EUROPEAN ACADEMIC RESEARCH
Vol. XIII, Issue 2/ May 2025

Impact Factor: 3.4546 (UIF)
DRJI Value: 5.9 (B+)

ISSN 2286-4822
www.euacademic.org

Effects of Sulfur Amendment on the Physicochemical Properties of Tropical Soils Intended for Ylang-Ylang (Cananga odorata) Cultivation in the Comoros

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Abstract

This study investigates the effects of sulfur (SO_2) amendment on the physicochemical properties of tropical soils intended for the cultivation of ylang-ylang (Cananga odorata). Analyses were conducted on soil samples treated with various sulfur concentrations (0.5 to 10 g/L), including measurements of electrical conductivity, total dissolved solids (TDS), salinity, pH, and absorbance at 800 nm using spectrophotometry. The results show that sulfur amendment significantly increases electrical conductivity and TDS, while maintaining levels conducive to healthy growth of tropical plants. Salinity remains low (<0.5%), and pH remains near neutral, with only slight alkalization observed at the highest concentration (10 g/L). Spectrophotometric analysis reveals increased absorbance and decreased light transmittance in sulfur-enriched soils, indicating enhanced nutrient mobilization. These findings suggest that moderate sulfur amendment improves soil fertility without causing immediate chemical stress; however, long-term monitoring is recommended to prevent risks of excessive salinization or alkalization.

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Key words: Sulfur (SO_2), Soil fertility, Tropical volcanic soil, Electrical conductivity, Total dissolved solids (TDS), Salinity, Soil pH, Ylang-ylang cultivation, Agricultural amendment, Comoros Islands.

1. INTRODUCTION

Soil fertility is a key determinant of agricultural productivity, especially in tropical regions where volcanic soils are often deficient in essential nutrients [1] . Enhancing this fertility without overreliance on conventional chemical fertilizers is a major challenge for the sustainability of agricultural systems [2]. Among natural amendments, elemental sulfur (S^0) proves to be an interesting alternative due to its key role in plant nutrition and the regulation of the physico-chemical properties of the soil.[3]

Sulfur plays a role in several fundamental biological processes, including protein synthesis and chlorophyll formation [4]. Son oxydation dans le sol conduit à la formation d'acide sulfurique, favorisant ainsi l'abaissement du pH et la libération de nutriments tels que le calcium (Ca^{2+}), le magnésium (Mg^{2+}) et le potassium (K^+) [5]. This nutrient-mobilizing capacity is particularly advantageous in humid tropical soils, which are often characterized by phosphorus fixation and micronutrient deficiencies.[6](FAO, 2006).

In the Comoros Islands, particularly in Mohéli, the volcanic-origin soils possess a mineral richness that remains largely untapped, but they are affected by constraints such as low availability of assimilable nutrients and, at times, excessive acidity. [7]. The development of cash crops such as ylang-ylang (*Cananga odorata*), a flagship plant of the archipelago, thus requires targeted amendment strategies to enhance mineral nutrition without degrading soil quality [8].

Several previous studies have shown that sulfur amendments, when applied at low to moderate doses, can improve nutrient availability while minimizing risks of salinization and ionic toxicity [9]. However, few investigations have focused on how sulfur affects parameters such as electrical conductivity, total dissolved solids (TDS), salinity, pH, and the optical properties of soil in a tropical island context.

The objective of this study is therefore to evaluate the effects of various concentrations of sulfur (SO_2) on the key physicochemical properties of tropical soil used for ylang-ylang cultivation. Particular attention is given to electrical conductivity, TDS, salinity, pH, and spectrophotometric absorbance characteristics, in order to determine optimal application thresholds that enhance agronomic performance while preserving soil quality.

2. METHODOLOGY AND DATA ANALYSIS

2.1 Soil Sampling

Soil samples were collected from the Hoani region, located on the island of Mohéli (Union of the Comoros). Sampling was conducted at a depth of 5 to 30 cm, corresponding to the active root zone of plants. A total of approximately 15 kilograms of soil was collected, carefully sealed in airtight bags to prevent contamination or alteration of its initial properties, and transported to the geoscience laboratory for further analysis.

2.2 Sample Preparation

In the laboratory, the raw soil was manually homogenized and sieved through a 2 mm mesh to remove coarse debris (stones, roots, organic matter). Precise aliquots of elemental sulfur were then added to soil suspensions at the following doses: 0.05 g, 0.1 g, 0.2 g, 0.5 g, 0.8 g, and 1 g of sulfur. Each mass of sulfur was dissolved in 100 mL of either distilled water or sodium nitrite solution to obtain the corresponding molar concentrations shown in Table 1.

