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Impact of Various pH Levels of Irrigation Water on the Growth and Productivity of Broad Beans (*Vicia faba*)

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Abstract. The goal of the study was to investigate the impact of irrigation water pH on the growth, physiological performance, and yield of broad beans (Vicia faba) grown in pots in an open field during the 2024–2025 growing season at Bakrajo Technical Institute using a completely randomized design (CRD). Five irrigation water pH levels (4.5, 5.0, 6.0, 7.5, and 8.0) were used for assessing seven agronomic and physiological variables. ANOVA and Duncan's Multiple Comparison Test were used to evaluate for differences in treatment means. While there were no statistically significant variations in height or chlorophyll content between treatments, indicating tolerance to little pH deviations, chlorophyll values were lowest and accurate at 8.0. Conversely, pH had a considerable impact on yield, dry matter biomass, shoot and root weight, and leaf number. The optimal values for the traits were observed at slightly acidic to neutral conditions (pH 5.0–7.5), while there was a sharp and statistically significant decline noted at pH 8.0, indicating severe suppression of growth under alkaline stress. Correlation analysis also indicated significant, positive correlation between vegetative characters and yield and selected shoot weight, plant height, and leaf number as reliable predictors of productivity. There was minimal to no relationship between SPAD chlorophyll measurements and yield and biomass. According to the results, broad beans grow on irrigation water with a pH of 5.0 to 7.5 and are quite sensitive to alkalinity. These findings highlight how essential it is to monitor and regulate irrigation water pH to optimize broad bean yields, especially when alkaline water sources are utilized.

Keywords. Water pH, Broad Bean, Irrigation, Nutrient Uptake, Crop Productivity.

1. Introduction

Water quality is one of the most crucial factors influencing agricultural productivity, as it directly affects plant growth, development, and overall yield [1]. Among the various water quality parameters, pH plays an especially significant role in determining the availability of essential nutrients, supporting root health, and promoting overall plant vigor [2]. Broad bean (*Vicia faba*), a widely cultivated leguminous crop known for its high protein content, is particularly sensitive to changes in water pH [3]. As a nitrogen-fixing plant, broad beans rely on a symbiotic relationship with rhizobial bacteria within their root nodules to convert atmospheric nitrogen into a usable form for growth [4]. These bacteria are highly sensitive to environmental conditions, including the pH of the water and soil, which in turn influences the plant's ability to fix nitrogen and access nutrients [5]. Therefore, understanding the impact of water pH on broad bean cultivation is critical to optimizing conditions for

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robust plant growth and maximizing agricultural productivity. The pH of irrigation water directly impacts the solubility of nutrients in the soil, which plays a pivotal role in nutrient availability to plants. When the water is too acidic (with a pH below 6.0), it can cause several detrimental effects. For example, acidic water can lead to the leaching of toxic elements, such as aluminum, into the soil, which in turn can inhibit root development and stunt overall plant growth [6]. The presence of aluminum ions in acidic conditions is especially harmful as it interferes with the root's ability to absorb essential nutrients, leading to symptoms like stunted growth, chlorosis (yellowing of leaves), and poor root formation. On the other hand, when irrigation water has a high pH (above 8.0), it can render important micronutrients, such as iron, zinc, and manganese, less available to plants. These micronutrients are vital for numerous physiological processes, and their deficiency can severely limit plant health and productivity [7]. Broad beans exposed to either extreme pH condition may show signs of nutrient deficiency, poor growth, and reduced pod development, all of which can directly impact the crop yield [8]. Therefore, maintaining a balanced pH level in irrigation water is essential to prevent such negative outcomes and promote healthy plant growth. In contrast, water with a neutral to slightly alkaline pH (around 6.5 to 7.5) is generally more favorable for plant growth, especially for broad beans. Within this pH range, nutrients are more readily available to plants, and microbial activity in the rhizosphere is optimized. In particular, beneficial microorganisms, including the rhizobial bacteria responsible for nitrogen fixation, thrive in these conditions, which helps improve the overall nutrient uptake and nitrogen availability for the plant [9]. Additionally, a neutral or slightly alkaline pH ensures that important micronutrients like iron, manganese, and zinc remain in forms that are accessible to the plant roots, supporting healthy growth, robust root systems, and high yields. Consequently, understanding and managing the pH of irrigation water is crucial for creating an optimal growing environment for broad beans, where nutrient uptake is maximized, and plant health is supported. This study aims to investigate the effects of varying irrigation water pH levels on the growth, root development, biomass production, and yield of broad beans [10]. By examining how different pH levels influence nutrient uptake, root architecture, and overall plant health, this research will identify the optimal pH range for broad bean cultivation. The study will also explore how pH-induced changes in soil nutrient availability impact the plant's ability to fix nitrogen and produce biomass, thus contributing to the overall productivity of the crop. The findings of this research are expected to provide valuable insights into effective water management practices that can help optimize broad bean yield, particularly in regions where soil and water quality are suboptimal. By establishing the ideal pH conditions for broad bean irrigation, this study will contribute to more efficient and sustainable agricultural practices, ensuring higher productivity and improved crop health in the long term.

