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Salinity, Organic Matter, Potassium, Zinc and Gypsum Influence Nutrients Availability in Coastal Saline Soil of Odisha

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ABSTRACT

Soil salinity caused by poor-quality irrigation, climate and drainage limits soil fertility and crop productivity, while amendments such as organic manure, K, Zn and gypsum can mitigate these effects. A 60-day laboratory incubation study was conducted to assess the impact of saline water and soil amendments on electrical conductivity and nutrient release pattern. Twenty treatment combinations were evaluated, consisting of four levels of saline water (SW0: normal water, SW1: 4 dS/m, SW2: 8 dS/m and SW3: 16 dS/m) and five amendments: control (C), organic manure @10 t/ha (OM), KCl @120 kg K/ha (K), $ZnSO_4$ @10 kg Zn/ha (Zn) and gypsum @5 q/ha (Gy). Salinity reduced soil pH by 0.8–2.15% and increased electrical conductivity by 36–146% over 60 days. Organic manure and Zn increased organic carbon by 62% and 71% respectively; K enhanced available K by 34–52% in SW3K and gypsum improved Ca by 75% at 45 days. All amendments reduced Na, with K and gypsum showing the highest reductions (8%). Incubation time increased soil pH, organic carbon and nutrient availability. Potassium under high salinity was most effective in mitigating stress, while Zn and organic manure enhanced organic carbon, showing amendments can alleviate salinity impacts and improve soil fertility.

***Key words**: Salinity, organic matter, potassium, zinc, gypsum*

INTRODUCTION

Coastal saline soils found in estuarine, low-lying deltaic and coastal depression regions worldwide, pose a major challenge for agriculture due to the impact of saline water on nutrient availability and plant growth. These soils are often classified under soil types such as Haplaquepts or Halaquepts and are characterized by high concentrations of soluble salts, fine clay texture, poor drainage and limited fertility due to nutrient deficiencies and imbalances (Sabareshwari & Ramya, 2018). The problem is further exacerbated by the intrusion of seawater and the use of saline irrigation water which alter soil physio-chemical properties.

Continuous use of saline irrigation water, which is common in coastal agriculture due to freshwater scarcity, affects the dynamics and release of essential plant nutrients such as N, P, K, Ca, Mg and micronutrients like Zn (Ding *et al*., 2023). While some nutrients become less available due to ionic competition or precipitation reactions, others may be lost through leaching or volatilization. As a result, nutrient deficiencies or toxicities may occur, severely impacting plant growth and reducing crop yield. In saline-irrigated coastal agriculture, osmotic stress, ion toxicity and altered soil processes limit crop performance. Application of organic amendments and mineral treatments, such as vermicompost, biochar and gypsum, improves soil structure, promotes salt leaching and supports crop growth (Yadav *et al*., 2024). Combined use with inorganic fertilizers

further enhances nutrient availability and salinity tolerance, with potassium and zinc supplementation playing an important role in maintaining nutrient balance and increasing crop yield (Hossin, 2024; Sakara and AlBakry, 2022).

Potassium plays a critical role in plants exposed to salinity stress by reducing sodium (Na^+) accumulation, improving potassium (K^+) levels and increasing the K^+/Na^+ ratio, thereby enhancing salt-tolerance mechanisms such as membrane stability and enzyme activation (Mohammadi *et al*., 2024). Additionally, improving the potassium (K^+) nutritional status in plants can greatly diminish the generation of reactive oxygen species (ROS) (Abbasi *et al*., 2014).

Salinity-induced zinc deficiency is common in coastal saline soils due to antagonistic ion interactions and low Zn mobility in the soil solution. Zinc application has been shown to protect chlorophyll from oxidative damage, stabilize biological membranes and enhance antioxidant enzyme activities under salinity stress (Shao *et al*., 2023).

The incorporation of organic matter improves soil properties by enhancing NaCl leaching, reducing exchangeable sodium and electrical conductivity, and increasing water infiltration, retention and aggregate stability. It also boosts soil microbial biomass and enzyme activities. Moreover, humic acid application further enhances plant salt tolerance, biomass production and nutrient availability (Dinçsoy & Sönmez, 2019).

Gypsum improves soil structure and enhances leaching of excess Na^+ ions from cation exchange sites, thereby reducing their uptake by plants and increasing the availability of Ca^{2+} for plant absorption (Gonçalo *et al*., 2019). This interaction between Ca^{2+} and Na^+ is beneficial for soil stabilization and permeability (Amer & Aboelsoud, 2023).

