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The Effect of Different Sulphur Sources Applied at Various Rates on Soil pH

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ABSTRACT

Soil pH, governed by the relative concentrations of hydrogen (H^+) and hydroxyl (OH^-) ions, is a key factor affecting the chemical, physical, and biological properties of soils. Most soils in Türkiye are alkaline due to calcareous parent material and climatic influences, which restricts the availability of essential nutrients to plants. Sulphur applications are widely employed to reduce soil pH and increase nutrient bioavailability. The use of Sulphur for the amelioration of alkaline soils will continue to be a crucial strategy for enhancing agricultural sustainability in the future. This study investigates the effects of different Sulphur sources on the pH of sandy and clay-loam texture soils. This study investigates the effects of different Sulphur sources on the pH of sandy and clay loam textured soils. The soil samples used in the research were taken from Pınarbaşı and Melikgazi districts of Kayseri province, and soil samples were taken from both regions from a depth of 30 cm and from 20 randomly determined different points. Sulphur applications were applied at rates of (0, 0.02, 0.04 g 100 g^{-1}) (X: powdered Sulphur) and (0, 0.044, 0.088 g 100 g^{-1}) (Y: granular Sulphur) based on weight for clay-loam and sandy textured soils, respectively. Samples taken on days 0, 15, 30, 60, 90, 180, and 360 post-applications showed that the impact of Sulphur applications on soil pH change was significant across all treatments ($p<0.01$). The lowest pH measurement, 6.92, was observed in sandy textured soils with an application from granular Sulphur at 0.088 g 100 g^{-1}. The pH change in clay-loam textured soils was found to range from 8.13 to 7.79, and in sandy textured soils from 7.69 to 6.92. These changes suggest that the acidifying effect of Sulphur oxidation on soil pH varies depending on the soil's buffering capacity, particle size ratio, application rate, and incubation day. Consequently, the granular Sulphur was found to be more effective compared to the control and powdered Sulphur , and an application rate of 0.088 g 100 g^{-1} might be effective for both clay-loam and sandy soils. However, due to its lack of economic feasibility, 0.044 g dose or the doses from powdered Sulphur might be more appropriate.

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Introduction

The acidity, neutrality, and alkalinity levels of soil can be expressed through the relative concentrations of hydrogen (H^+) and hydroxyl (OH^-) ions in the soil solution, representing a metric known as the soil pH value (Yaraş and Daşgan, 2012). Soil pH is among the abiotic factors affecting soil characteristics (Rath et al., 2019; Zeng et al., 2019). It significantly influences many chemical, physical, and biological properties of the soil. The effects on the availability, mobility, and activities of microorganisms of plant nutrient elements are critically important for agricultural sustainability. For healthy and high-quality plant growth, soil reaction is generally preferred to be between 6.5 and 7.5 in agricultural cultivation (Güneş and Sönmez, 2018). Turkish soils possess diverse soil characteristics due to the influence of active and passive soil factors (Paton, 2023). Active factors like climate conditions and passive factors such as the limestone and calcareous materials of the bedrock have generally led to an alkaline character in Turkish soils (Kapur et al., 2017). A study of Turkish soils has determined that a total area of 21 579 99 hectares exhibits slightly alkaline characteristics based on soil pH values (Sönmez et al., 2018; Uçgun et al., 2019), with the distribution of soil pH across Türkiye shown in Figure 1 (Sönmez et al., 2018).

Sulphur (S), used in the amelioration of calcareous and highly reactive soils (Karaman et al., 2012; Güneş and Sönmez, 2018), is considered the fourth essential macro-nutrient element following N, P, and K based on its contributions to plant metabolism and growth activities (Tietel et al., 2022). Sulphur is present in the soil in both organic (carbon-bonded S and ester sulfate) and inorganic (sulfate (SO_4^{-2}) and sulfite (SO_2^-)) forms (Awadalla et al., 2007; Abou Hussien et al., 2020). Plants obtain S sources from the atmosphere as SO_2^-, through their leaves via stomata in gas form, and as (SO_4^{-2}) from the soil solution (Zhao et al., 1999; Orman, 2012).