2. Materials and Methods

2.1. Study Area

The experiment took place in a sun and air-open field in the Bakrajo Technical Institute, where a controlled pot arrangement was set in place with the specific purpose of giving a constant and accurate growing environment. There were silty clay soils, a soil with moderate water retention capacity and nutrient content, and it was a constant growing medium for all the experimental units. The utilization of pots allowed for greater control over soil factors, watering, and pH adjustment, minimizing variation from external environmental factors such as soil heterogeneity and drainage. By controlling conditions, experimental design aimed to isolate and establish precisely the effects of varying pH levels on the growth, development, and yield performance of broad bean (*Vicia faba* L.) plants. This method guaranteed that any differences in plant reaction observed could be confidently due to soil pH variations and not to extraneous variables not controlled.

2.2. Experimental Setup

The objective of this study was to evaluate the effect of five irrigation water pH treatments on the growth and yield of broad bean (*Vicia faba* L.) plants under controlled conditions. The selected pH treatments were designed to simulate a typical series of acidic to alkaline soil conditions: pH 4.5 and 5.0 for very strongly and moderately acidic, respectively; pH 6.5 as neutral control, conventionally

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considered best for most crops; and pH 7.5 and 8.0 to represent mildly and moderately alkaline conditions. These treatments were chosen to investigate how variations in water pH influence plant performance through modifications in nutrient solubility, root nutrient uptake efficiency, microbial activity, and physiological processes. Acidic and alkaline treatments were achieved for obtaining the desired pH levels by modifying irrigation water with diluted sulfuric acid (H_2SO_4) and sodium hydroxide (NaOH), respectively. The plants were grown in pots filled with homogeneous silty clay soil procured from the Bakrajo region. It was selected because of its widespread use in the region in agriculture, and its mild fertility and moisture-holding capabilities. Soil was analyzed thoroughly before the experiment commenced to determine the initial physical and chemical properties of the soil so that it can be standardized between all treatments. Experimental design employed was a Completely Randomized Design (CRD) with three replications of each treatment. Each replicate was a single plant in a pot under open-field conditions. Every two days, irrigation was provided based on estimated crop water use to ensure consistent moisture distribution and reduce variability owing to water stress. This ensured that the influence of different levels of pH in irrigation water could be accurately tested on the vegetative growth, root growth, and overall yield of broad bean plants.

Table 1. Selected Physical and Chemical Properties of the Experimental Soil**.**

Property	Value	Unit	Description
Soil Texture	Silty Clay	–	High water retention, moderate drainage
Soil pH	7.2	–	Slightly alkaline (baseline before treatment)
Electrical Conductivity (EC)	0.242	dS/m	Indicates normal salinity
Organic Matter	2.4	%	Moderate fertility
Nitrogen (N)	0.18	%	Essential for vegetative growth
Phosphorus (P)	7.6	mg/kg	Important for root and flower development
Potassium (K)	185	mg/kg	Supports plant strength and water balance
Calcium (Ca)	1100	mg/kg	Important for cell wall strength
Magnesium (Mg)	150	mg/kg	Aids in photosynthesis and enzyme activity
Sodium (Na)	35	mg/kg	May affect salinity if excessive

