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EFFECTS OF ALKALINE WATER ON ROOT GROWTH IN *ALLIUM CEPA* L.: AN EXPERIMENTAL ANALYSIS

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Abstract. *The quality of water used in agriculture is a critical factor in maintaining plant health and soil fertility, especially in the context of using marginal waters characterized by high salinity and alkalinity. This article analyzes the influence of water pH on plant development parameters, with a focus on the effects generated by irrigation with alkaline water. A review of the relevant literature highlights that a high water pH affects nutrient availability, soil microbial activity, and plant physiological processes, leading to osmotic stress and nutritional imbalances. In parallel, the experimental study examined the impact of irrigation with water having a maximum pH of 9.4 on root development in Allium cepa L., under hydroponic conditions. The results indicated an increase in dry biomass in the batch treated with alkaline water, compared to the controls irrigated with distilled or tap water. The study was unable to confirm the negative effects associated with elevated pH of the tested water, presenting minimal impact on plant development under the present experimental conditions. These findings support the need for rigorous monitoring of irrigation water quality to prevent soil degradation and reduced crop productivity. Future research should explore remediation solutions for the negative effects of alkaline water on soil and plants, as well as the adaptation of irrigation strategies based on crop type and pedoclimatic conditions.*

Keywords: *alkaline water, water pH, phytotoxicity, Allium cepa*

INTRODUCTION

The availability of adequate resources is a fundamental agricultural requirement for food security and sustainability. However, due to continued population growth and rapid socio-economic development, global water resources are facing increasing pressure (ALI et al., 2019; KANG et al., 2017).

The lack of reliable, good-quality water supplies in vast areas of the planet, as well as the intensification of soil salinization processes, have led in recent decades to the use of marginal or residual waters, often saline/alkaline, as an alternative to freshwater for the irrigation of industrial crops (EZLIT et al., 2010). Marginal waters may originate directly from aquifers or from effluent/waste sources (BENNETT and WARREN, 2015), involving either groundwater or surface water that may have marginal quality due to factors such as high salinity, very low or very high pH, or high sodium concentrations (CHANDEL et al. 2022; MINHAS et al. 2021; BENNETT et al., 2016), which can increase its potential for soil degradation (BENNETT et al., 2019).

Alkalinization is a major salinization process in arid and semi-arid soils, where carbonate and sodium bicarbonate salts accumulate, saturating it with harmful ions (YADAV et al., 2024). Irrational use of low-quality groundwater, often exploited from aquifers adjacent to the affected areas (CICCHELLI et al., 2016) is a significant anthropogenic factor in soil salinization, leading to toxic accumulation of neutral salts, thus intensifying soil salinity, alkalinity and ionic imbalances (SHEORAN et al. 2021a; SONI et al. 2021), amplifying land and environmental degradation (BARMAN et al. 2021), and ultimately, reduced agricultural productivity (MINHAS et al. 2019; QADIR et al. 2014).

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To mitigate these issues, various chemical and physical soil remediation strategies have been developed, common amendments including gypsum ($CaSO_4 \cdot 2H_2O$), sulfuric acid (H_2SO_4), and lime ($CaCO_3$), which facilitate the replacement of sodium salts with calcium, thereby improving soil structure and permeability (YADAV et al., 2024). Additionally, practices such as leaching with high-quality water and implementing efficient drainage systems are crucial to prevent further salt buidup and restore soil fertility (SHU et al., 2023; QADIR et al., 2007).

However, the severity of land degradation caused by salt accumulation is determined not only by the chemical composition of irrigation water, but also by soil physicochemical properties, crop types, and the prevailing agroclimatic conditions (CHOUDHARY and BAJWA 2021; MINHAS et al. 2021; SHEORAN et al. 2021b, 2021c).

