Effects of Fertilizer Acidification on pH of Irrigated Desert Soil (Postprint)

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Abstract

To determine the ameliorative effects of water-fertilizer solutions with different acidity levels on the pH of irrigated desert soil under integrated water-fertilizer management, and to provide guidance for rational fertilization of alkaline soils. The experiment consisted of five irrigation solution pH levels: A1 (1.5), A2 (3.5), A3 (5.5), A4 (7.5) (control), and A5 (9.5), two irrigation amounts W1 (1500 $m^3 \cdot hm^{-2}$) and W2 (3000 $m^3 \cdot hm^{-2}$), and two nitrogen application rates N1 (450 $kg \cdot hm^{-2}$) and N2 (900 $kg \cdot hm^{-2}$), totaling 20 treatments, and was conducted through a pot experiment. The results showed that: (1) Soil pH was significantly positively correlated with irrigation solution pH. Under the A1 treatment, soil pH in the 0–5 cm layer could be reduced to 7.16–7.4, representing a decrease of 0.45–0.81 compared with the four treatments A2, A3, A4, and A5, with significant differences among treatments. (2) Increasing irrigation amount or nitrogen application rate had no significant effect on soil pH. (3) Soil pH was lowest on the day of irrigation solution application, then gradually recovered, and with increasing irrigation frequency, soil pH became progressively lower. (4) Under all treatments, soil pH increased with soil depth. Under the A1 treatment, soil pH in the 0–5 cm, 5–10 cm, 10–20 cm, 20–30 cm, and 30–40 cm layers was 7.27, 7.67, 7.84, 7.98, and 8.08, respectively, representing the greatest differences among soil layers. Acidic solutions can significantly reduce the pH of irrigated desert soil. Whether irrigation solution pH, irrigation amount, or nitrogen application rate, the primary effect was on the pH of the topsoil, with minimal impact on the pH of deeper soil layers. Therefore, in agricultural production, soil pH of alkaline soils can be reduced by adjusting solution acidity, thereby ensuring healthy crop growth.

Full Text

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Abstract

This study investigated the improvement effects of different acidity water-fertilizer solutions on irrigated desert soil under integrated water-fertilizer conditions to provide references for rational fertilization of alkaline soils. A pot experiment was conducted with five irrigation solution pH levels (A1=1.5, A2=3.5, A3=5.5, A4=7.5, and A5=9.5 as control), two irrigation amounts (W1=1500 $m^3 \cdot hm^{-2}$ and W2=3000 $m^3 \cdot hm^{-2}$), and two nitrogen application rates (N1=450 $kg \cdot hm^{-2}$ and N2=900 $kg \cdot hm^{-2}$), totaling 20 treatments. The results showed that: (1) soil pH was significantly positively correlated with irrigation solution pH, with the 0-5 cm soil pH under A1 treatment decreasing to 7.16-7.4, which was 0.45-0.81 units lower than other acidic treatments; (2) increasing irrigation amount or nitrogen rate had no significant effect on soil pH; (3) soil pH was lowest on the day of irrigation solution application, then gradually recovered, and became progressively lower with increasing irrigation frequency; and (4) under all treatments, soil pH increased with soil depth, with the largest inter-layer differences observed under A1 treatment (0-5 cm: 7.27, 5-10 cm: 7.67, 10-20 cm: 7.84, 20-30 cm: 7.98, and 30-40 cm: 8.08). Acidic solutions significantly reduced the pH of irrigated desert soil, but regardless of solution pH, irrigation amount, or nitrogen rate, the effects were primarily confined to the cultivated topsoil layer, with minimal impact on deeper soil layers. These findings demonstrate that adjusting solution acidity can effectively lower alkaline soil pH in agricultural production, providing a scientific basis for efficient nutrient resource management and ensuring healthy crop growth.

Keywords: acidic fertilizer; soil pH; irrigated desert soil; *Lolium perenne*; integration of water and fertilizer

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1 Introduction

Soil functions as a massive buffering system with strong capacity to neutralize both acids and bases. In China, soils exhibit a distinct geographic pattern of acidity in the south and alkalinity in the north. While soil acidification has become a serious concern in recent years, soil pH in northern regions remains relatively high, with some areas exceeding [threshold]. Crop growth requires a suitable pH environment, with most crops thriving at pH 6.5–7.5. Alkaline soils severely reduce nutrient availability and constrain sustainable agricultural development.

Lowering the pH of alkaline soils can promote healthy crop growth. Li Yanting et al. [?] investigated acidic rhizosphere fertilizers for calcareous soils and demonstrated significant improvement effects. Guo Junling et al. [?] reported that weathered coal and cow manure treatments produced the greatest pH reduction in soda saline soils. Tang Jiwei et al. [?] found that combined application of chemical fertilizer and organic manure maintained pH stability in salinized fluvo-aquic soils. Additionally, straw and its derived biochar can effectively ameliorate soil pH [?]. Numerous studies confirm that acidic substances can reduce alkaline soil pH. Building on this foundation, our study employed different degrees of fertilizer acidification combined with integrated water-fertilizer technology to examine the relationship between fertilizer acidity/dosage and soil pH, aiming to provide guidance for alkaline soil improvement and theoretical support for novel fertilizer development.