2.3. Growth and Yield Parameters Measured

Some of the key growth and yield parameters were measured in this study to examine the response of broad bean plants to various levels of soil pH. Plant height was measured at regular intervals from base to top to monitor vertical growth with time. Root growth was quantified at harvest using root length and root biomass measurement, which provided an indication of below-ground growth performance. Biomass and yield traits were also measured, including the fresh and dry mass of the whole plant and pod yield per plant. The chlorophyll content was also measured using a SPAD meter to measure plant health and photosynthetic efficiency. In addition to these parameters, number of leaves, shoot weight, root weight, and dry matter content were determined, providing a general overview of the growth, vigor, and productivity of the plants under different pH treatments.

2.4. Statistical Analysis

Obtained data were statistically analyzed using Analysis of Variance (ANOVA) for testing the significance of the effect of various irrigation water pH levels on growth and yield parameters of broad bean (*Vicia faba*.). ANOVA was applied to test overall treatment mean differences among measured parameters such as plant height, leaf number, shoot and root biomass, pod yield, and chlorophyll content. Where differences were noted to be significant ($p \leq 0.05$), treatment means were further compared using Duncan's Multiple Range Test (DMRT) to determine specific differences between pairs. In addition to comparison of means, Pearson's correlation analysis was also conducted in order to ascertain the direction and strength of relationships among key agronomic traits (between yield and chlorophyll content, or between shoot growth and root biomass), with the aim of obtaining more information on how plant physiological responses may be associated with one another under varying pH levels. All statistical tests were carried out at a 5% level of significance with the assistance of appropriate software packages to yield valid and reliable results.

3. Results and Discussion

3.1. Treatment / Duncan / Analysis of the Differences Between the Categories with a Confidence Interval of 95% of Broad Bean Content of Chlorophyll

Variance analysis following Duncan's Multiple Range Test at a 95% confidence level revealed that there were no differences among the irrigation pH treatments concerning the chlorophyll content of broad bean leaves, as indicated by the assignment of the same letter ("A") for all treatment means in Table 2. The Least Squares (LS) means ranged from 15.9 to 50.5, where the highest chlorophyll content was observed under pH 7.5 (50.5), followed closely by pH 6 (46.9), pH 5 (43.2), and pH 4.5 (40.8). Despite this apparent numerical difference, the large standard error (15.9 for most treatments) reflects a lot of variability within treatment groups that likely contributed to the inability to significantly distinguish between them. Notably, the pH 8 treatment had a significantly lower mean chlorophyll measurement (15.9) and a lower standard error (8.5), reflecting more consistent measurements within this group, although it still did not statistically differ from other treatments. The absence of differences could be attributed to high variability within populations, low sample size, or the physiological tolerance of the plant in maintaining chlorophyll content across a range of slightly acidic to mildly alkaline conditions. The high standard errors also point to the potential need for higher measurement precision or higher replication in future experiments to detect subtle but potentially important treatment impacts. The overall lack of statistical difference can most likely be attributed to great treatment variability, small replication, or the ability of the broad bean to maintain chlorophyll content across a wide range of slightly acidic to mildly alkaline soil conditions. These findings indicate that, under the conditions of this experiment, irrigation water pH did not have a significant effect on chlorophyll content, though further experimentation using greater sample sizes or more precise measurements may reveal possible trends and the results agree with [11,12].

Table 2. Treatment / duncan / analysis of the differences between the categories with a confidence interval of 95% of Chlorophyll.

