bright green hue. Subsequently, the sealed container is stored for a period of five days to facilitate the transformation of the solution into liquid organic fertilizer for Moringa leaves. An indicative sign of the successful conversion into liquid organic fertilizer is the release of noxious gases upon opening the container. The resulting Moringa liquid organic fertilizer exhibits a faded yellowish-green coloration with a green-brown sediment precipitate at the bottom.

Application of Liquid Organic Fertilizer for Moringa Leaves on Plants

The procedure for applying liquid organic fertilizer to Moringa leaves involves the extraction of 100 mL of liquid organic fertilizer for Moringa leaves, which is subsequently transferred into a 1-liter spray bottle. To achieve the desired concentration, 900 mL of water is introduced into the same container to dilute the liquid organic fertilizer for Moringa leaves by a factor of 10, thereby decreasing its concentration. This dilution process serves the purpose of aligning the fertilizer concentration with the specific requirements of the plants, as an excessively concentrated solution could potentially impede the optimal growth of the plants. Following the dilution, the resulting solution of liquid organic fertilizer for Moringa leaves is primed for application by thoroughly spraying the red spinach plants, with the application typically repeated over a span of 2-3 days.

Data Analysis Method

Effect of Soil pH on the Growth of Red Spinach Plants

Red spinach plants cultivated in soils characterized by varying pH levels of 3.5, 4, 4.5, 5, 5.5, 6, 6.5, and 7 underwent daily measurements of their plant height over a 30-day period. Each distinct pH level treatment was replicated three times to ensure robustness of the results, and subsequently, the mean growth outcomes were computed. Following this, a graphical representation was constructed, facilitating the comparative analysis of the influence of soil pH variations on both plant height and leaf width in red spinach.

Effect of Liquid Organic Fertilizer on Red Spinach Plant Height

Plant specimens subjected to two distinct treatments, involving watering and the application of liquid organic fertilizer derived from Moringa leaves, underwent daily measurements of their plant height over a continuous observation period of 30 days. The experiment was executed with each treatment category being subjected to three independent replicates, thereby enabling the computation of average developmental values. Subsequently, a graphical representation was constructed to facilitate a comparative analysis of the impact of Moringa leaf liquid organic fertilizer application on the growth of plant height and leaf width in red spinach.

3. RESULTS and DISCUSSION

Effect of soil pH on Plant Growth

The acidity or pH level of the planting substrate assumes a pivotal role in shaping the growth and development of plants. It is widely acknowledged that plants exhibit diverse responses to distinct pH levels, and these responses can exert a substantial influence on their overall growth and productivity. Within this framework, the present study seeks to explore the correlation between soil pH and the growth of red spinach plants, with a specific focus on the parameter of plant height.

To assess the influence of soil pH on plant height, measurements were taken from the soil surface to the youngest shoots of the red spinach plants. These measurements serve as a dependable indicator of plant growth and offer valuable insights into the physiological reactions of the plants to their growing habitat. Through meticulous observation and systematic documentation of the fluctuations in plant height, we can enhance our comprehension of how variations in soil pH shape the growth patterns of red spinach plants.

Figure 1 Depicts the response of red spinach plants to varying soil pH levels, the graph provides a clear illustration of the distinct growth patterns exhibited by the plants under different pH conditions. It is important to note that the plant response is non-linear and rather reveals discernible peaks and troughs, signifying the intricate and multifaceted relationship between soil pH and plant height.

Under optimal soil pH levels, red spinach plants tend to display robust growth with increased plant height. This can be attributed to the favourable conditions afforded by the optimal pH range, which facilitates the absorption of essential nutrients and enhances metabolic processes within the plants. Consequently, the plants flourish and exhibit vigorous growth, as evident in the elevated plant heights depicted in Figure 1.

Conversely, as the soil pH deviates from the optimum range, the growth of red spinach plants is negatively impacted. Acidic or alkaline soil conditions can hinder nutrient availability and uptake, resulting in stunted growth and reduced plant height. The graph conspicuously shows a decrease in plant height as the soil pH departs from the optimal range. This underscores the sensitivity of red spinach plants to shifts in soil pH and underscores the importance of maintaining suitable pH levels for optimal growth and development.