The interactive effects of saline-water irrigation and the application of organic matter, K, Zn and gypsum on nutrient-release patterns in coastal saline soils remain poorly understood. In view of the above facts, we hypothesize that: (i) Has saline water irrigation any impact on nutrient release pattern? and (ii) Can application of organic matter, K, Zn and gypsum modify the release and availability of essential nutrients in coastal saline soils irrigated with saline water. This study aimed to investigate how these treatments influence the release of critical nutrients in coastal saline soils with goal of improving nutrient availability and optimizing fertilizer use in coastal agroecosystem.

MATERIALS AND METHODS

Experimental site

An incubation study was conducted during March, 2023 in Department of Soil Science & Agricultural Chemistry, Institute of Agriculture Science (IAS), SOA Deemed to be University, Bhubaneswar, Odisha to study the effect of organic manure, K fertilizer, Zn fertilizer and gypsum on electrical conductivity and nutrients release pattern in saline soil treated with brackish water.

Soil and saline water used in this study

The soil used in the incubation experiment was collected from saline research farm, Keshpur, Ganjam district during March 2023. Surface soil (0 to 15 cm depth) was collected from a rice-fallow field to the laboratory, air dried and processed through 2 mm sieve and utilized for the incubation experiment. The physio-chemical properties of soil were determined following standard procedures and presented in **Table 1**. The brackish water used for the experiment was obtained from Bay of Bengal at Puri. It was alkaline in reaction (pH =7.99) with EC value of 43 dS/m which was diluted to 4, 8 and 16 dS/m for use as irrigation in the study.

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Treatments and experimental design

The experiment was carried out in a 3-factorial completely randomized design with three replications. There were 20 treatment combinations consist of four levels of saline water (SW0- normal water, SW1- saline water irrigation @4 dS/m, SW2- saline water irrigation @8 dS/m and SW3- saline water irrigation @16 dS/m), and five amendments: control (C), organic manure @10 t/ha (OM), KCl @120 kg K/ha (K), $ZnSO_4$ @10 kg Zn/ha (Zn) and gypsum @5 q/ha (Gy). One hundred grams of processed soil sample was mixed with organic manure, KCl, $ZnSO_4$ or gypsum as per the treatments and kept in 200 cc plastic container. Measured quantity of normal and saline water irrigation was given to each container as per the treatments. The moisture of the soil in container was maintained at field capacity by adjusting the container weight. Soil samples were collected at 15, 30, 45 and 60 days of incubation, air dried, processed and kept for estimation of pH, ECe, available K, Ca, Mg, Na and organic carbon.

Soil analysis

The pH and ECe of the experimental soil (soil: water ratio of 1: 2.5) was undertaken following methods of Jackson (1973) and organic carbon by wet oxidation method of Walkley and Black (1934). According to Piper (1950), the particle size was measured using a Bouyoucos hydrometer (ASTAM 151H). The available N in the soil was determined by using the modified alkaline permanganate method (Kelplus classic DX Nitrogen auto analyser) (Subbiah and Asija, 1956). According to Hanway and Heidals (1952), available K and Na were extracted by using neutral normal ammonium acetate and measured using a flame photometer (Systronic flame photometer 128). Soil available calcium and magnesium were extracted with 1N NH_4OAC and determined using the versinate titration method (Jackson, 1973).

Statistical analysis

Statistical differences between treatments were determined by Duncan Multiple Range (DMRT) test using MSTATC software and Microsoft Excel was used to draw the histograms.

RESULTS AND DISCUSSION

Effect of salinity, fertilizers and amendments on soil pH

The pH in control (SW0C) treatment was higher than saline water treatments up to 45d of incubation. However, at 60d, SW3 treatment recorded highest pH (6.91) followed by SW2 (6.71), SW0 (6.69) and SW1 (6.68) (**Fig. 1**). Averaged over the incubation period and amendments, the pH was significantly ($P < 0.01$) reduced by 0.8% in SW1, 2.15% in SW2 and 0.8% in SW3 over SW0 (normal water treatment) **(Fig. 2a**). Similar trends were reported by Priyanka *et al*. (2020), where slight pH reduction was attributed to the formation of organic acids from the decomposition of crop residues and organic manure (Sharma *et al*., 2013). Long-term saline irrigation may increase soil pH due to slower leaching of $HCO3^-$ relative to other ions (Zhang *et al*., 2024).