Table 1: Summary of sulfur dosages and resulting concentrations

Sulfur Mass Added (g)	Solution Volume (mL	Resulting Concentration (g/L)
0,05	100	0,5
0,1	100	1,0
0,2	100	2,0
0,5	100	5,0
0,8	100	8,0
1,0	100	10,0

2.3 Physicochemical Measurements

To assess the effects of sulfur treatment on soil properties, several physicochemical parameters were measured:

- Electrical Conductivity (EC): Measured using a HANNA Model N°55 conductivity meter after 30 minutes of equilibration at room temperature.
- Total Dissolved Solids (TDS) and Salinity**:** Derived from EC readings based on the conversion coefficients provided by the manufacturer.
- pH: Measured using a HI9813-5 pocket pH meter, previously calibrated with standard buffer solutions.

2.4 Spectrophotometric Analysis

UV-visible spectrophotometry (UV-visible Model 4211/50) was employed to measure the absorbance of soil suspensions at 800 nm. Each measurement was repeated three times to ensure accuracy and assess variability.

2.5 Experimental Design

Each treatment was conducted in duplicate (technical replicates). Results are expressed as mean ± standard deviation, and deviations were compared to control samples with no sulfur addition.

2.6 Data Analysis

The data were organized into tables and graphs using Microsoft Excel 2021. The mean and standard deviation of each measurement series (conductivity, TDS, salinity, pH, and absorbance) were calculated. A one-way analysis of variance (ANOVA) was performed to test for statistically significant differences among treatments, with a significance threshold set at $p < 0.05$. In cases of significant differences, a Tukey HSD post-hoc test was applied to identify homogeneous groups. The correlation between the amount of added sulfur and the measured parameters (electrical conductivity, TDS, pH, and absorbance) was also examined using Pearson's correlation coefficient (r). The objective was to evaluate the relationship between sulfur input and the chemical response of the soil in solution.

3. RESULTS AND DISCUSSION

3.1 Electrical Conductivity Response to Sulfur Treatment: Patterns, Nutrient Release, and Agronomic Implications

The results presented in Figure 1 show a contrasting trend in electrical conductivity (EC) depending on whether the soil was treated with sulfur (SO_2) or not. Overall, conductivity increased with the treatment concentration, but much more markedly in the sulfur-treated samples. For example, at a concentration of 10 g/L, EC reached 177.2 µS/cm in the sulfur-enriched soil compared to only 15.72 µS/cm in the control sample. These findings suggest that sulfur addition promotes the dissolution of mineral salts and enhances nutrient availability for plants. According [10],], elemental sulfur plays a catalytic role in releasing essential nutrients such as potassium (K^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}), which are vital for cash crops like ylang-ylang (*Cananga odorata*).

Moreover, the observed conductivity remained within a generally low salinity range (100 to 250 µS/cm,, [11] which is compatible with healthy growth of tropical plants that are sensitive to moderate salt stress. However, at the lowest concentration (1 g/L), the conductivity of the sulfur-treated soil was lower than that of the control (7.316 vs. 25.09 µS/cm). This anomaly could be due to specific interactions between sulfur and soil components, such as adsorption phenomena or temporary ion precipitation, in line with the findings of[12] Chien et al. (2009).

Between 5 and 8 g/L, a plateau appears to be reached: conductivity increases significantly without exceeding critical thresholds, indicating an optimal trade-off between agronomic stimulation and environmental safety.

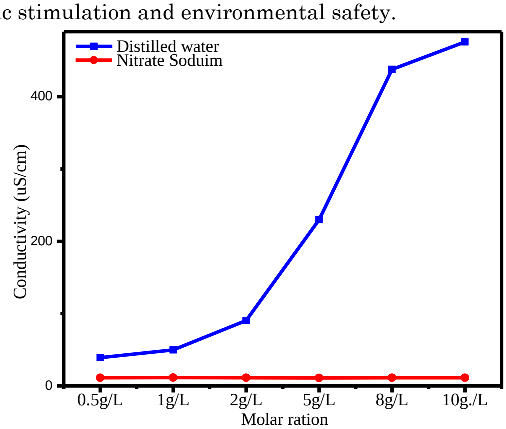

Figure 1: Evolution of soil electrical conductivity as a function of sulfur (SO_2) treatment concentrations.