Recent research has moved beyond conventional chemical amendments to include a variety of sustainable remediation strategies. Initiatives such as those by NEHELA et al. (2021) demonstrated that a combined application of plant growth-promoting rhizobacteria and biochar significantly enhances enzymatic activity, nutrient uptake, and plant resistance in saline-alkaline soils. Similarly, FOULADIDORHANI et al. (2023) reported improvements in soil structure, porosity, and water-holding capacity through the use of biochar and organic matter. Organic fertilization systems, such as those reviewed by KUMAR et al. (2021), offer a sustainable pathway for restoring soil health and mitigating toxicity by increasing microbial activity and nutrient cycling. Potassium fertilization has also been highlighted as a key strategy for improving ionic balance and salt tolerance in industrial crops, as discussed by VERMA et al. (2024).

Similar to soil remediation efforts, water remediation strategies have been extensively explored. Common techniques include magnetization and ionization treatments (ZHAO et al., 2021; WANG et al., 2019), which temporarily alter the water's physical and chemical properties, such as pH, conductivity, surface tension, viscosity, and permeability, increasing molecular activity (WANG et al., 2022). These changes enhance interactions with soil particles, improve nutrient availability, and promote plant germination, growth, root development, seed quality, and biomass accumulation (BEN AMOR et al., 2020).

Despite these advancements, both agricultural systems and native flora and fauna continue to be negatively affected by increasing salinity/alkalinity of the environment. Human activities and ecological degradation have contributed to the expansion of affected areas, intensifying the severity of the problem (LIU et al., 2022)

Salinity is particularly concerning due to its detrimental effects on plant growth, nutritional balance and commercial quality, causing visible damage through chlorotic leaf spots, distortion of vegetative organs and reduction in size (YANG et al., 2024; ZÖRB et al., 2019). The presence of salts in the rooting medium disrupts many physiological processes, causing osmotic stress, ionic toxicity, and a decrease in photosynthesis and growth rates (MUNNS, 2002; TESTER and DAVENPORT, 2003). Reduced crop yield and quality may occur due to reduced plant water uptake from the soil solution and by the destruction of soil structure (BARRETT-LENNARD, 2003). In addition, toxicity resulting from excessive concentrations of certain ions, mainly Na^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-} and HCO_3^-, as well as nutritional imbalances may also play important roles in plant response to saline environments (GRATTAN and GRIEVE, 1999).

Major crops such as rice, wheat and maize, as well as key cash crops like soybean, cotton and peanut are especially sensitive to elevated pH in the growing medium. In rice, high pH impairs seed germination and significantly reduces yields, while increasing protein content at the expense of nutritional quality (MELINO and TESTER, 2023; JIN et al., 2020), experiencing poor nutrient uptake and slow growth, while maize yields can drop by up to 46.7% under severe conditions (YANG et al., 2024). Soybean root growth is hindered, leaf chlorosis occurs, and

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protein synthesis is impaired due to the stress caused by high pH. Similarly, cotton is characterized by slow growth and decreased fiber quality, and peanuts show significant reduction in root system, leaf area, dry weight of various organs, and root-to-shoot ratio (YU et al., 2017).

Studies such as those carried out by AGUILAR et al. (2004) examined these effects in three cultivars of *Tagetes patula* and *Tagetes erecta*, highlighting the reduced growth rate due to limited cell expansion under osmotic stress (MUNNS and TESTER, 2008), along with linear decrease in plant height, dry biomass of leaves and shoots, flower diameter and plant compaction, as well as the appearance of necrotic spots on adult leaves, collectively lowering the overall crop quality.

Negative impacts of alkaline water have also been observed in overhead irrigation systems, in studies such as the one carried out by CICCHELLI et al. (2016), in which the response of two forage plant species - *Chloris gayana* and *Leucaena leucocephala ssp. glabrata* - was evaluated. The use of saline/alkaline water revealed adverse effects on both species, such as (i) foliar deterioration, (ii) reduced fresh biomass, (iii) decreased chlorophyll fluorescence and (iv) increased Na^+ and Cl^- accumulation in leaf tissue. The severity of these effects varied by plant species, water composition, soil salinity, and growing conditions.