Comprehending the influence of soil pH on plant height holds significant importance within the realm of agriculture and crop administration. This knowledge empowers farmers and horticulturists to make well-informed choices pertaining to soil enhancements and pH modifications, thereby ensuring the creation of an optimal growth milieu for red spinach plants. Through the vigilant supervision and calibration of soil pH levels, the potential for optimizing plant growth, increasing crop yields, and fostering sustainable agricultural methods can be realized.

To sum up, the outcomes of this research underscore the significant impact of soil pH on the development of red spinach plants, particularly with regard to their vertical growth, i.e., plant height. These findings underscore the significance of maintaining optimal pH levels as a means to secure conducive growth circumstances and to fully exploit plant growth and yield potential. By grasping the intricate correlation between soil pH and plant height, agricultural practitioners and researchers can employ efficacious tactics for fostering robust and flourishing red spinach crops. In doing so, they contribute to the advancement of sustainable agriculture and food security.

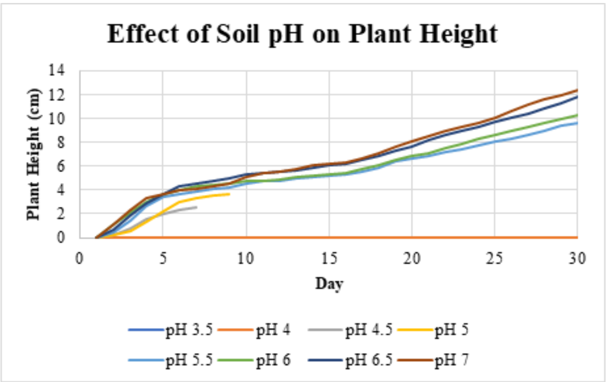

Figure 1. Graph of the effect of Soil pH on plant height

Referring to Figure 1, it is apparent that plants exhibit suboptimal growth when cultivated in soils characterized by a pH range spanning from 3.5 to 4. Furthermore, red spinach plants raised in soil with a pH of 4.5 manifest a notably abbreviated lifespan, limited to a mere seven days. Additionally, these plants display anomalies typified by reddish-green stems and leaves, a deviation from the typical vibrant red coloration. Conversely, red spinach plants cultivated in soil with a pH of 5 demonstrate relatively regular growth, featuring no overt physical distinctions in their stems and leaves. Nonetheless, their development is stunted in comparison to the average red spinach plants, as they are capable of thriving for a maximum of nine days.

Conversely, red spinach plants grown in soils characterized by pH values of 5.5, 6, 6.5, or 7 exhibit unremarkable growth patterns and are capable of thriving throughout the entire study period, extending up to 30 days. The development of plants under these pH conditions appears reasonably uniform, devoid of noteworthy disparities. Nevertheless, it is worth noting that the growth rate of red spinach plants reaches its zenith in soils with a neutral pH of 7.

To determine the optimal soil pH for red spinach plants, an analysis of the mean daily growth in plant height is warranted. Table 1 presents data pertaining to the average daily increase in the height of red spinach plants during their growth cycle, specifically in soils with pH values of 4 and 4.5.

Based on the data presented in Table 1, it is discernible that red spinach plants cultivated in soil with a pH of 4 demonstrate an average daily growth rate of 0.2 cm per day. In contrast, those grown in soil with a pH of 4.5 exhibit a slightly lower average daily growth rate, amounting to 0.15 cm per day. These observations indicate that a pH level of 4 may be more conducive to the growth of red spinach plants when compared to a pH of 4.5. Nevertheless, it is noteworthy that these growth rates are relatively modest in comparison to plants cultivated in soils characterized by higher pH values.

The findings derived from this research underscore the pivotal significance of soil pH in shaping the growth and maturation of red spinach plants. The preservation of an ideal pH level stands as a fundamental requisite for fostering robust plant development and optimizing output. In light of these observations, it is advisable to consider the cultivation of red spinach plants in soils characterized by pH values spanning from 5.5 to 7 to promote their optimal growth and enduring vitality.

Additional research is merited to delve into the precise mechanisms by which soil pH exerts its influence on the physiological processes of red spinach plants. Gaining a comprehensive comprehension of these mechanisms holds the potential to furnish invaluable insights for the formulation of precise agricultural strategies, including soil modifications and pH fine-tuning, aimed at augmenting red spinach cultivation and elevating crop yields.