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2 Materials and Methods

2.1 Experimental Materials

The study employed both simulation and pot experiments. The simulation experiment was conducted in the laboratory of Gansu Academy of Agricultural Sciences, while the pot experiment was performed in a greenhouse at the Wuwei Oasis Experimental Station of the same institution. Test soil was collected from the experimental station' s field, characterized by low fertility. After sieving, air-drying, and homogenization, the soil was stored for use. Its physicochemical properties were: organic matter 1.08%, alkaline hydrolyzable nitrogen 0.77 $g \cdot kg^{-1}$, available phosphorus 39.8 $mg \cdot kg^{-1}$, and available potassium 85.22 $mg \cdot kg^{-1}$. The test crop was ryegrass (*Lolium perenne* Linn.). Nitrogen fertilizer was Kunlun brand urea ($ $46.4% N).

2.2 Simulation Experiment

The simulation experiment was a single-factor design using the pH of laboratory tap water as S5=7.8 (control). Plastic containers were filled with 500 g of soil. Prepared solutions were added at 98% of the weight of remaining dry soil. Soil pH was measured daily beginning with the first irrigation, and the experiment continued for [duration].

2.3 Pot Experiment

The pot experiment was a multi-factor design with: (1) two nitrogen rates: low nitrogen (N1=450 kg·hm^{-2}) and high nitrogen (N2=900 kg·hm^{-2}); (2) two irrigation amounts: low water (W1=1500 m^3·hm^{-2}) and high water (W2=3000 m^3·hm^{-2}); and (3) five irrigation solution pH levels based on simulation results: A1(1.5), A2(3.5), A3(5.5), A4(7.5), and A5(9.5) (control), totaling 20 treatments with replications. Direct use of concentrated H_2SO_4 was avoided due to measurement difficulties and safety concerns; instead, different H_2SO_4 solutions were used to acidify the urea.

Experimental pots (30 cm diameter × 53 cm height) were filled with 42 kg of prepared soil, leaving 20 cm from the soil surface to the rim. Five holes on the pot sides corresponded to soil layers of 0-5, 5-10, 10-20, 20-30, and 30-40 cm. A tube buried at the bottom served as an ammonia volatilization collection device [?]. Ryegrass was planted in a zigzag pattern with ~10 cm spacing between nests.

Tap water was acidified with 98% H_2SO_4, and urea was dissolved proportionally. The solution was delivered via a storage bottle and drip irrigation system. All water and fertilizer were applied in [number] installments, with weekly irrigation events. Dosages of H_2SO_4 or NaOH per irrigation are shown in Table 1 .

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3 Results

3.1 Dynamic Changes of Soil pH During Simulation Experiment

Soil pH in all treatments (S1-S6) fluctuated continuously with irrigation solution addition (Fig. 2 [Figure 2: see original paper]). pH values on irrigation days were lower than the previous day, showing a gradual decreasing trend with increasing irrigation frequency, though a late-stage rise-then-fall pattern in some treatments requires further investigation.

Early-stage fluctuations were substantial, while mid-to-late-stage changes stabilized. Alkaline or strongly acidic solutions introduced abundant hydroxide or hydrogen ions that continuously neutralized soil ions, maintaining relatively stable pH. Near-neutral or weakly acidic solutions were neutralized within the irrigation day, after which soil pH recovered.

3.2 Dynamic Changes of Soil pH During Pot Experiment

Soil pH exhibited distinct dynamic patterns across different irrigation solutions. pH was lowest on irrigation day, then gradually recovered. With increasing irrigation frequency, pH decreased progressively. Conversely, alkaline solutions caused slight pH increases (<0.1 units). The magnitude of pH change varied by treatment and soil layer, with minimal changes below 20 cm depth. Under high irrigation, pH reduction in the 0-20 cm layer exceeded that under low irrigation.

During the pot experiment, weekly monitoring after the sixth irrigation showed that, except for [treatment], all treatments had lowest pH on irrigation day, with maximum inter-layer differences at that time. The high-pH solution caused a rise-then-fall trend. Under high irrigation, greater H^+ delivery to deeper layers reduced subsoil pH, while low irrigation limited H^+ transport, resulting in higher subsoil pH.

3.3 Effects of Different Treatments on Soil pH in Simulation Experiment

Variance analysis of final simulation results (Fig. 4 [Figure 4: see original paper]) revealed the soil pH ranking: S1<S2<S3<S5<S4<S6, with extremely significant differences ($P<0.01$). The A1 treatment reduced pH by [value] units compared with the control, demonstrating that more acidic solutions produced more significant reductions. The A2 treatment showed a non-significant [value]-unit reduction, while A3 showed an extremely significant [value]-unit reduction. The A4 treatment slightly increased pH by [value] units.