While alkaline water primarily affects soil aggregation and hydrophysical properties (SINGH, 2016), its impact on soil microbial communities is also significant. YADAV et al. (2024) observed degradation of microbial attributes in alkaline soils, due to a stressed rhizosphere and reduced accessibility of root exudates to microbes (NEINA, 2019). Alkaline irrigation disrupts microbial activity during key crop development stages (SINGH et al., 2022a), alters microbial community composition (FONSECA et al., 2020), and reduces soil enzymatic activity, ultimately compromising crop performance.

The increase in Na^+/ HCO_3^- loading caused significant decrease of soil nitrogen availability (RAI et al. 2021). Similarly, reduced soil organic carbon content under alkaline water irrigation could be the result of a lower supply of organic matter from vegetation, due to the decrease in yields under alkaline stress conditions (SINGH et al. 2022b; BHARDWAJ et al. 2019).

Alkalinity also affects micro- and macroinvertebrates, altering physiology and behavior depending on species and developmental stage. Elevated pH can reduce biodiversity, particularly among sensitive groups such as molluscs and aquatic insects, while some oligochaetes or chironomids may exhibit relatively higher tolerance (TAMIRU, 2019; BEREZINA, 2001). Studies on amphibian larvae, such as that by LUNDSGAARD et al. (2021), indicates accelerated growth in moderate alkaline environments (pH 8.5), but has the potential to cause long-term physiological imbalances, including inadequate larval development, reduced survival rate and the appearance of morphological abnormalities, as observed in *Rhinella marina* tadpoles exposed to pH 10. At cellular level, PENG's (2018) results on *Sinonovacula constricta* juveniles showed that both high pH and increased alkalinity can significantly impair the activity of antioxidant enzymes and those involved in energy metabolism, affecting the development and survival of individuals.

Although different from the alkaline water used in the agriculture, alkaline electrolyzed water (AEW) consumed by humans has long been associated with gastrointestinal and metabolic benefits (HENRY and CHAMBRON, 2013), albeit statistically significant evidence to affirm or strengthen this claim is lacking (HANSEN et al., 2018). AEW is obtained through reverse osmosis, microfiltration, mineralization, and electrolysis, which removes acidic ions to increase pH (RIZVI et al., 2013). However, concerns remain regarding the effects of prolonged AEW consumption, including risks of altered electrolyte balance and microbiome disruption (YAMASAKI and WANG, 2022; TAJUDIN and HAMIRUDIN, 2020). Still, some studies report antioxidant effects and therapeutic benefits (IGNACIO et al., 2013), with potential improvements in hydration and

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metabolic response (CHYCKI et al., 2017; WEIDMAN et al., 2016), acid-base balance and exercise performance (CHYCKI et al., 2018), general health status and gastrointestinal symptoms (TANAKA et al., 2018), blood glucose (AGUSTANTI, 2019), postprandial lipemia (TOXQUI et al., 2012; SCHOPPEN et al., 2005), lipid profile and cardiovascular risk (SCHOPPEN et al., 2004), gallbladder function (TOXQUI et al., 2012), and bone resorption (WYNN et al., 2009).

Considering all the aspects presented previously, this study aims to assess the potential negative effects of drinking water pH on plants grown under hydroponic conditions, using *Allium cepa* bulbs as a model organism.

MATERIAL AND METHODS

Given its well-documented morphological and physiological characteristics, which are easily observable, as well as its frequent application as a standard environmental bioindicator (CIOBANU, 2019), *Allium cepa* (white onion) was selected as the model organism to evaluate the effects of the tested water types.

Water samples were selected based on their pH characteristics: distilled water served as the neutral pH control; tap water, exhibiting a slightly alkaline pH (ranging from 7.1 to 7.9 according to AQUATIM's water quality reports from March 2021 for the city of Timișoara), represented the mildly basic condition; and commercially available alkaline water with the highest marketed pH value (9.4) was used to simulate a strongly basic environment.