In summary, it is evident that the pH of the substrate exerts a substantial influence on the growth and longevity of red spinach plants. The research outcomes underscore that red spinach plants attain their maximum growth potential in soils characterized by a neutral pH of 7. Conversely, soil pH levels falling below 4 and within the range of 4.5 to 5 are associated with hindered growth and abbreviated lifespans among these plants. Vigilant monitoring and deliberate pH adjustments in the planting medium are of paramount importance for farmers and horticulturists to create an optimal milieu for the cultivation of red spinach plants, thereby contributing to sustainable agriculture and ensuring food security.

Table 1. The average daily development of plant height

Soil pH	Average Daily Plant Height Development (cm)
3.5	0
4	0
4.5	0.4167* (7 day)
5	0.4542** (9 day)
5.5	0.3322
6	0.3540
6.5	0.4058
7	0.4264

Upon reviewing the data presented in Table 1, it becomes evident that plant growth is hampered when the soil pH levels descend to 3.5 and 4. Conversely, red spinach plants cultivated in soil with a pH of 4.5 experience a reduced lifespan of just 7 days, accompanied by an average daily growth rate of 0.4167 cm. In comparison, red spinach plants raised in soil featuring a pH of 5 can endure for 9 days, manifesting an average daily growth rate of 0.4542 cm. In contrast, plants thriving in soil with pH values of 5.5, 6, 6.5, and 7 demonstrate sustained vitality over the entire 30-day duration of the study, displaying average daily growth rates of 0.3322 cm, 0.3540 cm, 0.4058 cm, and 0.4264 cm, respectively. Thus, it may be inferred that plants attain their optimal growth in soil with pH levels of 5.5, 6, 6.5, or 7, with the most rapid growth being observed at a pH of 7.

In addition to assessing plant height, another metric indicative of plant growth is leaf length, as longer or more substantial leaves often signify a healthier plant. The quantification of leaf length is measured from the stem's base to the leaf's tip. The variability in plant responses to diverse soil pH levels is reflected in **Figure 2.**

Figure 2 visually depicts the diverse reactions of plants to varying soil pH levels. It becomes apparent that plants cultivated in acidic soil with a pH of 4 experience restrained growth, featuring leaves that are shorter and smaller in comparison to those cultivated in soil characterized by neutral or slightly alkaline pH levels. With a pH increase to 4.5, a modest enhancement in leaf length is discernible, though the growth remains restricted. Nevertheless, when the pH reaches 5, the leaf length becomes akin to that of plants cultivated in ideal conditions, denoting a healthy growth pattern with leaves of typical size and morphology.

Moreover, as the soil pH attains levels of 5.5, 6, 6.5, and 7, the plants manifest vigorous growth, characterized by notably lengthy leaves. This suggests that a pH range marginally acidic to neutral is conducive to the flourishing of red spinach plants. Within these pH intervals, the plants display an augmented capacity for nutrient uptake from the soil, leading to the promotion of robust leaf development.

The outcomes derived from this investigation underscore the importance of upholding an ideal soil pH level for the prosperous growth and maturation of red spinach plants. The soil's pH exerts a direct influence on an array of physiological and biochemical mechanisms within the plants, encompassing nutrient assimilation, enzymatic functions, and hormonal regulation. By securing the suitable pH level in the planting medium, agricultural practitioners and horticulturists have the means to foster more robust plant growth, enhance crop yields, and elevate the overall quality of agricultural produce.

In summary, this study underscores the significance of soil pH as a determinant of growth and development in red spinach plants. The plants exhibit diverse reactions to distinct pH levels, with the most favourable growth occurring in soils characterized by pH values of 5.5, 6, 6.5, or 7. Ensuring the adequacy of soil pH is paramount for the cultivation of robust and flourishing plants, thereby contributing to a successful crop production.

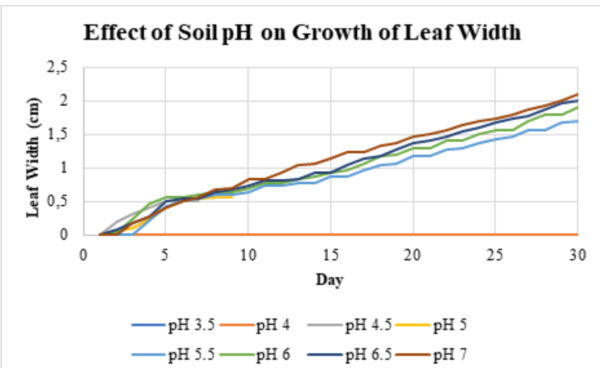

Figure 2. Graph of the effect of soil pH on the growth of leaf width

Figure 2 reveals a conspicuous absence of significant variation in soil pH concerning leaf length. Planting seeds in soils with a pH range spanning from 3.5 to 4 leads to their failure to germinate and establish growth. Consequently, the assessment of leaf length holds no relevance under these conditions. Conversely, plants thriving in a pH of 4.5 exhibit marked distinctions in the physical characteristics of their leaves compared to those grown in alternative soil conditions.

