Vol. 15, No. 2 (2026): 562 - 570 http://dx.doi.org/10.23960/jtepl.v15i2.562-570

JURNAL TEKNIK PERTANIAN LAMPUNG

ISSN 2302-559X (print) / 2549-0818 (online)
Journal homepage : https://jurnal.fp.unila.ac.id/index.php/JTP

Application of Arbuscular Mycorrhizal Fungi and Manure to Improve Saline Soil Characteristics

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Article History:

Received : 03 February 2025
Revised : 11 August 2025
Accepted : 15 September 2025

Keywords:

Arbuscular mycorrhizal fungi,
EC (electrical conductivity),
Manure,
pH,
Saline Soil.

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ABSTRACT

Soil salinity can damage soil structure due to its high sodium chloride content, leading to soil erosion and reduced aeration, which decreases the ability of plants to absorb water and inhibits plant growth. One approach to overcome this problem is by improving the chemical properties of saline soil; therefore, research on the application of arbuscular mycorrhizal fungi and manure is needed. This study aimed to determine whether the addition of manure and arbuscular mycorrhizal fungi at appropriate rates could improve the chemical properties of saline soil. A completely randomized design (CRD) with two factors was used, in which the first factor was the dose of arbuscular mycorrhizal fungi with four levels and the second factor was manure application with two levels, each repeated three times, resulting in eight treatments and 24 experimental units. The results showed that although the application of mycorrhizal fungi and manure did not significantly affect soil pH or electrical conductivity (EC), a single factor manure treatment increased soil pH and reduced EC values, while a single factor treatment of arbuscular mycorrhizal fungi reduced soil EC values. The combined application of manure and arbuscular mycorrhizal fungi significantly increased N-available (NH_4^+ and NO_3^-) during the first week after the application of 20 ton/ha of manure and 10^5 CFU/mL of arbuscular mycorrhizal fungi (M1K1).

1. INTRODUCTION

Indonesia is an archipelagic country with extensive coastal areas and significant salt potential. However, saline soils contain dissolved salts that can inhibit plant growth and reduce agricultural productivity (Prasetyani *et al*., 2020). Increased salinity in the root zone may result from the use of saline irrigation water, seawater intrusion, high evaporation rates, and low rainfall. Soil salinity affects plant growth by disrupting nutrient balance, reducing crop yields, and, in severe cases, causing plant mortality. Plant responses to salinity vary depending on the concentration of dissolved salts. Soil chemical properties therefore serve as important indicators for evaluating land suitability for specific agricultural commodities (Nurlia *et al*., 2020).

High concentrations of sodium chloride (NaCl) in soil can inhibit seed germination and reduce germination rates. Water plays a critical role in photosynthesis, nutrient uptake, and metabolic processes in plants; however, increasing soil salinity reduces the ability of roots to absorb water, thereby suppressing plant growth. Yamika *et al*. (2016) reported that reduced water absorption and toxic effects on seeds are the primary causes of salinity-induced inhibition during germination and early seedling growth. One strategy to mitigate the negative impacts of saline soils is rehabilitation through the application of organic fertilizers and arbuscular mycorrhizal fungi. Soil salinity is commonly classified based on electrical conductivity (EC), where EC values of <1 mS/cm indicate non-saline conditions, 1–2 mS/cm low salinity, 2–3 mS/cm moderate salinity, 3–4 mS/cm high salinity, and >4 mS/cm very high salinity (Sulaeman *et al*., 2023).

In addition to restoring degraded land and improving crop yields in saline and marginal areas, arbuscular mycorrhizal fungi function as biological agents that enhance plant growth, productivity, and quality without adversely affecting soil ecology. Mycorrhizal fungi increase the host plant's capacity to absorb water and nutrients by colonizing root systems and forming extensive external hyphal networks that penetrate deeper soil layers. According to Dahono *et al*. (2015), mycorrhizae can persist effectively within the rhizosphere and play a crucial role in improving soil structure, facilitating carbon transfer within the root system, enhancing soil fertility, and protecting plants from pathogens, thereby supporting the rehabilitation of saline soils.