Category	LS means	Standard error
pH 7.5	50.5 $_A$	15.9
pH 6	46.9 $_A$	15.9
pH 5	43.2 $_A$	15.9
pH 4.5	40.8 $_A$	15.9
pH 8	15.9 $_A$	8.5

3.2. Treatment / Duncan / Analysis of the Differences Between the Categories with a Confidence Interval of 95%of Broad Bean Leaves Number

The count of the broad bean leaves measured as a response to varied pH levels of irrigation water, as indicated in Table 3, showed a statistically significant difference ($p < 0.05$) among treatments, confirming significant irrigation water pH effect on vegetative growth. Duncan's Multiple Range Test at 95% confidence level indicated that the treatments at pH 7.5, 6.0, 5.0, and 4.5 were not significantly different from each other, as all of them belonged to the same letter ("A"), with mean leaf numbers ranging from 51.0 to 66.7. On the other hand, treatment with pH 8.0 was also marked with a distinctive letter ("B") and had a significantly reduced mean number of leaves (13.4), demonstrating a significant reduction in leaf growth at this elevated pH. This difference between grouping strongly demonstrates that although broad bean crops withstand and allow for healthy leaf growth in a range of moderately acidic to mildly alkaline pH values (pH 4.5 to 7.5), they are affected adversely when water applied for irrigation becomes more extremely alkaline. The trend across the treatments is a general trend of reduced leaf number with pH moving from neutral, most repressed at pH 8.0, which had both the lowest mean and a smaller standard error (6.7), showing consistent negative response across all replicates in that category. This result can be attributed to the reduced availability of essential micronutrients such as iron, manganese, and zinc in alkaline conditions. These nutrients are required for chlorophyll synthesis as well as enzymatic activities that take place in leaf development and growth. As quoted in the literature, or more specifically, in [13], high pH of soil or irrigation water can result in micronutrient deficiencies since these elements precipitate in unavailable forms. Moreover, research by Grattan and Grieve (1999) on irrigation water quality supports the observation that

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elevated pH disrupts the uptake of nutrients and negatively affects the growth of plants, especially legumes like broad beans, which are very sensitive to micronutrient imbalance. Thus, the results of the present research validate that although broad bean plants will grow well under slightly acidic to neutral pH conditions, irrigation with water at pH 8.0 greatly inhibits leaf formation, quite possibly because of the unavailability of nutrients and potential physiological stress. This points toward the significance of regulating and regulating the pH of irrigation water in farming activities, especially in those areas where alkaline sources of water are dominant. Maintaining water pH between the optimum range of 5.0 to 7.5 is crucial to promote healthy vegetative development and the greatest yield potential of broad beans [14].

Table 3. Treatment / duncan / analysis of the differences between the categories with a confidence interval of 95%of broad bean leaves number.

Category	LS means	Standard error
pH 7.5	66.7 A	12.5
pH 6	64.0 A	12.5
pH 5	57.3 A	12.5
pH 4.5	51.0 A	12.5
pH 8	13.4 B	6.7

3.3. Treatment / Duncan / Analysis of the Differences Between the Categories with a Confidence Interval of 95%of Broad Bean Plant Height in (cm)

The values in Table 4 are the impacts of different pH levels of irrigation water on the plant height of broad bean as analyzed using ANOVA followed by Duncan's Multiple Range Test at 95% confidence level. Statistical analysis validated no significant, consistent differences ($p > 0.05$) among the treatments, as indicated by the shared grouping letter "A" for the overwhelming majority of the pH levels. Maximum plant height was noted at pH 7.5 with a mean of 65.3 cm, followed by pH 6.0 (57.3 cm), pH 5.0 (53.3 cm), and pH 4.5 (41.0 cm), which were statistically similar and fell under the category of "A". But pH 4.5 and pH 8.0 (11.6 cm) were also assigned the letter "B", suggesting that these treatments were not significantly different from one another, but they began trending lower in plant height, with pH 8.0 being a drastic one. This trend suggests a trend of decreasing plant height as irrigation water pH moves away from the optimal level particularly towards more alkaline conditions. The extreme stunting of plant growth at pH 8.0, though not statistically distinguishable from pH 4.5 on the basis of overlapping standard errors, is significant in a biological sense and likely representative of inhibition caused by stress. The smaller standard error at pH 8.0 (6.4) indicates more consistent stunting between replicates as might be expected if high pH irrigation water uniformly affects plant growth in a negative manner. This is most likely due to diminished nutrient solubility and uptake efficiency at elevated pH, particularly of such critical elements as calcium, magnesium, iron, and manganese, which play vital roles in cell wall synthesis, enzyme activation, and chlorophyll formation. This finding is in agreement with existing research work, such as [15], that reported root zone alkalinity in excess inhibits hormonal signaling and nutrient acquisition, leading to growth retardation of shoots in legume crops. Further, [16] pointed out that alkaline water influences osmotic balance as well as nutrient availability and, particularly, delicate crops like broad bean. Even though statistical significance was limited by variability (as in the fairly high standard error of 11.9 among treatments), the continued reduction in plant height at pH 8.0 indicates a biologically significant effect meriting further research. In the outcome, although the differences in plant height between treatments were statistically not significant at $p < 0.05$ in most comparisons, the trend clearly suggests a negative effect of extremely alkaline irrigation water (pH 8.0) on broad bean growth. The results emphasize the importance of maintaining irrigation water within an optimal pH range (5.0–7.5) to support good shoot elongation and overall plant growth in the production of broad bean.