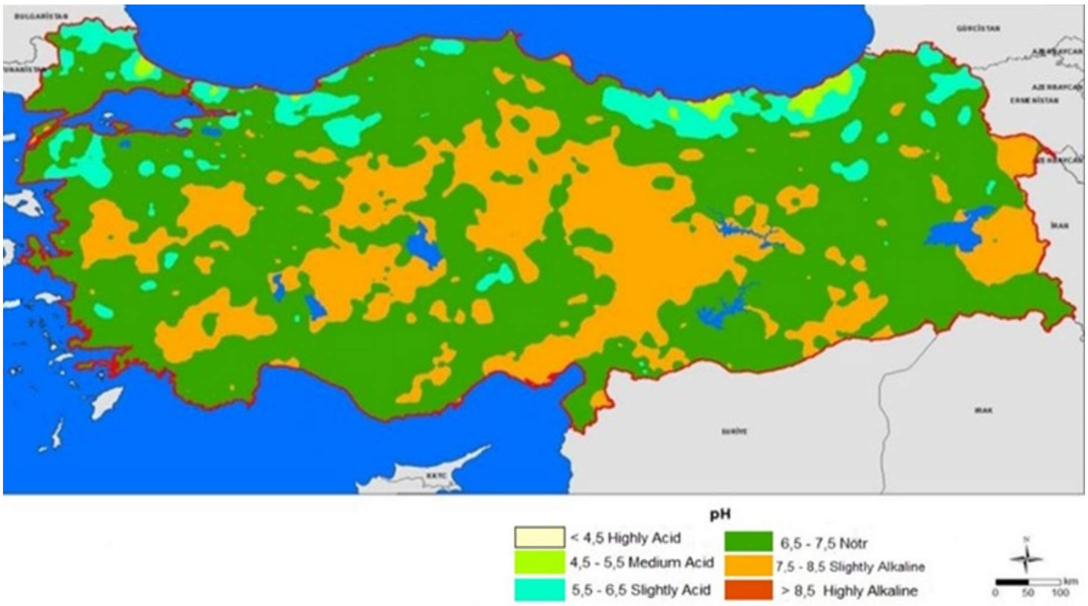

Figure 1. Map illustrating the pH distribution across the soils of Türkiye

Figure 2. Google Earth image of the location where the soil sample was taken in Pınarbaşı district

In agriculture, ammonium sulfate, iron sulfate, and potassium sulfate are among the alternative S-containing fertilizers, with elemental S also being used in agricultural applications and for amelioration purposes (Fahad et al., 2021). Elemental S applications, particularly in soils rich in calcium carbonate and with high pH values, are implemented to improve plant growth and nutrient availability. This method aims to enhance the availability of phosphorus (P) and other micro-nutrients critical to plants by lowering soil acidity (Zhao et al., 2015; Fuentes-Lara et al., 2019).

The current literature contains a limited number of studies examining the interactions of applications in different soil textures over time and according to S doses. The primary objective of this study is to determine the effect of various S sources on pH changes in different soil textures and to identify the most effective S dose.

Materials and Methods

The soil samples used in the study were randomly collected from the coordinates 38°44'12''N, 36°22' 37''E from Pınarbaşı district of Kayseri province and 38°42'53''N, 35°42'33''E from Melikgazi district. It was taken from different points from 0-30 cm soil depth (Figure 2, Figure 3). The research was carried out at Erciyes University Faculty of Agriculture Research Unit. The soil samples taken from the fields were passed through 4 mm sieves and added to 100 gram containers in 3 replicates. The physical and chemical properties of the experimental soil taken from the Pınarbaşı and Melikgazi district are given in Table 1. Soil analyses were conducted using the hydrometer method for particle size analysis (Bouyoucos, 1951), pH, and EC (1:2.5 soil: distilled water) (USSL Staff, 1954).