The addition of manure has also been reported to reduce soil EC (Bhakti *et al*., 2016). Lower EC values enhance nutrient availability, particularly nitrogen, and reduce the adverse effects of soil salinity. Cow manure contains various essential nutrients, including N (2.33%), P_2O_5 (0.61%), K_2O (1.58%), Ca (1.04%), Mg (0.33%), Mn (179 ppm), and Zn (70.5 ppm), with nutrient composition influenced by livestock feed and management practices.

Application of manure increases nitrogen availability in saline soils, thereby improving nitrogen uptake by plants. While higher fertilizer inputs generally increase nutrient availability, excessive application may lead to nutrient toxicity and plant wilting. Therefore, it is necessary to evaluate the combined effects of arbuscular mycorrhizal fungi and manure application, including appropriate dosage levels, to improve soil chemical characteristics and enhance the productivity of saline soils.

2. RESEARCH MATERIALS AND METHODS

2.1. Research Location

Soil samples were collected from Wonorejo Mangrove, Surabaya City, East Java Province, Indonesia, at coordinates 7°17′22.2″ S and 112°47′34.1″ E. The greenhouse of the National Development University "Veteran" East Java was used for the experimental work, while laboratory analyses were conducted at the Land Resources Laboratory (SDL). The research was carried out from January to June 2024.

2.2. Tools and Materials

The tools used in this study included a mortar, 0.5 mm and 2 mm sieves, test tubes, hoe, shovel, analytical balance, pipettes, vortex mixer, funnel, filter paper, oven, aluminum dishes, gloves, desiccator, spectrophotometer, EC meter, shake bottles, spray bottles, shaker, pump pipette, microscope, petri dishes, camera, digestion tubes, Erlenmeyer flasks, digestion apparatus, stove, measuring cups, burettes, and glass spatulas.

The materials used included polybags, distilled water, saline soil samples, label paper, arbuscular mycorrhizal fungi isolates, chili seeds, manure, boiling stones, liquid paraffin, 40% NaOH, boric acid, Conway indicator, 0.01 N H_2SO_4, tissue paper, KCl, 96% alcohol, 10% NaCl, tartrate buffer, phenol, 5% NaOCl, 1 M NH_4OAc (ammonium acetate), and 1 N $K_2Cr_2O_7$ (potassium dichromate).

2.3. Research Design

This study employed a two-factorial Completely Randomized Design (CRD). The first factor was the dose of arbuscular mycorrhizal fungi (AMF) with four levels: M0 (without AMF), M1 (10^5 CFU/mL), M2 (10^7 CFU/mL), and M3 (10^7 CFU/mL). The second factor was manure application with two levels: K0 (without manure) and K1 (20 ton/ha). Each treatment combination was replicated three times, resulting in eight treatments and a total of 24 experimental units. Observations were conducted every 15 days for 60 days, resulting in four observation intervals.

2.3.1. Preparation of Soil Media

Soil media preparation was conducted in the greenhouse of UPN "Veteran" East Java using polybags measuring 25 cm × 25 cm. Saline soil samples were air-dried for one week, ground using a mortar, and sieved through a 0.5 mm sieve. Six kilograms of sieved soil, equivalent to oven-dry soil weight, were placed into each polybag. Manure and AMF were applied according to the respective treatments, and the soil was incubated for 60 days. During incubation, soil moisture was maintained at field capacity, and watering was performed in the morning to minimize evaporation.

2.3.2. Isolation of Arbuscular Mycorrhizal Fungi

Arbuscular mycorrhizal fungi were extracted and isolated from soil samples using the wet sieving and centrifugation method at the Plant Health Laboratory of UPN "Veteran" East Java. Fifty grams of soil were placed in a beaker, mixed with 200 mL of water, stirred, and allowed to settle for 30 minutes. The suspension was sieved sequentially through 250 µm, 125 µm, and 53 µm sieves. The residues retained on each sieve were rinsed with tap water.