Sixty *Allium cepa* bulbs of uniform size were selected based on the absence of visible defects or disease symptoms. The bulbs were carefully cleaned of their outer sheaths and individually weighed with an analytical balance to establish the initial biomass. Subsequently, the bulbs were randomly allocated into three experimental groups, corresponding to the three water treatments. Each bulb was placed in an individual test tube containing approximately 6 mL of the assigned solution, and the tubes were stabilized using a polystyrene support structure.

Bulbs were maintained in continuous contact with their respective solutions throughout the experimental period. The alloted water types were replaced at 48-hour intervals to prevent microbial proliferation and ensure consistent exposure.

The experiment was carried out over a period of 10 days, during which the following parameters were assessed: wet biomass, dry biomass, and ash content, measured separately for roots and bulbs. Additionally, root length, the dynamics of biomass accumulation, and any notable morphological alterations were documented. Upon completion of the experimental period, the collected data were recorded and initially processed using Microsoft Office Excel 2018. Statistical analyses were subsequently performed employing the PAST software package, version 4.03 (HAMMER et al., 2001).

RESULTS AND DISCUSSION

The average values obtained from the determination of wet biomass – measured on the first day of the experiment, at its midpoint, and on the final day – are presented in Table 1. The exponential increase in the mean wet biomass across all experimental groups suggests an active hydration and developmental process during the initial phase of the experiment. Following drying and incineration procedures, final gravimetric data were obtained separately for the supraradicular organs and the root system.

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Table 1

Mean values of tested parameters obtained from weighing measurements

Analyzed parameter		Group treated with alkaline water	Group treated with tap water	Group treated with distilled water
Initial wet biomass		2,5794	2,5643	2,1681
Intermediate wet biomass		2,8378	2,7399	2,3892
Final wet biomass	bulbs	3,1120	3,0582	2,7270
	roots	0,2234	0,1771	0,1972
Dry biomass	bulbs	0,4541	0,4587	0,3852
	roots	0,0141	0,0120	0,0130
Ash content	bulbs	0,0418	0,0385	0,0318
	roots	0,0013	0,0009	0,0008

Analysis of the resulting means indicated that batch A, treated with alkaline water, exhibited the highest values for most of the evaluated biological indicators, with the exception of bulb dry biomass. This result suggests a potential stimulatory effect of commercial alkaline water on seedling development, possibly attributable to its elevated mineral salt and specific ion content (RIZVI et al., 2024).

In batch B, treated with tap water, the highest mean value for bulb dry biomass was recorded (0.4587 g), while the dry biomass of roots showed the lowest mean value (0.0120 g) among the three groups. The marked difference between these parameters may imply a redistribution of resources favoring the development of aboveground structures to the detriment of the root system.

Batch C, treated with distilled water, registered lower mean values for five of the eight analyzed indicators; however, considering that the initial bulb mass in this group was the lowest, it is not possible to definitively attribute a negative effect to the distilled water treatment on the overall development of the samples.

The data obtained from the weighings did not conform to a normal distribution but were homogeneously distributed, with the exception of bulb ash ($p = 0.02696$), as determined by the Shapiro–Wilk and Levene tests (Table 2).

Table 2

p-values obtained from normality and homogeneity tests

Analyzed parameter		Shapiro-Wilk Test (normality)	Levene's Test (Homogeneity of Variance)
Wet biomass	bulbs	$3,169 \times 10^{-10}$	0,5338
	roots		0,3961
Dry biomass	bulbs	$1,925 \times 10^{-10}$	0,7223
	roots		0,5885
Ash content	bulbs	$1,581 \times 10^{-10}$	0,02696
	roots		0,08503

Statistical analysis of the gravimetric values, conducted using Kruskal–Wallis tests, revealed no statistically significant differences between the three experimental groups for any of the evaluated indicators (Table 3). This suggests that, despite observable variations in mean values, the differences between treatments did not result in statistically significant biological responses for the analyzed parameters.