3.2 Impact of Sulfur Amendment on TDS and Mineral Salt Dissolution

Figure 2 confirms that the TDS measurements follow the same trends observed with electrical conductivity: sulfur-treated soils show significantly higher TDS levels compared to untreated soils, particularly from 5 g/L onwards (47.45 ppm vs. 3.662 ppm). This result is consistent with the findings of Said et al[13]. during potassium extraction from sulfur-amended soils. These observations suggest that the addition of sulfur promotes the dissolution of mineral salts, thereby enhancing nutrient availability for plants.The highest value was recorded at 10 g/L, reaching 88.54 ppm. The positive correlation between TDS and sulfur concentration indicates a gradual solubilization of soil elements, likely due to localized acidification caused by sulfur oxidation, as described by Brady & Weil (2010) [14]. At moderate concentrations (2 to 5 g/L), this increase in TDS is beneficial, as it enhances nutrient availability without posing toxicity risks. Even at higher doses (8–10 g/L), TDS levels remain well below the critical threshold of 1000 ppm for tropical crops (FAO, 2006).

The inconsistency observed at 1 g/L (TDS lower than at 0.5 g/L) may be attributed to complex chemical reactions such as adsorption or secondary precipitation. This anomaly warrants further investigation into parameters such as pH, cation exchange capacity (CEC), and chemical speciation [15].

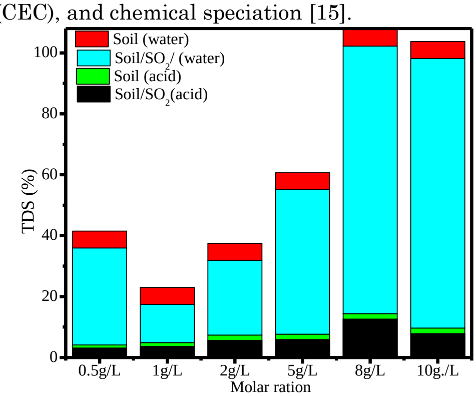

Figure 2: Variation of total dissolved solids (TDS) in the soil with respect to sulfur (SO_2) treatment concentrations.

3.3 Salinity Dynamics in Sulfur-Amended Soils and Implications for Ylang-Ylang Cultivation

The salinity of soils not treated with sulfur remains negligible, while a gradual increase is observed in enriched soils, reaching 0.3% at concentrations of 8 and 10 g/L. Although elevated, these values remain very low and well below the critical threshold of 1.5% for most crops [14] (Richards, 1954). In the case of ylang-ylang, which is moderately sensitive to salt stress, salinity levels below 0.5% do not pose a threat and may even be beneficial by stimulating root absorption [15] (Maas & Hoffman, 1977). However, prolonged and uncontrolled use of high sulfur doses could lead to gradual salinization, especially under poor drainage conditions. Periodic monitoring of pH and salinity will therefore be necessary to prevent long-term degradation.

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3.4 pH value

Figure 3 shows that soil pH varies slightly around neutrality between 0.5 and 8 g/L (6.6–7.0), which is ideal for most tropical crops [18] (Mengel & Kirkby, 2001). At 10 g/L, a slight alkalinization is observed (pH = 7.7).This increase may be attributed to the precipitation of acidic ions at higher concentrations or to the soil's buffering capacity, possibly linked to the presence of carbonates or local clay minerals. At moderate dosages, sulfur addition does not significantly affect soil acidity and remains compatible with optimal development of ylang-ylang. However, a continued rise above pH 7.5–8 could reduce the availability of certain micronutrients (e.g., Fe, Zn), thus requiring careful agronomic monitoring [19].

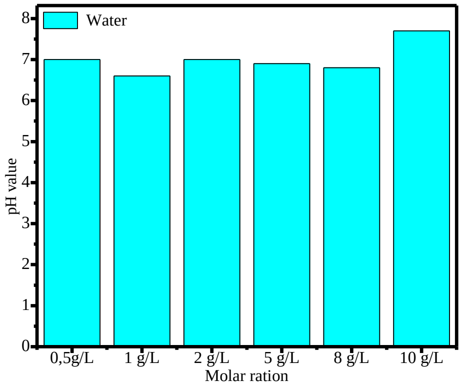

Figure 3: Evolution of soil pH with respect to sulfur (SO_2) treatment concentrations

3.5 Spectrophotometric Results at 800 nm

Spectrophotometric analyses at 800 nm reveal significant changes in light transmission and absorbance of the soil following sulfur treatment ln theTable 2.

Table 2: Effect of sulfur (SO_2) treatment on soil absorbance and light transmission at 800 nm.

Sample	Wavelength (nm)	Absorbance	Light Transmission (%)
Sol seul	800 **nm**	0.163	68.7
Sol + SO_2	800 **nm**	0.223	59.8

The decrease in light transmission and the increase in absorbance in sulfur-enriched soils suggest the formation of dissolved or colloidal compounds, which increase the optical density of the medium [20]. This turbidity may reflect greater release of sulfur ions (SO_4^{2-}) or organic complexes, thereby promoting nutrient mobilization in the soil.