Figure 3. Google Earth image of the location where the soil sample was taken in Melikgazi district

Table 1. Selected physical and chemical characteristics of the soil sample collected from Pınarbaşı and Melikgazi district

Soil properties	Value	
	Pınarbaşı	Melikgazi
Textural class	Clay loam	Sand
pH (1:2.5)	8.13	7.67
EC (dS m^{-1}) (1:2.5)	0.67	0.21
$CaCO_3$ (%)	11.08	2.6
Organic matter (%)	1.24	0.89
Available P (mg kg^{-1})	13.12	3.11
Extractable Zn (mg kg^{-1})	0.89	0.27
Extractable Fe (mg kg^{-1})	5.49	1.49
Extractable Cu (mg kg^{-1})	0.91	0.64
Extractable Mn (mg kg^{-1})	0.63	0.13

The determination of $CaCO_3$ was performed using the Scheibler calcimeter method (Richards, 1954), organic matter content by the Walkley-Black method (Walkley and Black, 1934), available P by the Olsen method (Olsen and Sommers, 1982), and trace elements by the DTPA (Diethylene triamine penta acetic acid) extraction method (Lindsay and Norvell,1978).

The experiment was designed as a randomized complete block design with three replications. A 100 g soil sample was modified with powdered Sulphur at concentrations of 0 (X0), 0.02 (X1), and 0.04 g (X2), and with granular Sulphur at concentrations of 0 (Y0), 0.044 (Y1), and 0.088 g (Y2). The samples were then brought to field capacity and incubated at 24 °C for 360 days. pH measurements were recorded at the beginning of the experiment and on days 0, 15, 30, 60, 90, 180, and 360. The average results of the study were analysed using JMP 13.2.0 statistical software, and differences between means were determined using Tukey's test at a significance level of $p < 0.005$ (Snedecor and Cochran, 1967).

Results and Discussion

The experimental findings indicated that the two different S sources caused significant alterations in soil pH across all sampling times, soil textures, and application doses ($p<0.01$). Considering all sampling periods and application doses across varied textures, a decrease in average soil pH values was detected compared to the control group. According to all results, the highest soil pH was observed in the control groups, while the lowest pH, recorded at 6.92, was found in sandy textured soil with the Y2 application on the 360th day. The variations in soil pH over the sampling times ranged from 7.67 to 7.53 for the X1 application and 7.69 to 7.21 for the X2 application in sandy textures. For the Y1 application, it ranged from 7.67 to 7.23, and for the Y2 application, from 7.69 to 6.92. In clay textures, for the X1 application, pH ranged from 8.11 to 7.83, for the X2 application from 8.13 to 7.79, for the Y1 application from 8.09 to 7.81, and for the Y2 application from 8.10 to 7.74 (Table 2). The interactions of dose application time are presented in Figure 2. The effects of the applications in sandy textures led to a more pronounced decrease in pH values compared to clay textures. The impact of x S source applications on soil pH in sandy and clay textures is illustrated in Figure 3, and the impact of y S source applications on soil pH in sandy and clay textures is depicted in Figure 4.

The process of elemental S oxidation within the soil environment initiates a cascade of chemical reactions, predominantly the generation of Sulphur ic acid (H_2SO_4), which inherently leads to a decrement in soil pH through its interaction with calcium carbonate ($CaCO_3$) present in the soil, thereby facilitating the formation of calcium sulphate ($CaSO_4$).

Table 2. Temporal average changes in soil pH due to applications of different S sources

Texture	Dose	Period							
		7 th day	15 th day	30 th day	60 th day	90 th day	180 th day	360 th day	Average
Clay loam	X0	8.10^{a}	8.11^{a}	8.11^{a}	8.10^{a}	8.10^{a}	8.10^{a}	8.11^{a}	8.10^{a}
	X1	8.11^{a}	8.11^{a}	8.11^{a}	8.09^{a}	8.05^{a}	7.91^{b}	7.83^{bc}	8.03^{b}
	X2	8.13^{a}	8.13^{a}	8.11^{a}	8.09^{a}	8.03^{ab}	7.88^{bc}	7.79^{c}	8.02^{b}
Clay loam	Y0	8.09^{a}	8.10^{a}	8.09^{a}	8.09^{a}	8.09^{a}	8.09^{a}	8.09^{a}	8.09^{a}
	Y1	8.09^{a}	8.09^{a}	8.07^{a}	8.07^{a}	8.00^{ab}	7.88^{b}	7.81^{bc}	8.00^{b}
	Y2	8.10^{a}	8.09^{a}	8.07^{a}	$8.04a^{b}$	7.90^{b}	7.82^{bc}	7.74^{c}	7.96^{bc}
Sand	X0	7.68^{c}	7.69^{c}	7.67^{c}	7.67^{c}	7.67^{c}	7.69^{c}	7.68^{c}	7.67^{c}
	X1	7.67^{c}	7.61^{cd}	7.61^{cd}	7.60^{cd}	7.58^{cd}	7.54^{d}	7.53^{d}	7.59^{c}
	X2	7.68^{c}	7.62^{cd}	7.60^{cd}	7.56^{d}	7.29^{f}	7.28^{f}	7.21^{f}	7.46^{cd}
Sand	Y0	7.67^{c}	7.67^{c}	7.66^{c}	7.66^{c}	7.66^{c}	7.68^{c}	7.68^{c}	7.67^{c}
	Y1	7.66^{c}	7.65^{c}	7.64^{c}	7.60^{cd}	7.37^{df}	7.36^{df}	7.23^{f}	7.50^{cd}
	Y2	7.69^{c}	7.66^{c}	7.60^{cd}	7.52^{d}	7.28^{f}	7.20^{f}	6.92^{fg}	7.41^{f}