In particular, the leaves of red spinach plants cultivated in soil with a pH of 4.5 exhibit a distinctive reddish-green hue, deviating from the typical vibrant red coloration of red spinach leaves. Moreover, the elongated leaves of red spinach plants grown at a pH of 4.5 cease their growth on the fifth day post-planting, eventually succumbing on the seventh day.

Furthermore, red spinach plants cultivated in soil with a pH of 5 exhibit typical visual characteristics, featuring their characteristic red coloration. Nevertheless, a considerable portion of their leaves lacks a smooth texture and may display minor undulations or irregularities. Furthermore, leaves developed under these pH conditions exhibit a slow growth pattern. The growth initiation transpires on the second day post-planting, and leaf length can be quantified from that juncture onwards. This growth continues until the eighth day, beyond which no further development transpires, culminating in the plant's expiration on the ninth day.

Conversely, plants raised in soils characterized by pH levels of 5.5, 6, 6.5, and 7 consistently commence growth on the second day and sustain themselves for the entire 30-day duration or until the conclusion of the leaf length assessment.

To determine the optimal soil pH, the average daily growth in red spinach leaf length is employed as an evaluative parameter. Table 2 offers data pertaining to the mean daily advancement in the length of red spinach leaves during their entire life span when grown at pH levels of 4 and 4.5.

Table 2. Data on the average daily growth of leaf width

Soil pH	Average Development of Daily Plant Leaf Width (cm)
3.5	0
4	0
4.5	0.0833* (7 day)
5	0.0708** (9 day)
5.5	0.0586
6	0.0655
6.5	0.0689
7	0.0724

Drawing from the data furnished in **Table 2**, it becomes apparent that red spinach plants encounter impediments under specific soil pH circumstances. Seeds sown in soils with pH values of 3.5 and 4 prove unsuitable for sustaining the growth of red spinach plants. Conversely, red spinach plants cultivated in soil with a pH of 4.5 manifest a restricted life span, surviving for a mere 7 days. These plants exhibit an average daily growth rate of 0.0833 cm concerning leaf length..

Moreover, red spinach plants raised in soil with a pH of 5 demonstrate an extended survival period, lasting up to 9 days. The measurement of average daily leaf length growth under these pH conditions yields a rate of 0.0708 cm. However, the most favorable conditions for red spinach plants are encountered in soils characterized by pH levels of 5.5, 6, 6.5, and 7, where they can thrive throughout the entire 30-day study period. Within these pH conditions, the average daily leaf length growth rates are documented as 0.0586 cm, 0.0655 cm, 0.0689 cm, and 0.0724 cm, respectively. It can be concluded that red spinach plants experience their optimal growth in soils with pH values of 5.5, 6, 6.5, and 7. Notably, the most rapid leaf length growth is observed in soils with a pH of 7.

Soil pH assumes a pivotal role in delineating soil fertility from a chemical standpoint by influencing the accessibility of nutrients. The optimal pH spectrum for nutrient accessibility in soil typically ranges from 6.0 to 7.0. Within this scope, macro elements are made optimally available, while the levels of micronutrients remain relatively subdued, thereby mitigating the risk of micronutrient toxicity. Nutrients present in the soil can be classified into two categories: macronutrients and micronutrients. Macronutrients encompass vital elements, including carbon, nitrogen, phosphorus, potassium, calcium, magnesium, and sodium. Conversely, micronutrients comprise elements such as iron (Fe), manganese (Mn), and copper (Cu).