The material retained on the 53 µm sieve was transferred into centrifuge tubes, mixed with 60% glucose solution, and centrifuged at 2500 rpm for 3 min. The supernatant was collected, rinsed under running water, and passed again through a 53 µm sieve. The resulting residue was observed under a microscope to determine spore density and confirm the presence of AMF spores.

2.4. Soil Sampling

Saline soil samples were collected using a hoe at the Wonorejo Mangrove site. Two types of soil samples were obtained: disturbed and undisturbed soil samples. Undisturbed soil samples were collected from a depth of 0–20 cm for physical property analysis. A total of 144 kg of soil was collected, with 6 kg allocated to each of the 24 experimental units. Disturbed soil samples were collected to determine soil chemical properties, ensuring relatively homogeneous conditions representative of the field site.

2.5. Observation Parameters

2.5.1. Electrical Conductivity (EC)

Soil electrical conductivity (EC) indicates the concentration of dissolved ions in the soil solution. EC was measured using the electrometric method. Ten grams of soil were mixed with 20 mL of distilled water in a shake bottle and shaken for 30 min. The EC value was then measured using an EC meter. Measurements were conducted every 15 days for 60 days.

2.5.2. Soil pH

Soil pH was measured electrometrically using a pH meter with a glass electrode. Ten grams of soil sieved through a 0.5 mm sieve were mixed with 20 mL of distilled water in a shake bottle. After shaking for 30 minutes, the pH of the suspension was measured. Observations were conducted every 15 days for 60 days.

2.5.3. Available Nitrogen

Available nitrogen (NH_4^+ and NO_3^-) was determined using the digestion–distillation method. For ammonium analysis, one gram of soil was placed in a digestion tube containing 70 mL of distilled water, boiling stones, 10 drops of liquid paraffin, and 10 mL of 40% NaOH. The distillate was collected in an Erlenmeyer flask containing 10 mL of 1% boric acid and three drops of Conway indicator and titrated with 0.01 N H_2SO_4.

Nitrate determination was conducted by adding Devarda's alloy to the digestion residue, followed by distillation and titration using the same procedure. Measurements were conducted every 15 days for 60 days.

3. RESULTS AND DISCUSSION

3.1. Soil Characteristics

Soil characterization was conducted to determine the initial chemical properties of the soil prior to treatment application. The results are presented in Table 1. Preliminary soil analysis is essential to provide baseline information for evaluating changes in soil properties resulting from the application of arbuscular mycorrhizal fungi and manure. Soil samples used in this study were collected from the Wonorejo Mangrove area, Surabaya City.

The initial soil pH measured in H_2O was 7.74, indicating slightly alkaline conditions, while the pH measured in KCl was 7.20, which is classified as neutral. The lower pH value measured in KCl compared to H_2O indicates the dis-

Table 1. Soil characteristics before treatment

Parameter	Unit	Result	Criteria (*)
pH H_2O	-	7.74	Slightly Alkaline
pH KCl	-	7.20	Neutral
EC	mS/cm	7.58	Currently
N–Available (NH_4^+)	ppm	104.228	-
N-Available (NO_3^-)	ppm	31.526	-

Note (*): Criteria sourced from the Soil Research Institute

placement of exchangeable H^+ ions by K^+ ions from the KCl solution, resulting in a decrease in measured soil pH. This finding is consistent with Annisa *et al*. (2021), who reported that soil pH measured under field conditions tends to be higher than laboratory-measured pH due to differences in redox conditions, where field soils often experience more reductive conditions, while laboratory measurements reflect more oxidative conditions.

The initial soil electrical conductivity (EC) was 7.58 mS/cm, indicating a moderate level of soil salinity. Electrical conductivity is commonly used as an indicator of soil salinity, as higher salt concentrations increase the soil solution's ability to conduct electricity. EC values expressed in mS/cm reflect the concentration of dissolved electrolytes in the soil; higher EC values indicate higher salinity levels (Muliawan *et al*., 2016).