X1: Application of 0.02 g of from powdered Sulphur to the soil, X2: Application of 0.04 g of from powdered Sulphur to the soil, Y1: Application of 0.044 g of from granular Sulphur to the soil, Y2: Application of 0.088 g of from granular Sulphur to the soil; *: Treatments denoted by the same letter within the same column are not significantly different ($p<0.05$).

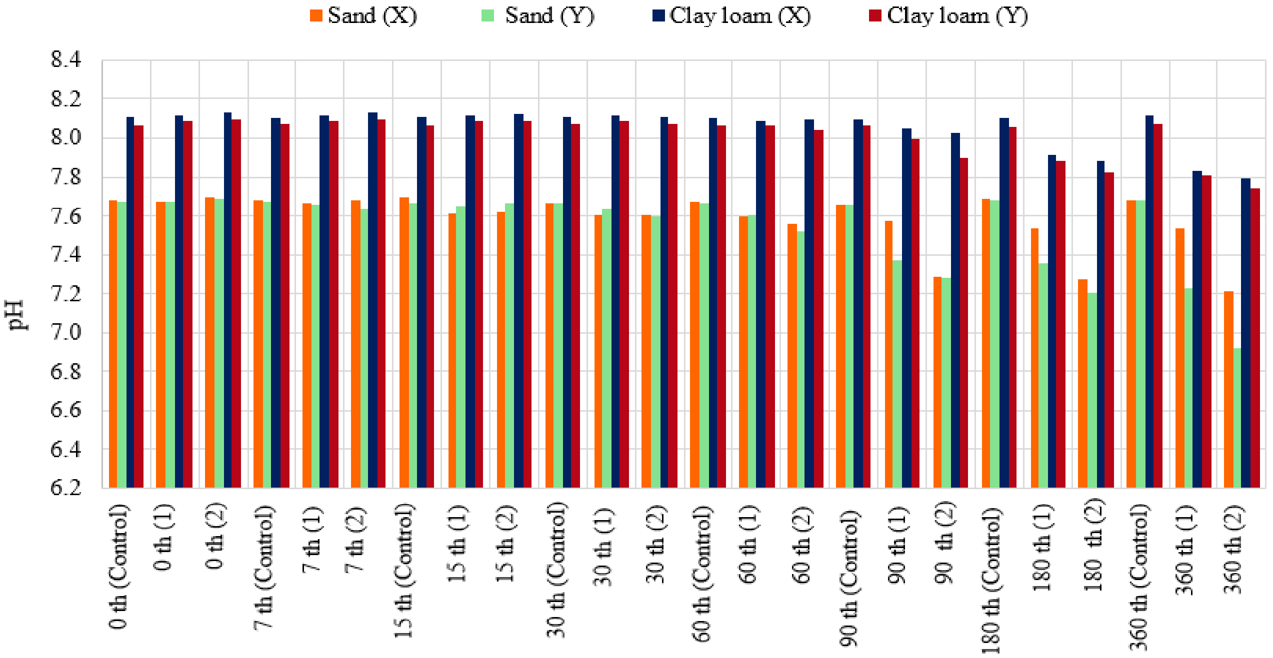

Figure 2. The effect of dose*application*time interaction on soil pH change

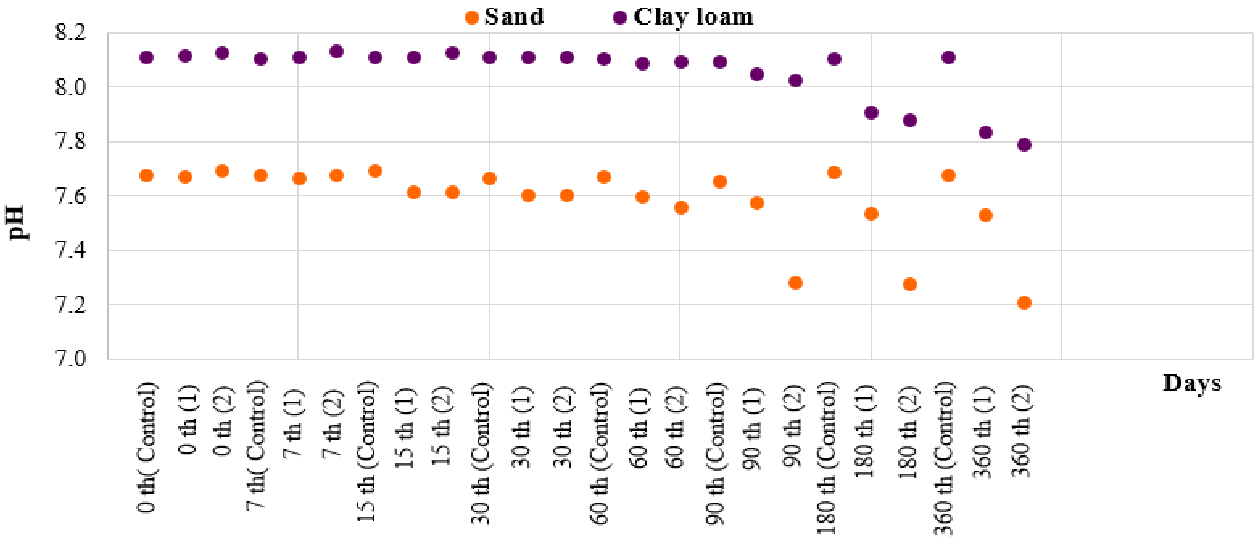

Figure 3. The impact of granular Sulphur applications on soil pH in sand and clay loam textures