The soil's pH level assumes a pivotal role in dictating nutrient uptake by plants. Each plant species exhibits specific pH requirements essential for achieving optimal growth, and nutrient availability is intricately tied to soil pH. This investigation underscores that red spinach plants flourish in soil conditions that verge on being slightly acidic to neutral, characterized by pH levels spanning from 5.5 to 7. Soils situated beyond this range, such as those maintaining a pH of 3.5 or 4, prove unsuitable for fostering the growth and maturation of red spinach plants. Consequently, in the cultivation of red spinach or any other plant, it is imperative to consider the soil's pH, given its direct influence on the plant's capacity to assimilate indispensable nutrients, thereby significantly impacting its overall vitality and productivity.

The Effect of Moringa Leaves Liquid Organic Fertilizer on Red Spinach Plant Growth

Plant growth is visually evident through the progression of both plant height and leaf length. The assessment of plant height was conducted over a 30-day duration, and the outcomes for plants subjected to regular watering and those receiving liquid organic fertilizer derived from Moringa leaves are depicted in **Figure 3**.

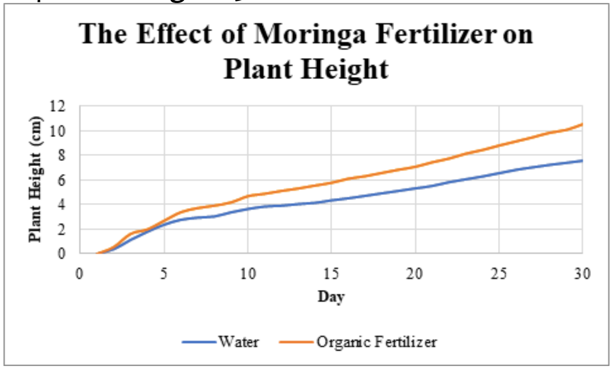

Figure 3. The effect of moringa fertilizer on plant height

Figure 3 illustrates that both sets of plants, those receiving conventional water irrigation and those benefiting from the supplementation of liquid organic fertilizer derived from Moringa leaves, sustained growth throughout the entire 30-day study period. However, a discernible divergence was observed in the daily growth rates between these two groups. Initially, both sets of plantsinitiated growth on the second day, and their growth rates remained roughly equivalent up to the fifth day. Subsequently, plants subjected to the liquid organic fertilizer derived from Moringa leaves exhibited an accelerated growth rate compared to those exclusively watered. The mean daily growth rates for plants under both water and liquid organic fertilizer conditions are presented in **Table 3.**

Watering with	Average daily plant height development (cm)
Water	0.25977
Organic Fertilizer	0.36437

Table 3 reveals that red spinach plants receiving standard water irrigation exhibit a height growth rate of 0.25977 cm per day. In contrast, plants that were irrigated with the supplementary liquid organic fertilizer derived from Moringa leaves experienced an accelerated growth, with an average daily plant height increase of 0.36437 cm per day. Consequently, it can be deduced that the height growth of red spinach plants receiving the additional liquid organic fertilizer is 1.4 times faster than that of red spinach plants solely subjected to water irrigation. The graphical representation of these findings is presented in **Figure 4.**

Figure 4. Height of red spinach plants with (a) and without (b) Moringa leaf liquid organic fertilizer

In addition to plant height, another parameter suitable for assessing plant development and fertility is leaf width. The elongation of red spinach leaves, evident in **Figure 5,** reflects the growth achieved over 30 days for plants subjected to standard water irrigation and those receiving the supplemental liquid organic fertilizer.

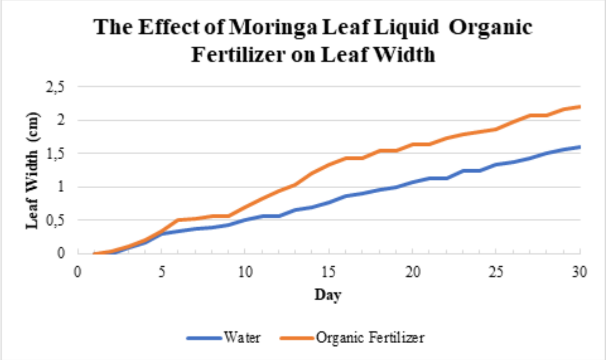

Figure 5. Graph of the effect of moringa fertilizer on leaf width

Figure 5 depicts that red spinach plants can thrive for 30 days when subjected to water irrigation as well as the supplementation of Moringa fertilizer. The growth pattern of both sets of red spinach plants exhibited a synchronized initiation of growth on the second day, and there was no noticeable disparity in their growth up to the fifth day. However, starting from the sixth day and onwards, the leaf length expansion of red spinach plants benefiting from the additional liquid organic fertilizer surpassed that of the plants exclusively irrigated with water. The daily leaf width growth rates are detailed in **Table 4.**