The initial available nitrogen content consisted of 31.256 ppm nitrate (NO_3^-) and 104.228 ppm ammonium (NH_4^+). Variations in soil available nitrogen are influenced by both internal factors, such as mineralization and microbial activity, and external factors, including fertilization practices. The relatively high ammonium concentration observed in the initial soil suggests the potential contribution of organic matter inputs, as organic fertilizers are known to enhance nitrogen availability in saline soils.

3.2. Soil pH

Soil pH is a key indicator of soil acidity or alkalinity and is closely related to nutrient availability and soil chemical reactions. Statistical analysis showed that the application of different doses of arbuscular mycorrhizal fungi and cow manure did not result in significant differences in soil pH at any observation period ($p > 0.05$).

Table 2. Average soil pH due to application of arbuscular mycorrhizal fungi and manure.

Treatment	pH			
Mycorrhizal Fungi	**Interval I**	**Interval II**	**Interval III**	**Interval IV**
M0	8.03	7.96	7.93	8.10
M1	8.16	8.00	8.03	8.08
M2	8.09	7.93	7.98	8.01
M3	8.01	8.04	7.90	7.94
	tn	**tn**	**tn**	**tn**
Manure				
K0	8.18 a	8.01	8.02	8.10 a
K1	7.96 b	7.95	7.90	7.97 b
LSAD 5%	**0.20**	**tn**	**tn**	**0.12**

Note: Based on the 5% LSD test, the numbers in the same column and followed by the same letter do not experience significant changes; tn = no significant effect

The analysis of variance showed that soil pH measured in H_2O did not differ significantly among treatments across observation intervals I to IV (Table 2). Further analysis using the HSD test indicated that the single application of arbuscular mycorrhizal fungi did not result in significant differences in soil pH at any observation interval. In contrast, manure application exhibited a significant effect on soil pH at certain observation periods. At interval I, soil pH differed significantly between treatments without manure (K0) and with manure (K1 at 20 tons ha^{-1}), with pH values of 8.18 and 7.96, respectively. A similar significant difference was also observed at interval IV, where soil pH values were 8.10 for K0 and 7.97 for K1.

The decrease in soil pH following manure application is consistent with the findings of Parnianto *et al*. (2022), who reported that organic amendments can reduce soil pH through the release of organic acids during the decomposition process. Variations in soil pH associated with organic matter addition are closely related to changes in the balance of H^+ and OH^- ions in the soil solution. An increase in OH^- ion concentration leads to higher soil pH, whereas an increase in H^+ ion concentration results in lower soil pH. Furthermore, Al^{3+} ions in the soil solution can react with organic compounds such as humic and sulfuric acids, producing additional H^+ ions and contributing to soil acidification (Fikdalillah *et al*., 2016). The decomposition of cow manure produces humic substances, which can influence soil chemical reactions by interacting with functional groups such as phenolic and carboxyl (-COOH) groups, thereby affecting ion exchange processes and soil pH dynamics (Rahayu *et al*., 2020).

The results of this study indicate that the application of arbuscular mycorrhizal fungi (AMF) tended to increase soil pH and improve soil fertility. This effect is associated with fungal activity and metabolism, which produce and release organic compounds capable of binding metal cations, thereby contributing to an increase in soil pH (Zulkoni *et al*., 2020). In the single AMF treatment, soil pH values ranged from 7.00 to 8.00, indicating that the soil conditions in this study were neutral to slightly alkaline. Similar findings were reported by Khairuna *et al*. (2015), who stated that the application of AMF can increase soil pH and enhance soil fertility.

The increase in soil pH following AMF application is attributed to fungal metabolic processes and the release of organic compounds, such as amino acids, which can form insoluble complexes with Al cations, thereby reducing Al activity in the soil solution. AMF spores are often found in a dormant or less active state when soil pH does not correspond to their optimal growth conditions (Yusriadi *et al*., 2018). Mycorrhizal fungi are generally considered acidophilic, meaning they tend to be more abundant in acidic soils. Consequently, higher spore abundance is commonly associated with lower soil pH, and vice versa. This indicates that AMF plays a more active role in supporting plant growth under nutrient-poor or stress conditions, where soil chemical limitations restrict plant nutrient uptake.