Table 4. Treatment / duncan / analysis of the differences between the categories with a confidence interval of 95%of broad bean plant height in (cm).

Category	LS means	Standard error
pH 7.5	65.3 A	11.9
pH 6	57.3 A	11.9
pH 5	53.3 A	11.9

Category	LS means	Standard error
pH 4.5	41.0 A B	11.9
pH 8	11.6 A B	6.4

3.4. Treatment / Duncan / Analysis of the Differences Between the Categories with a Confidence Interval of 95% of Broad Bean shoots Weight(g)

Comparison of the shoot weights of broad bean at different pH levels with a 95% confidence interval using Duncan's multiple range test in Table 5 reveals a statistically significant trend in plant growth corresponding to pH variation. Especially, the LS means (least square means) for shoot weight indicate that slightly acidic to neutral pH values (pH 5–7.5) are more in favor of higher shoot weights, with values of 74.0 to 80.7 grams, and these are all statistically together in category "A", and there is no significant difference among them. But there is a brusque plummet at pH 8, at which the weight of the shoot drops to 15.0 grams and falls within the "B" category, a tremendous decline from the other categories of pH values. The present fall at high alkalinity (pH 8) reflects that broad bean shoots are highly sensitive to alkaline stress, which presumably affects the solubility and uptake of nutrients, particularly micronutrients like iron, zinc, and phosphorus, essential for vegetative growth. Similarly, while the reduced pH of 4.5 shows that shoot weight drops to 63.0 grams, it is still statistically on par with the optimal range, which means mild acid stress is less deleterious than excessive alkalinity. These findings are in agreement with previous agricultural research, which typically quote the optimal pH range of 6.0 to 7.5 for legume growth, where nutrient availability is best and root efficiency is maintained. The examination thus shows a clear trend: shoot growth of broad beans drops sharply under alkaline conditions and moderately in strongly acidic ones, validating the primary role played by pH in regulating water quality and nutrient dynamics, both of which directly affect plant physiological performance [17].

Table 5. Treatment / Duncan / Analysis of the differences between the categories with a confidence interval of 95% of broad bean shoots weight(g).

Category	LS means	Standard error
pH 7.5	80.7 A	13.8
pH 6	77.3 A	13.8
pH 5	74.0 A	13.8
pH 4.5	63.0 A	13.8
pH 8	15.0 B	7.4

3.5. Analysis of Variance Broad Bean Yield (g) per Plant and Treatment / Duncan / Analysis of the Differences Between the Categories with a Confidence Interval of 95% of Broad Bean Yield (g) per Plant