Table 4. Effect of moringa leaf organic fertilizer on leaf width

Watering with	Average daily leaf width development (cm)
Water	0.055172
Moringa Leaf Organic Fertilizer	0.075862

Based on the aforementioned data and analysis, it can be inferred that red spinach plants exhibit distinct pH prerequisites for optimal growth. The investigation underscores that red spinach plants face challenges in environments with pH levels spanning from 3.5 to 4. Nonetheless, when placed in soil characterized by a pH of 4.5, these plants can manage to persist for a week. Similarly, under a pH of 5, red spinach plants can extend their growth period slightly to 9 days. Furthermore, the research reveals that red spinach plants showcase their most robust growth in soils maintaining pH levels of 5.5, 6, 6.5, and 7, albeit with varying growth rates.

Within these distinct pH ranges, red spinach plant growth attains its zenith in soil characterized by a pH of 7. In such circumstances, the plants undergo an exceptional daily height increment, with growth rates reaching an approximate 0.4264 cm per day. Alongside height, the study also assessed leaf width growth, which was observed to be approximately 0.0724 cm per day in soil with a pH of 7. These findings underscore the critical importance of preserving an ideal pH level of 7 for achieving the most favorable growth outcomes in red spinach plants.

Furthermore, the study examined the effects of incorporating liquid organic fertilizer sourced from Moringa leaves on red spinach growth. The results demonstrate a notable influence of adding this organic fertilizer in augmenting the growth pace of red spinach plants. Upon administering the liquid organic fertilizer from Moringa leaves to the red spinach plants, their growth rate was observed to be 1.4 times swifter in comparison to plants devoid of organic fertilizer. Moreover, the growth rate of red spinach leaves, when exposed to the liquid organic fertilizer, was determined to be 1.375 times faster in contrast to leaves that were not subjected to organic fertilizer treatment.

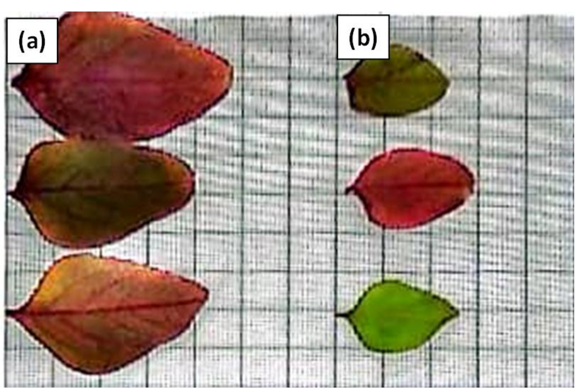

Figure 6. The difference in the width of the leaves of plants that are watered with (a) and without (b) Moringa fertilizer

4. DISCUSSION

The soil's degree of acidity, determined through pH measurements, holds critical significance, as it serves as an indicator of the availability of essential macronutrients such as nitrogen (N), potassium (K), and phosphorus (P), each of which is required by plants in specific quantities. Furthermore, soil acidity levels also provide insights into the presence of elements that can be detrimental to plant health. In soils characterized by excessive acidity and low pH values, aluminum is a prevalent presence, posing potential harm to plants by poisoning them and binding the crucial phosphorus they require. Plants absorb aluminum ions due to a transformation process that results in smaller-sized ions, making absorption easier. The acidic soil conditions can influence the alteration of metallic forms, rendering them more readily absorbable by plants. However, when plants take up metals like aluminum, their capacity to effectively assimilate phosphorus may become compromised. Additionally, excessively acidic soils are rich in trace elements that hinder the utilization of nitrogen, phosphorus, potassium, and other indispensable nutrients by plants. This, in turn, can lead to the poisoning of larger plants by heavy metals, ultimately resulting in their demise.

This investigation revealed that red spinach plants exhibited optimal growth in soil characterized by a pH range spanning from 5.5 to 7.0. Within this favorable pH range, the proliferation of organic-decomposing fungi and bacteria in the soil was facilitated. Additionally, beneficial microorganisms conducive to root health thrived under these specific pH conditions, thereby contributing to the holistic development of plants. Notably, specific soil bacteria played a pivotal role in nitrogen fixation, enabling the conversion of atmospheric nitrogen into a plant-accessible form.