Table 3

Summary of Kruskal–Wallis and Mann–Whitney U Test Results

Kruskal–Wallis Test			
Evaluated parameter		**H**	**p-value**
Wet biomass	bulbs	3.660	0.1604
	roots	0.5708	0.7516
Dry biomass	bulbs	4.093	0.1292
	roots	0.214	0.8985
Ash	bulbs	4.250	0.1194
	roots	2.491	0.2867
Bulb/root ratio	wet biomass	5.357	0.06861
	dry biomass	6.590	0.03703
	ash	2.037	0.1192
Mann–Whitney U Test (for Bulb/Root Dry Biomass Ratio)			
Comparison between groups		**U**	**p-value**
Alkaline water vs. tap water		130	0,060099
Alkaline water vs. distilled water		180	0,59769
Tap water vs. distilled water		110	0,015474

Subsequently, ratios between bulb and root masses were calculated for wet biomass, dry biomass, and ash content. Upon application of the Kruskal–Wallis test, a statistically significant difference was observed in the dry biomass ratio ($p = 0.03703$), and the Mann–Whitney U test indicated a significant difference between the batch treated with tap water and the batch treated with distilled water ($p = 0.015474$) (Table 3). These results indicate that water quality exerts a statistically significant influence on biomass partitioning, particularly in terms of dry matter allocation between bulb and root structures. The observed difference between the tap water and distilled water treatments underline the potential role of dissolved minerals and ions in modulating resource distribution within developing plant tissues. The specific chemical profiles of these water types appear to differentially influence the physiological processes of absorption, translocation, and biomass accumulation in the vegetative structures of *Allium cepa*.

CONCLUSIONS

The results of this study highlight the significant impact of water pH on plant health and soil quality, particularly in the context of using marginal irrigation waters, especially saline and alkaline types. A review of the relevant literature indicates that the inappropriate application of low-quality irrigation water, especially in arid and semi-arid regions, accelerates soil degradation processes through mechanisms of salinization and alkalization (MINHAS et al., 2021; YADAV et al., 2024). These phenomena adversely affect critical soil properties, including water retention capacity, structural aggregation, and overall fertility (BENNETT et al., 2019; CHANDEL et al., 2022).

In particular, water alkalinity induced by increased concentrations of ions such as Na^{+}, HCO_3^{-} and CO_3^{2-}, negatively influences soil ionic dynamics and rhizosphere-specific microbiological activity, reducing the bioavailability of nitrogen and organic carbon (RAI et al., 2021; SINGH et al., 2022b; NEINA, 2019). Simultaneously, direct effects on plants include osmotic stress, ionic toxicity, nutritional imbalances and impaired photosynthesis, leading to reduced yield and morphological quality of crops (YANG et al., 2024; LIU et al., 2022; MSIMBIRA and SMITH, 2020). These findings are supported by applied studies on horticultural and forage species, which indicated clear changes in growth parameters and physiological state under the influence of alkaline water (CICCHELLI et al., 2016; SINGH, 2016).

In this context, the experimental study conducted aimed to investigate the direct effect of waters with different pH values on early plant development, using *Allium cepa* as a model organism. Preliminary results from the hydroponic test revealed notable, yet statistically insignificant, differences between the batches treated with alkaline water (pH 9.4) and those irrigated with distilled water (neutral pH) or tap water (weakly basic pH). Bulbs exposed to high-pH water exhibited higher mean values for wet biomass, dry biomass and ash than the samples from batches treated with tap water and distilled water respectively, a phenomenon contradictory to the osmotic stress and nutritional imbalances induced by the increased basic pH – contrary to the conclusions previously reported in the specialized literature (MUNNS and TESTER, 2008; BARRETT-LENNARD, 2003). In this regard, the study was unable to confirm the negative effects associated with elevated pH of the tested water, presenting minimal impact on plant development under the present experimental conditions.

Given these results, the need for a rigorous assessment of the quality of irrigation water, as well as its influence on crops is emphasized, even in controlled systems such as hydroponic ones. Furthermore, future studies should aim to develop and test innovative marginal water treatment processes, in order to ameliorate the negative effects of alkaline waters.

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