3.4 Effects on Different Soil Layers

3.4.1 Under Same Treatment Averaging across water-fertilizer combinations revealed that nitrogen and irrigation rates minimally affected the pH trend across layers: 0–5 cm < 5-10 cm < 10-20 cm < 20-30 cm < 30-40 cm. Under A1 treatment, the lowest pH values were recorded: [values]. The 0–5 cm layer differed from the 30–40 cm layer by [values]. Increased irrigation or nitrogen enlarged inter-layer pH differences. Variance analysis showed extremely significant differences ($P<0.01$) among layers for all treatments except the 5–10 cm layer in one combination.

Analysis of irrigation solution pH effects (Fig. 6 [Figure 6: see original paper]) confirmed that pH increased with depth, with extremely significant differences between 0–5 cm and 30–40 cm layers. Under A1 treatment, this difference was relatively small. Differences among the 0–5, 5–10, and 10–20 cm layers were extremely significant, as were differences among other layers. Compared with [treatment], inter-layer differences decreased under [treatment], though most remained extremely significant.

Overall, acidic solutions produced obvious pH reductions. Solutions of pH [value] and [value] significantly reduced soil pH, while pH [value] showed minimal effect.

3.4.2 Under Different Treatments In the 0–5 cm layer, soil pH varied significantly among treatments. Under the same nitrogen rate, increasing irrigation alone reduced pH, with extremely significant differences among treatments but no significant differences among the four irrigation levels. Compared with A2W1N1, A2W2N1 showed significant differences.

Figures 7-11 [FIGURE:7-11] illustrate treatment effects on each soil layer. For three water-fertilizer combinations, irrigation solution pH significantly reduced soil pH, with A1 differing significantly from other solutions. Differences ranged 0.09-0.16 units but were extremely significant. In the 5-10 cm layer, increasing irrigation or nitrogen further reduced pH, especially under A1 treatment. The reduced difference between 0-5 cm and 5-10 cm layers indicates diminishing pH effects with depth.

For 20-30 cm and 30-40 cm layers, variance analysis showed no or minimal differences among most treatments, with consistent trends across water-fertilizer combinations, confirming weak effects of irrigation solution pH below 20 cm.

3.4.3 Effects of H_2SO_4 Dosage Integrating soil pH across the experiment revealed that pH in the 0-20 cm layer decreased with increasing H_2SO_4 dosage. The relationship between 98% H_2SO_4 dosage (x, $L \cdot hm^{-2}$) and soil pH (y) was:

$$y = 5 \times 10^{-8} x^2 - [\text{value}]x + 7.9253 \quad (R^2 = 0.9952)$$

This indicates that applying sufficient H_2SO_4 can effectively reduce alkaline soil pH. Table 3 shows the effects of H_2SO_4 dosage on 0-20 cm soil pH.

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4 Discussion

Recent research has demonstrated soil pH improvement from liquid fertilizers [?]. Our water-fertilizer integration study showed significant pH reduction from acidic solutions compared with the control, consistent with previous findings [?, ?, ?]. Zhang Haoyu et al. [?] reported that acidifiers reduced calcareous soil pH, with smaller reductions in the 5-10 cm layer due to stronger surface effects. Acidic irrigation solutions markedly reduced surface soil pH by >[value] units compared with original soil and local irrigation water.

Generally, greater acid inputs produce larger pH reductions [?]. Wu Xi et al. [?] found alkaline soil pH decreased with sulfur application, though excessive sulfur harmed rape growth. In our pot experiment, high irrigation with A1 solution produced significantly lower 0-5 cm pH ([value]) than low irrigation ([value]), confirming significant positive correlation between irrigation amount and H^+ delivery. Chang Qing et al. [?] reported similar results with wood vinegar dilutions.

Comparison of simulation and pot experiments revealed that irrigation solutions first reacted with surface soil, causing substantial surface pH changes. Heavy nitrogen use accelerates soil acidification [?]. Although urea temporarily increases pH [?], it eventually acidifies soil. In this short-term experiment, increased irrigation or nitrogen caused only minor, non-significant pH changes because urea-driven acidification is a long-term cumulative process.

5 Conclusion

1. Acidic solutions significantly reduce irrigated desert soil pH. After irrigation, soil pH first decreases then slowly recovers, becoming progressively lower with repeated irrigation.
2. Irrigation solution pH [value] can reduce 0–5 cm soil pH to 7.16–7.4, with significant differences among treatments. Soil pH increases with depth, showing maximum inter-layer differences at solution pH [value].
3. Increasing irrigation amount or nitrogen rate does not significantly affect soil pH. Regardless of solution pH, irrigation amount, or nitrogen rate, changes are primarily confined to the cultivated topsoil layer.

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Note: Figure translations are in progress. See original paper for figures.