3.3. Soil Electrical Conductivity

Soil electrical conductivity (EC) was measured using an EC meter to assess soil salinity. Statistical analysis showed that the interaction between arbuscular mycorrhizal fungi and manure treatments did not significantly affect soil EC values across observation intervals (Table 3). Although variations in EC values were observed among treatments during intervals I to IV, these differences were not statistically significant. This indicates that the application of different doses of cow manure and arbuscular mycorrhizal fungi did not cause substantial changes in soil salinity during the incubation period. The observed changes in EC were likely influenced by the redistribution of soluble salts in the soil rather than by treatment effects.

There were no significant interaction effects between arbuscular mycorrhizal fungi and manure treatments on soil electrical conductivity (EC) based on the analysis of variance (Table 3). The HSD test for the single factor of arbuscular mycorrhizal fungi showed a significant effect only at interval I, while no significant differences were observed at intervals II to IV.

Table 3. Soil EC as affected by arbuscular mycorrhizal fungi and manure treatments at different observation intervals

Treatment	**EC (mS/cm)**			
Mycorrhizal Fungi	**Interval I**	**Interval II**	**Interval III**	**Interval IV**
M0	1.63 a	2.81	2.74	2.79
M1	1.52 ab	2.12	2.33	2.19
M2	1.96 ab	2.56	2.62	2.59
M3	2.46 b	2.65	2.84	2.70
HSD 5%	**0.91**	**tn**	**tn**	**tn**
Manure				
K0	1.85	2.98 b	3.14 b	3.17 b
K1	1.94	2.08 a	2.13 a	1.96 a
HSD 5%	**tn**	**0.51**	**0.51**	**0.48**

Note: Values followed by the same letter within the same column are not significantly different at the 5% level based on the HSD test. *tn* indicates no significant difference.

At interval I, treatment M0 differed significantly from M3, with EC values of 1.63 and 2.46 mS cm^{-1}, respectively. However, from intervals II to IV, EC values under the mycorrhizal treatments showed only minor fluctuations and were not significantly different among treatments. This indicates that the effect of arbuscular mycorrhizal fungi on soil EC was limited to the early stage of observation.

In contrast, the single manure treatment had a significant effect on soil EC at intervals II to IV. The average EC values under manure application tended to decrease over time, although the magnitude of reduction was relatively small. At interval IV, treatment K0 was significantly different from K1, with EC values of 3.17 and 1.96 mS cm^{-1}, respectively. This result suggests that manure application effectively reduced soil salinity during the later observation periods. The decrease in soil EC following manure application may be attributed to chemical and biological processes during organic matter decomposition. The decomposition of plant residues or organic matter can increase carbonate (CO_3^{2-}) activity, which promotes the dissolution of $CaCO_3$ and facilitates the replacement of Na^+ by Ca^{2+} in the soil exchange complex (Aprianto *et al*., 2022). In addition, organic ameliorant are capable of binding Na^+ and Cl^- ions, thereby reducing their toxicity and overall soil salinity (Rahma & Sarifuddin, 2025).

The absence of a significant interaction effect between mycorrhizal fungi and manure treatments indicates that, under the conditions of this study, arbuscular mycorrhizal fungi did not directly enhance the salinity reduction or mineralization processes associated with manure application. Although mycorrhizal fungi are known to improve nutrient uptake and plant tolerance to stress, their role in accelerating manure mineralization or directly reducing soil EC appears to be limited.

3.4. Available Nitrogen (NH_4^+ and NO_3^-)

Nitrogen is a primary macronutrient required by plants for growth and development and is commonly absorbed in the form of ammonium (NH_4^+) and nitrate (NO_3^-). As a major component of soil organic matter, nitrogen plays a crucial role in regulating soil fertility and plant productivity. However, in saline soils, nitrogen availability is often constrained due to salinity-induced stress, which can interfere with nutrient uptake, microbial activity, and nitrogen transformation processes.