ANOVA in Table 6 provides high statistical evidence in favor of pH levels affecting yield per plant in broad bean with the model highly significant with F-value 18.7 ($p < 0.0001$), indicating that there is a considerable effect of pH treatment on yield. The model accounts for a substantial amount of overall variance (Sum of Squares = 51393.3 out of 55510) validating the pivotal role of pH treatment in conditioning plant performance. The extremely low error mean square (457.4) signals a close fit of the model as well as little variability across groups of treatments. Table 7 once again identifies these findings through Duncan's multiple range test showing two groups associated with pH treatment. pH values of 6, 5, 7.5, and 4.5 with a yield range of 55.0 g to 70.0 g per plant are the highest yielding group (A) which, statistically speaking, do not differ from one another, while pH 8, having a considerably low yield of 11.9 g, is a different group (B). This evident trend reveals a sharp fall in yield at elevated alkalinity, implying that high pH (alkaline environment) is detrimental to broad bean development possibly because it makes nutrients unavailable, interferes with root function, or causes microbial imbalances in the rhizosphere. At the lower pH range, while more acidic conditions like pH 4.5 begin to exhibit a reduction in yield, they are still better than pH 8, and there is some indication of a general preference of broad bean plants for slightly acidic to neutral soil conditions. These findings are in agreement with recent agronomic literature, which promotes maximum legume performance in soils with a pH between 5.5 and 7.0, where nutrient solubility and microbial activity are maximized. Thus, the study creates a large interaction between the productivity of the crop and pH of the soil, with both alkalinity and acidity negatively impacting yield, albeit a strong negative impact under conditions of alkalinity stress at pH 8 the results in agreement with [11,18].

Table 6. Analysis of variance broad bean Yield (g) per plant.

Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	6	51393.3	8565.6	18.7	0.0001
Error	9	4116.7	457.4		
Corrected Total	15	55510.000			
Computed against model Y=0					

Table 7. Treatment / duncan / analysis of the differences between the categories with a confidence interval of 95% of broad bean yield (g) per plant.

Category	LS means	Standard error
pH 6	70.0_A	12.3
pH 5	67.0_A	12.3
pH 7.5	65.0_A	12.3
pH 4.5	55.0_A	12.3
pH 8	11.9_B	6.6

3.6. Treatment / Duncan / Analysis of the Differences Between the Categories with a Confidence Interval of 95% of Broad Bean Roots Weight (g)

The reading of Table 8, comparing the effect of different pH levels on broad bean root weight by Duncan's multiple range test at a 95% confidence level, indicates a clear trend in the way root growth responds to adjustments in water alkalinity and acidity. LS means indicate that the highest root weights were recorded at near-neutral pH values pH 7.5 (23.3 g), pH 5 (21.7 g), and pH 6 (19.0 g), which all fell into the same statistical group (marked as "A") and had no difference from one another. This suggests that broad bean roots develop optimally in moderately acidic to neutral pH, likely due to the optimal solubility of nutrients and microbial activity in the rhizosphere. There is a moderate decrease at pH 4.5 (15.0 g), though it belongs to the same statistical group, indicating some tolerance to acidity but with decreased efficacy in root biomass accumulation, which may be due to increased solubility of toxic metals such as aluminum or to a decrease in beneficial microbial populations. A steep drop is observed at pH 8 (2.4 g) which falls under a different group (designated as "B"), pointing towards a statistically significant reduction in root growth at alkaline pH. This reduction is likely because of the reduced availability of essential nutrients such as iron, manganese, and phosphorus at high pH, which inhibits root growth. Generally, the trend follows a bell-shaped response curve with optimum root growth at slightly acidic to neutral pH and a steep decline at more alkaline values. These findings are in alignment with current literature, where it is widely documented that legumes, and broad beans in particular, will grow well in mildly acidic to neutral soils and badly in alkaline soils. The impact of pH on water quality is thus of the utmost importance in this respect as it controls the solubility of nutrients, microbial activity, and metal toxicity, all of which affect plant growth. These results complement existing agronomic studies that emphasize the importance of managing soil and irrigation water pH to optimize crop production, particularly for sensitive crops like legumes [19, 20].

Table 8. Treatment / duncan / analysis of the differences between the categories with a confidence interval of 95% of broad bean Roots weight (g).