In OM treatments, pH values increased with time of incubation higher being in normal water (SW0) and decreased in saline treatments (SW1, SW2 and SW3). With addition of K fertilizer, pH increased over the time of incubation in normal and saline treatments and the highest value was 7.34 in SW0K at 60d of incubation. However, a reversed trend was observed in Zn treatments. The pH in Zn treatments were higher in SW3 followed by SW2, SW1 and SW0 at all incubation period.

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Gypsum addition increased the pH in normal and saline treatments up to 30d. This trend was maintained in SW0 and SW3 up to 60d whereas, it declined in SW1 and SW2 treatments. Higher pH was maintained in SW3 + Gy throughout the incubation period.

Comparing the effects of amendments on soil pH, it was observed that, soil pH (averaged over salinity and incubation period) decreased with OM by 1.69% and with Gy by 0.89%, whereas it was increased by 0.81% in K treatments and by 3.3% in Zn treatments over amendments control (pH-6.44) (**Fig. 2b**). The decline is linked to organic acid formation from OM decomposition (Hossain *et al*., 2019) and the conversion of gypsum to H_2SO_4 under humid conditions (Wiedenfeld, 2011; Temiz & Cayci, 2018). The interaction effects of salinity × amendments and salinity × amendments × incubation period is significant at 1% level of significance.

Table 1: Physico-chemical properties of experimental soil

Parameters	Value
Soil pH	6.08
ECe (dS/m)	5.32
Sand (%)	72.64
Silt (%)	10.80
Clay (%)	16.56
Soil texture	Sandy Loam
Organic carbon (%)	1.03
Available nitrogen (kg/ha)	395.0
Available potassium (mg/kg)	54.72
Available calcium (%)	0.03
Available magnesium (%)	0.17
Available sodium (mg/kg)	657.88
DTPA zinc (mg/kg)	1.38
Water soluble potassium (mg/kg)	20.5
Water soluble sodium (mg/kg)	185.2

Effect of salinity, fertilizers and amendments on soil ECe

In control (SW0C), the ECe increased from 5.32 dS/m (initial) to 7.0 dS/m at 60d of incubation whereas it decreased to 6.0 dS/m in SW0 OM, 5.0 dS/m in SW0K and SW0Zn and 6.20 dS/m in Gy treatment indicating that addition of amendments significantly reduced the salinity (**Fig. 3**). With increasing the level of salinity, the mean ECe (averaged over amendments and incubation period) increased by 36%, 79% and 146% in SW1, SW2 and SW3 treatments, respectively over SW0 (14.74 dS/m) (Fig. 4a). Among all treatment combinations, highest ECe of 22.86 dS/m was recorded in SW3C treatment at 60d. likely due to salt accumulation (Zhang *et al*., 2024).

However, with application of amendments the ECe decreased significantly in SW3 treatments. It was decreased by 11.5 to 21% in SW3 OM, 19- 25% in SW3K, 2- 6% in SW3Zn and 6- 30% in SW3Gy treatment over SW3C (amendment control). Higher reduction in K and gypsum treatments indicated the antagonistic relationship between K and Ca with Na.