These physicochemical transformations could also enhance microbial activity and the mineralization of organic matter key components of sustainable soil fertility particularly beneficial for high-value crops such as ylang-ylang.

3.6 Correlation between Production, Labor, and Soil Degradation

Figure 5 shows that between 2014 and 2016, ylang-ylang production increased significantly, rising from 127 to 386 tons [21], driven by a growing labor force and favorable conditions. However, from 2017 onward, despite a peak in workforce numbers, production began to decline, indicating a drop in productivity likely due to soil degradation, aging plantations, or inadequate agricultural practices rising from 127 to 386 tons, supported by a growing labor force and favorable conditions. However, from 2017 onward, despite a peak in workforce numbers, production began to decline, revealing a drop in productivity likely due to soil exhaustion, aging plantations, or inadequate farming practices. From 2018 to 2024, this decline continued to a critical level (10 tons annually), reflecting an almost complete abandonment of the sector. This crisis is largely attributed to soil degradation, lack of technical support, and the disengagement of producers[22].The average production of 109.64 tons masks significant variability, as indicated by a high standard deviation (134.89). The peak of 386 tons in 2016 contrasts sharply with the 10 tons produced annually between 2021 and 2024. Workforce: The average number of workers is 76.64, with a maximum of 234 in 2017, a year when production already started to decline. Productivity: Productivity ranges from 0.57 to 2.46 tons per worker. The average of 1.18 reveals a decreasing trend in recent years, pointing to resource exhaustion or inefficient agricultural practices.

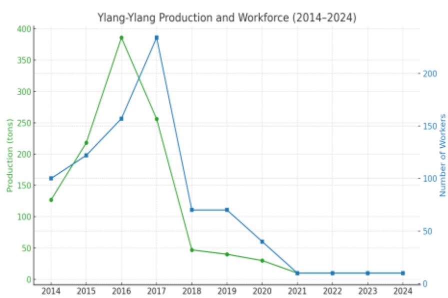

Figure 4: Annual Trends in Ylang-Ylang Production, Workforce, and Productivity (2014–2024)

Table 3. Statistical Analysis of Ylang-Ylang Production (2014–2024)

Indicator	Production (tons)	Workers	Productivity (tons/worker)
Average	109.64	76.64	1.18
Minimum	10.00	10.00	0.57
Maximum	386.00	234.00	2.46
Standard	134.89	73.50	0.59

This study explores the impact of sulfur (SO_2) amendment on the physicochemical properties of tropical soils intended for ylang-ylang (Cananga odorata) cultivation in the Comoros. Sulfur treatments at concentrations ranging from 0.5 to 10 g/L were applied to soils from the Hoani region of Mohéli. Key parameters like electrical conductivity (EC), total dissolved solids (TDS), salinity, pH, and spectrophotometric absorbance were measured.

The results indicate that sulfur significantly increases EC and TDS, which suggests enhanced nutrient mobilization through the dissolution of mineral salts. However, these increases remain within ranges that are conducive to healthy plant growth. The salinity remained low (<0.5%), and the pH remained near neutral, with slight alkalization observed only at the highest sulfur concentration (10 g/L). Spectrophotometric analysis showed increased absorbance and decreased light transmission, indicating the formation of dissolved compounds that could enhance soil fertility.

The study emphasizes that moderate sulfur amendment (5-8 g/L) improves soil fertility without posing significant risks to soil quality, making it a promising approach for enhancing agricultural productivity, especially for ylang-ylang cultivation. Long-term monitoring is recommended to prevent potential salinization or alkalization over time. The research highlights the importance of balancing sulfur application to optimize both agronomic benefits and environmental sustainability.

4. CONCLUSION

The amendment of tropical soils with sulfur (SO_2) proves to be an effective strategy for enhancing their chemical fertility, particularly by increasing electrical conductivity, nutrient availability, and total dissolved solids, while maintaining salinity and pH levels that are favorable for the cultivation of ylang-ylang. Concentrations between 2 and 8 g/L appear to be optimal, as they maximize agronomic benefits without compromising soil health. However, the slight alkalinization observed at higher concentrations (10 g/L) and the progressive increase in salinity suggest the need for careful management of application rates.

Further investigations into pH and salinity dynamics, as well as field trials under real cultivation conditions, are essential to validate these findings over the long term. Ultimately, the controlled use of sulfur could serve as a promising lever to sustainably improve the yields of tropical crops sensitive to nutrient deficiencies, such as ylang-ylang, in the volcanic soils of the Comoros.

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