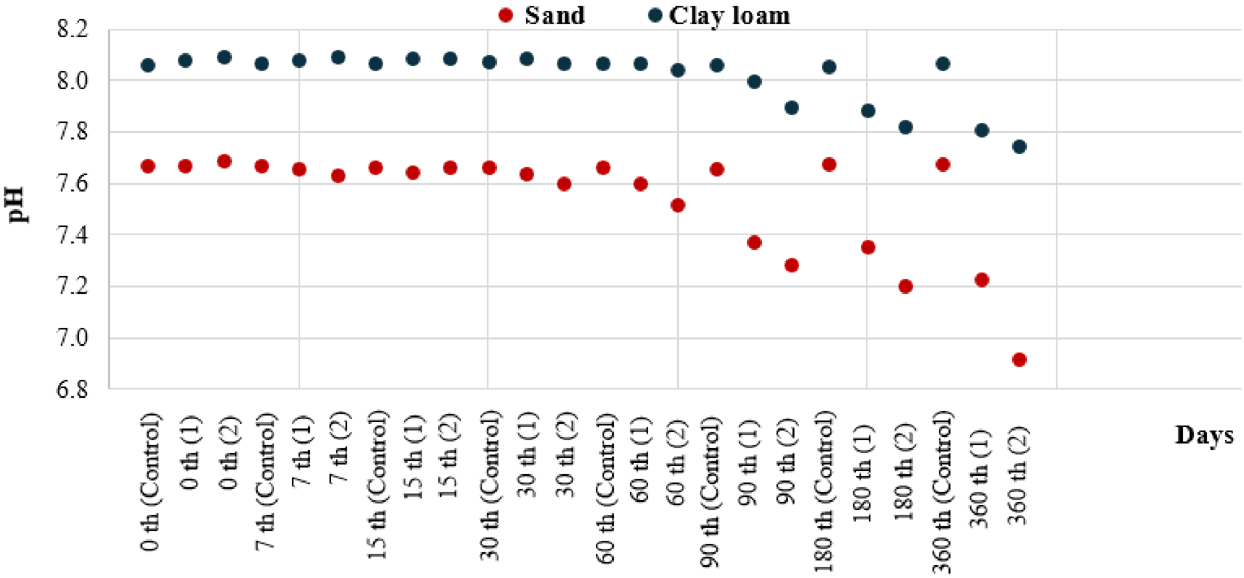

Figure 4. The influence of powdered Sulphur applications on soil pH in sandy and clay loam textures

This compound subsequently dissociates into calcium (Ca^{2+}) and sulfate ($SO_4{}^{2-}$) ions, effectuating a reduction in the soil pH from its initial state, an outcome that is significantly influenced by a multitude of factors including, but not limited to, the specific quantity of elemental S applied, the granular size distribution within the soil, and the intrinsic buffering capacity of the soil itself (Orman and Kaplan, 2000; Lisowska et al., 2022). Within the scope of the incubation experiments conducted, it was elucidated that alongside the establishment of optimal environmental conditions such as temperature and aeration, the dosage of S applied plays a pivotal role in expediting the oxidation process, thus leading to a discernible reduction in soil pH subsequent to the 60-day mark, albeit this reduction exhibits considerable variability when juxtaposed against the backdrop of differing soil textures. In their empirical investigation, Tabak et al., (2020) identified a relative reduction in soil pH after a period of 120 days in a soil possessing a loamy sandy texture, contingent upon the lime content, in comparison to a control group. Moreover, Zhao et al., (2015) delved into the intricate relationship between S oxidation and the physicochemical properties of soil, uncovering that in soils with a diverse composition of sand, silt, and clay, those samples exhibiting a lower buffering capacity witnessed a more accelerated reduction in soil pH, with the overarching effect on pH diminution being both temporally bound and dependent upon the structural composition of the soil. Similarly, Akay (2022) embarked on a study to ascertain the impact of biochar incorporation on the S uptake and growth of plants, with a specific focus on determining the optimal S fertilization dosage for the cultivation of turnips. This involved the integration of elemental S (0, 200, 400 mg kg^{-1}), S in sulfate form (0, 25, 50 mg kg^{-1}), and varying dosages of biochar (0, 1%, and 2%) into the growing medium. The findings from this study highlighted a statistically significant reduction in soil pH by 0.07 units within a clay-loamy textured soil when benchmarked against a control group ($p<0.01$), thus underlining the efficacy of S amendments in modulating soil pH.