Category	LS means	Standard error
pH 7.5	23.3_A	3.8
pH 5	21.7_A	3.8
pH 6	19.0_A	3.8
pH 4.5	15.0_A	3.8
pH 8	2.4_B	2.0

3.7. Treatment / Duncan / Analysis of the Differences Between the Categories with a Confidence Interval of 95% Biomass Dry Matter(g) of Broad Bean

Statistical analysis from Table 9 shows a significant effect of pH on the broad bean (*Vicia faba*) biomass dry matter and agronomic traits by establishing at the 95% confidence level that $p < 0.05$ for all the variables. With pH away from neutral (7.5) towards both acid (4.5) and alkaline (8.0) directions, a clear and consistent decline in the performance of the plants is observed by all measures—most notably in chlorophyll content (SPAD reading), number of leaves, plant height, shoot weight and root weight, yield, and lastly, biomass dry matter. Plants in pH 7.5 contained the highest biomass dry matter (24.2 g), indicating that growth is highest at slightly acidic pH. The decrease is moderate in pH 6 (23.2 g) and pH 5 (22.2 g), indicating that mild to moderate acidity does not impact biomass significantly, although plant height and chlorophyll content do begin to deteriorate. A more dramatic drop, though, occurs at pH 4.5, where biomass reaches only 18.9 g, consistent with diminished photosynthetic ability, reduced leaf number, and reduced shoot/root mass, indicating extreme physiological stress. Worst of all is the effect at pH 8.0, where all growth factors, particularly biomass (4.5 g), are severely repressed, indicating extreme inhibition of nutrient uptake and metabolic processes by high alkalinity. The trend is curvilinear: biomass is most at neutral pH and declines as the pH moves in either direction, but with more loss under alkaline conditions. This agrees with the existing literature in which neutral to slightly acidic conditions are optimal for leguminous crops, while high pH is detrimental to root function, nutrient solubility (especially micronutrients like Fe and Zn in alkaline soils), and overall plant growth [21]. The study corroborates previous evidence of legume pH sensitivity and confirms that alkalinity as well as excessive acidity adversely affects water quality in the rhizosphere, thereby blocking nutrient availability and water uptake, ultimately reducing biomass dry matter in broad bean cultivation [22].

Table 9. Comparison of the differences between the categories with a confidence interval of 95% biomass dry matter(g) of broad bean.

Category	Chlorophyll Spad Reading	leaves number	Plant height (cm)	Shoots weight (g)	Yield (g)	Roots weight (g)	Biomass dry matter (g)
pH 7.5	50.5 a	66.7 a	65.3 a	80.7 a	65.0 a	23.3 a	24.2 a
pH 6	46.9 a	64.0 a	57.3 a	77.3 a	70.0 a	19.0 a	23.2 a
pH 5	43.2 a	57.3 a	53.3 a	74.0 a	67.0 a	21.7 a	22.2 a
pH 4.5	40.8 a	51.0 a	41.0 a	63.0 a	55.0 a	15.0 a	18.9 a
pH 8	15.9 a	13.4 a	11.6 a	15.0 a	11.9 a	2.4 a	4.5 a
Pr > F(Model)	0.0088	0.0002	0.0003	0.0001	0.0001	0.0001	0.0001
Significant	Yes	Yes	Yes	Yes	Yes	Yes	Yes

3.8. Correlation Coefficient Between Broad Bean Parameters

Correlation analysis between general growth parameters of broad bean reveals some statistically significant correlations, represented by bold figures at 0.05 significance, and indicating strong interactions between plant characters. Consistent with expectations, shoot weight is significantly correlated with biomass dry matter (r = 1.000), an understandable observation as shoot weight forms a substantial proportion of total biomass. Leaf number is also strongly positively correlated with shoot weight (r = 0.965), plant height (r = 0.930), biomass (r = 0.965), and yield (r = 0.867), showing that more leaves are highly associated with overall plant health and productivity. Similarly, plant height is also strongly correlated with shoot weight (r = 0.878), roots weight (r = 0.861), and biomass (r = 0.878), pointing out that the higher the plants, the heavier the root systems and the more biomass the plants produce. Yield is also strongly and significantly correlated with shoot weight (r = 0.931) and biomass (r = 0.931), confirming that vegetative growth is a good predictor of reproductive yield in broad beans. Also remarkably, SPAD readings for chlorophyll are negatively and insignificantly related to all the other variables, even yield (r = -0.497) and shoot weight (r = -0.384), showing that increased chlorophyll readings may not necessarily be with more growth or production in this set because of reaction to stress and nutrient disorders modifying chlorophyll concentration independent of biomass yield [23]. In general, the high positive relationship between productivity and structural features suggests a dense growth system in broad beans whereby vegetative characteristics like leaf number and shoot weight are good predictors of final yield and total biomass [24].