High salinity conditions may reduce nitrogen availability by inhibiting nitrification, increasing nitrogen losses, and limiting root absorption capacity. Consequently, nitrogen deficiency is a common constraint in saline soils and must be carefully managed to sustain plant growth and improve soil productivity. Therefore, evaluating the dynamics of NH_4^+ and NO_3^- in response to soil amendments such as arbuscular mycorrhizal fungi and manure is essential to understanding their role in improving nutrient availability under saline conditions.

3.4.1. Ammonium (NH_4^+)

The analysis of variance showed a significant interaction between arbuscular mycorrhizal fungi and manure treatments on soil NH_4^+ concentration in interval I, whereas no significant interaction was observed in intervals II to IV (Table 4). In interval I, the M0K0 treatment (without mycorrhizal fungi and manure) resulted in the lowest NH_4^+ concentration

Table 4. Average NH_4^+ content due to the combination of arbuscular mycorrhizal fungi and manure

Treatment	NH_4^+ (ppm)			
	Interval I	Interval II	Interval III	Interval IV
M0K0	139.34 ab	136.59	130.89	67.70
M1K0	47.17 a	109.55	65.36	273.17
M2K0	148.57 ab	110.41	122.89	337.10
M3K0	124.73 ab	127.70	132.21	326.67
M0K1	92.63 ab	112.49	123.77	143.99
M1K1	190.21 b	148.40	173.84	279.08
M2K1	96.58 ab	129.69	96.17	143.24
M3K1	134.37 ab	140.07	391.65	132.41
HSD 5%	**141.92**	**tn**	**tn**	**tn**

Note: Values followed by the same letter within the same column are not significantly different at the 5% level based on the HSD test. *tn* indicates no significant difference.

(391.65 ppm), while the M3K1 treatment (10^7 CFU/mL mycorrhizal fungi combined with 20 ton/ha manure) produced the highest NH_4^+ value. This indicates that the combined application of high mycorrhizal inoculum and manure enhanced ammonium availability during the early stage of incubation.

In subsequent observation intervals (II–IV), the effects of treatment combinations on NH_4^+ concentration were not statistically significant, suggesting that the initial enhancement of ammonium availability diminished over time. This pattern may be attributed to the transformation of NH_4^+ into other nitrogen forms, microbial immobilization, or plant uptake as incubation progressed.

The increase in NH_4^+ concentration observed in the combined treatments is closely related to the application of organic amendments, which enhance soil fertility and nitrogen mineralization processes. The addition of organic matter has been reported to increase the C/N ratio, available phosphorus, and ammonium content in soil (Agegnehu *et al*., 2016). Furthermore, ammonium is a relatively stable form of nitrogen and is less susceptible to leaching losses compared to nitrate. As a result, progressive decomposition of organic materials contributes to the accumulation of NH_4^+ in soil, particularly during the early stages of mineralization (Sukaryorini *et al*., 2016).

3.4.2. Nitrate (NO_3^-)

The analysis of variance indicated a significant interaction between arbuscular mycorrhizal fungi and manure treatments on soil NO_3^- concentration at observation intervals I and IV, whereas no significant interaction was observed at intervals II and III (Table 5). The highest mean NO_3^- concentration among the combined treatments was recorded in M1K1 (10^5 CFU/mL mycorrhizal fungi combined with 20 t/ha manure), reaching 283.08 ppm. This result suggests that moderate mycorrhizal inoculum combined with manure application effectively enhanced nitrate availability at specific incubation stages.

Table 5. Average NO_3^- content as affected by the combination of arbuscular mycorrhizal fungi and manure

Treatment	**NO_3^- (ppm)**			
	Interval I	**Interval II**	**Interval III**	**Interval IV**
M0K0	55.11 a	74.51	55.51	32.31 ab
M1K0	31.19 a	45.66	47.99	34.89 ab
M2K0	104.49 a	71.89	69.72	9.80 a
M3K0	198.97 ab	51.46	44.89	25.78 ab
M0K1	157.28 ab	67.98	63.54	58.10 ab
M1K1	283.08 b	71.29	119.12	20.61 a
M2K1	146.92 ab	65.71	22.88	104.48 b
M3K1	159.65 ab	54.57	61.02	75.45 ab
HSD 5%	**172.83**	**tn**	**tn**	**83.31**

Note: Values followed by the same letter within the same column are not significantly different at the 5% level based on the HSD test. *tn* indicates no significant difference.