Conclusion

The modulation of soil pH through the strategic application of S-based amendments emerges as a critical consideration in the realm of agronomic practices, particularly in contexts where soil pH levels are inherently elevated and pose a constraint to the bioavailability of essential nutrient elements for plants. The outcomes of this comprehensive study elucidate that S applications, emanating from a spectrum of sources, engender a pronounced reduction in soil pH across varied soil textural classes over the duration of the incubation period. This reduction, however, is subject to variation, predicated on the physicochemical attributes of the soil, including but not limited to, its particle size and buffering capacity. Furthermore, the investigation delineates that the application of 0.088 g of S culminates in the maximal reduction of soil pH across both soil textures by the 360th day, yet the practical feasibility and economic viability of this specific S dosage for field applications necessitates a reevaluation. Consequently, the exploration of alternative S sources or the adoption of lower S dosages (e.g., 0.044 g) is posited as a viable and economically judicious alternative for agronomic endeavors, with the overarching aim of optimizing S applications within soil management paradigms to foster the advancement of sustainable agricultural methodologies, thereby embracing an approach that harmoniously integrates environmental sustainability and cost-effectiveness.

Declarations

Conflicts of Interest

We declare that there is no conflict of interest between us as the article authors.

Authorship Contribution Statement

Concept: Osman Sönmez; Design: Osman Sönmez.; Data Collection or Processing: Fatma Nur Kılıç.; Literature Search: Fatma Nur Kılıç.; Writing and Editing: Fatma Nur Kılıç, Osman Sönmez

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