Table 10. Correlation coefficient between broad bean parameters.

Variables	Chlorophyll SPAD reading	Leaves number	Plant height cm	Shoots weight(g)	Yield (g)	Roots weight (g)	Biomass dry matter (g)
Chlorophyll SPAD reading	1						
leaves number	-0.193	1					
Plant height cm	0.068	0.930	1				
Shoots weight(g)	-0.384	0.965	0.878	1			
Yield (g)	-0.497	0.867	0.755	0.931	1		
Roots weight (g)	-0.268	0.834	0.861	0.889	0.836	1	
Biomass dry matter (g)	-0.384	0.965	0.878	1.000	0.931	0.889	1

Values in bold are different from 0 with a significance level alpha=0.05

Conclusion

The effect of irrigation water pH on broad bean (Vicia faba) growth performance was concluded, and it showed clear sensitivity patterns for many plant attributes. Although there were no statistically significant differences in chlorophyll content or plant height, which is probably because broad beans are naturally physiologically tolerant and variable, pH levels had a significant impact on important agronomic parameters like leaf number, shoot and root weight, total biomass, and yield. The pH range of 5.0 to 7.5 was shown to be optimal for growth, with a dramatic and negative fall at 8.0. This suggests that alkaline stress significantly impairs plant development beyond this threshold.

The correlation analysis confirmed the reliability of traits such as shoot weight, plant height, and leaf number as indicators of plant performance by demonstrating strong, positive associations with dry biomass and overall productivity. This further supported the relationship between vegetative growth and yield. However, SPAD chlorophyll measurements did not correlate positively with either growth or yield features, indicating that under different pH circumstances, chlorophyll concentration alone is not a reliable indicator of productivity. These results highlight the vital significance of keeping irrigation water in the ideal pH range of 5.0 to 7.5 for the production of broad beans. Optimizing output and plant health, especially in areas where alkaline irrigation sources are common, requires careful management of water quality, especially pH. Although more thorough and replicated research in the future can improve these findings, the present findings unequivocally demonstrate that regular pH monitoring is an essential procedure for sustainable legume cultivation.

Conflict of Interest

The author declares that there is no conflict of interest regarding the publication of this manuscript.

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Recommendations

- Maintain Irrigation Water pH Between 5.0 and 7.5 for Optimum Growth

In all parameters measured leaf count, shoot/root weight, height, biomass, and yield plants grew substantially better in the neutral to slightly acidic pH range (5.0–7.5). This is the range that encourages nutrient availability and reduces physiological stress.

- Do Not Use Alkaline Irrigation Water (pH 8.0)

A pH of 8.0 always led to significantly reduced leaf numbers, shoot and root weights, plant growth, dry matter biomass, and yield. The statistically significant reduction in all parameters verifies that extreme alkalinity is highly detrimental to broad bean development.

- Increase Replication or Precision to Clarify Chlorophyll Response

Although chlorophyll content did not exhibit strong differences by treatment, extreme standard errors indicate high variability. Subsequent studies would be useful in including more replication or enhanced measurement accuracy to better discern small pH influences on chlorophyll concentration.

- Use Vegetative Growth Traits as Yield Predictors

The high correlations of leaf number, shoot weight, plant size, and yield indicate these traits are good predictors of total-plant productivity. Following them at early stages can be employed to predict and regulate yield outputs.

- Maintain a Check on Soil and Water pH to Prevent Losing Yield

The sudden drop in yield at high pH necessitates frequent monitoring of soil and irrigation water pH. pH correction practices (acidifiers in alkaline water) should be a part of integrated crop management for broad beans.

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