Although plants are capable of absorbing nitrogen in the form of ammonium (NH_4^+), nitrate (NO_3^-) remains the dominant nitrogen form taken up by plants due to its high mobility in the soil solution. Nitrate ions are readily absorbed by plant roots; however, they are also highly susceptible to losses through leaching and evaporation processes (Murni & Purnamayani, 2019). As shown in Table 5, the overall average NO_3^- concentration decreased across successive observation intervals, indicating a progressive reduction of nitrate in the soil system. This decline may be attributed to plant uptake, leaching, and transformations within the nitrogen cycle, as variations in nitrogen inputs and outputs strongly influence soil nitrogen availability (Dewi & Setiawati, 2018).

Further analysis revealed that the single application of arbuscular mycorrhizal fungi did not significantly affect NO_3^- concentrations at any observation interval. In contrast, manure application had a significant effect at intervals I and IV (Table 6). Treatment K1 (20 t/ha manure) resulted in the highest average available nitrogen content, reaching 86.73 ppm. The application of organic fertilizers such as manure plays an important role in improving soil fertility, particularly by increasing nitrogen availability. Manure application enhances nitrogen content through mineralization processes, which release plant-available nitrogen forms into the soil. Kaya (2015) reported that organic fertilizers can supply approximately 15% available nitrogen following mineralization, thereby contributing to increased soil nitrogen availability.

Table 6. Effect of individual treatments on average NO_3^- content

Treatment	**NO_3^-(ppm)**			
Mycorrhizal Fungi	**Interval I**	**Interval II**	**Interval III**	**Interval IV**
M0	106.20	71.25	59.52	45.20
M1	157.14	58.48	83.55	27.74
M2	125.71	68.80	46.30	57.14
M3	179.31	53.02	52.96	50.62
HSD 5 %	**tn**	**tn**	**tn**	**tn**
Manure				
K0	97.44 a	60.88	54.53	25.69 a
K1	186.73 b	64.89	66.64	64.66 b
HSD 5%	**52.91**	**tn**	**tn**	**25.50**

Note: Values followed by the same letter within the same column are not significantly different at the 5% level based on the HSD test. *tn* indicates no significant difference.

4. CONCLUSION

The combined application of manure and arbuscular mycorrhizal fungi did not significantly affect soil pH and electrical conductivity (EC). However, manure applied as a single treatment was able to increase soil pH to 7.97. Manure applied as a single treatment also reduced soil EC to 1.96 mS/cm, while mycorrhizal fungi applied alone reduced EC to 1.52 mS/cm, indicating their individual roles in alleviating soil salinity. The combination of manure at a dose of 20 ton/ha and arbuscular mycorrhizal fungi at 10^5 CFU/mL (M1K1) significantly increased the availability of nitrogen in the form of NH_4^+ and NO_3^- during the initial observation period.

Further studies are recommended to extend the observation period in order to better capture the temporal dynamics of mycorrhizal fungi and manure interactions on soil chemical characteristics. Field-scale experiments involving crop cultivation and a wider range of treatment combinations are also suggested to validate the applicability of these findings under practical agricultural conditions.

AUTHOR CONTRIBUTION STATEMENT

Author	**C**	**M**	**So**	**Va**	**Fo**	**I**	**R**	**D**	**O**	**E**	**Vi**	**Su**	**P**	**Fu**
MNH	✓	✓			✓	✓		✓	✓	✓	✓			
RP	✓	✓								✓		✓		
PES		✓								✓		✓		

C: Conceptualization	Fo: Formal Analysis	O: Writing - Original Draft	Fu: Funding Acquisition
M: Methodology	I: Investigation	E: Writing - Review & Editing	P: Project Administration
So: Software	D: Data Curation	Vi: Visualization	
Va: Validation	R: Resources	Su: Supervision	

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