Conversely, excessively alkaline soil proves detrimental to plant growth. In alkaline soil, plants encounter impediments in the efficient absorption of macronutrients. Although plants may not necessitate macronutrients in substantial quantities, they remain reliant on them as a vital nutritional source. Elevated soil alkalinity prompts the transformation of macronutrients such as iron and copper into larger, less accessible forms, thereby hindering their absorption by plants. Consequently, plants face a deficiency of these critical nutrients, culminating in suboptimal growth. Consequently, the higher the soil's alkalinity, the more formidable the challenge for plants to assimilate these macronutrients, ultimately constraining their comprehensive development.

It is apparent that the maintenance of the correct soil pH level holds paramount importance in guaranteeing the optimal availability and absorption of nutrients by plants. Red spinach, akin to numerous other plant species, flourishes within a specific pH spectrum, underscoring the precise equilibrium essential for their growth and maturation. Through a meticulous evaluation and regulation of soil pH, agricultural practitioners and horticulturists can establish a conducive milieu that fosters robust plant growth and augments agricultural yield.

These outcomes underscore the significance of incorporating soil pH into the deliberation when engaging in the cultivation of red spinach plants. The conclusions propose that red spinach plants are predisposed to flourish most optimally within a pH spectrum extending from 5.5 to 7, with a pH of 7 specifically conferring advantages. This discernment can function as a beneficial directive for agriculturists and horticulturists intent on enhancing the development and output of red spinach harvests.

Moreover, this investigation illuminates the pivotal role of pH concerning soil nutrient accessibility. The level of soil acidity, as mirrored by pH, assumes a critical position in determining the availability of indispensable macronutrients like nitrogen (N), potassium (K), and phosphorus (P), all of which are fundamental for the growth and development of plants. Soil acidity further governs the presence of elements that may exert toxicity on plants. In cases of excessively acidic soil characterized by low pH values, the presence of aluminum constitutes a peril for plants, as it can obstruct the absorption of phosphorus and potentially lead to toxicity. The acidic soil conditions prompt a transformation of aluminum into a smaller, more readily absorbable form by plants. This altered aluminum structure hinders the appropriate absorption of phosphorus, subsequently affecting the overall health of the plants. Additionally, significantly acidic soil harbors an abundance of trace elements that may obstruct the utilization of nitrogen, phosphorus, potassium, and other nutrients vital for plant growth. The accumulation of these trace elements can potentially precipitate heavy metal poisoning in plants, ultimately culminating in their demise.

On the contrary, excessively alkaline soil is also disadvantageous for plant growth. Under such circumstances, plants encounter difficulties in the efficient absorption of macronutrients, as high soil alkalinity triggers the transformation of macronutrients such as iron and copper into larger, less accessible forms for plants. This, in turn, renders plants incapable of procuring the vital nutrients essential for their robust growth and development. The higher the degree of alkalinity in the soil.

5. CONCLUSION

Drawing from the aforementioned information, it becomes apparent that red spinach plants exhibit distinct growth patterns contingent on the prevailing pH soil. These plants manifest their optimal growth potential within the pH range of 5.5 to 7, while under more acidic pH conditions, their growth may be hindered or altogether impeded. Remarkably, red spinach plants demonstrate their most prolific growth when cultivated in soil with a pH of 7. Under these conditions, the plants exhibit an exceptional daily increase in height, approximately measuring 0.4264 cm per day, in addition to leaf width growth at a rate of 0.0724 cm per day.

Furthermore, the incorporation of liquid organic fertilizer derived from Moringa leaves into the irrigation regimen can significantly enhance the growth rate of red spinach. Red spinach plants subjected to this organic fertilizer experience a growth rate 1.4 times faster than those without organic supplementation. Additionally, the growth rate of red spinach leaves treated with liquid organic fertilizer from Moringa leaves is 1.375 times faster than those not exposed to organic fertilizer

In conclusion, the results indicate that red spinach plants exhibit distinct pH requirements for their most favorable growth. The inclusion of liquid organic fertilizer obtained from Moringa leaves can additionally enhance the growth of red spinach plants, resulting in accelerated plant height and leaf width development. These findings underscore the significance of controlling appropriate pH levels and integrating organic fertilization strategies to optimize the growth and productivity of red spinach plants.

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