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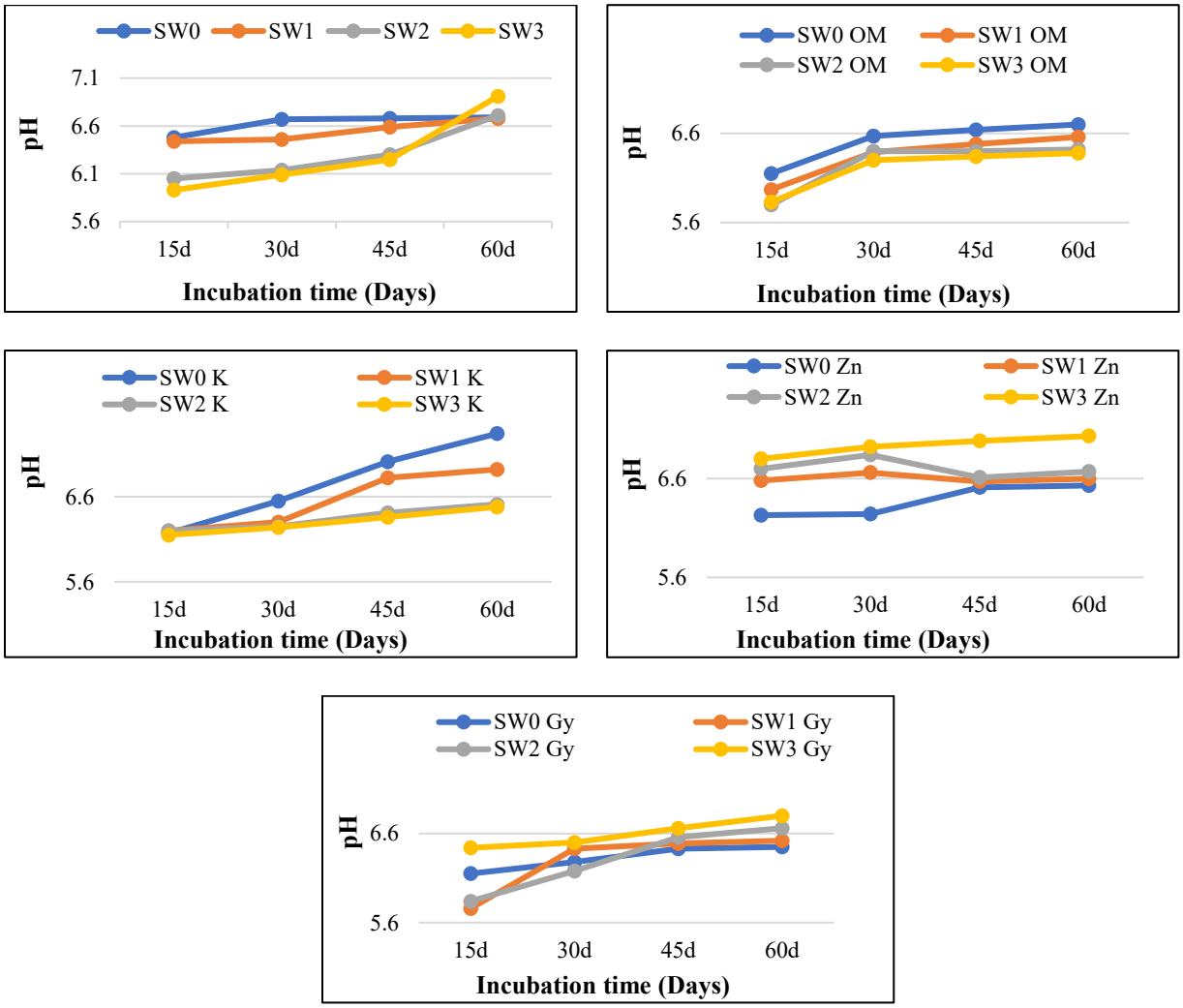


Fig 1. Effects of salinity levels (SW) and amendments on soil pH during the incubation period

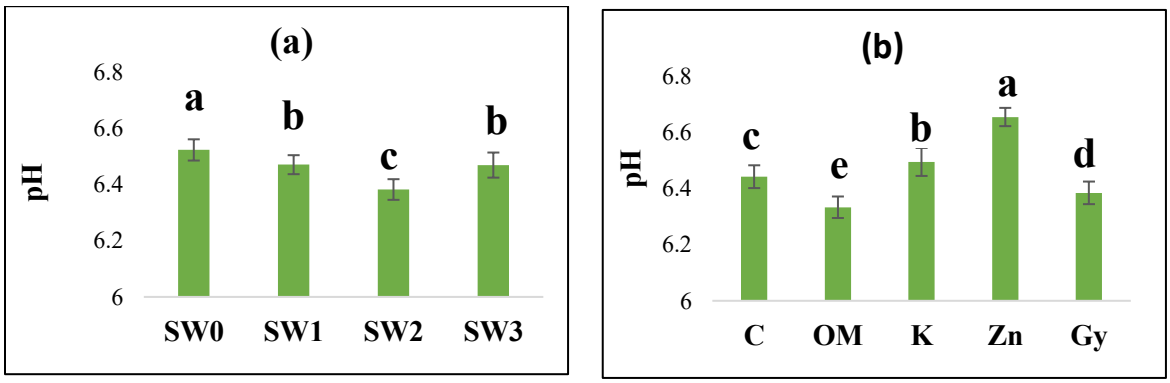


Fig 2. Effects of (a) salinity (n=20) and (b) amendments (n=16) on soil pH.
Notes: Means followed by same letter (s) do not differ significantly

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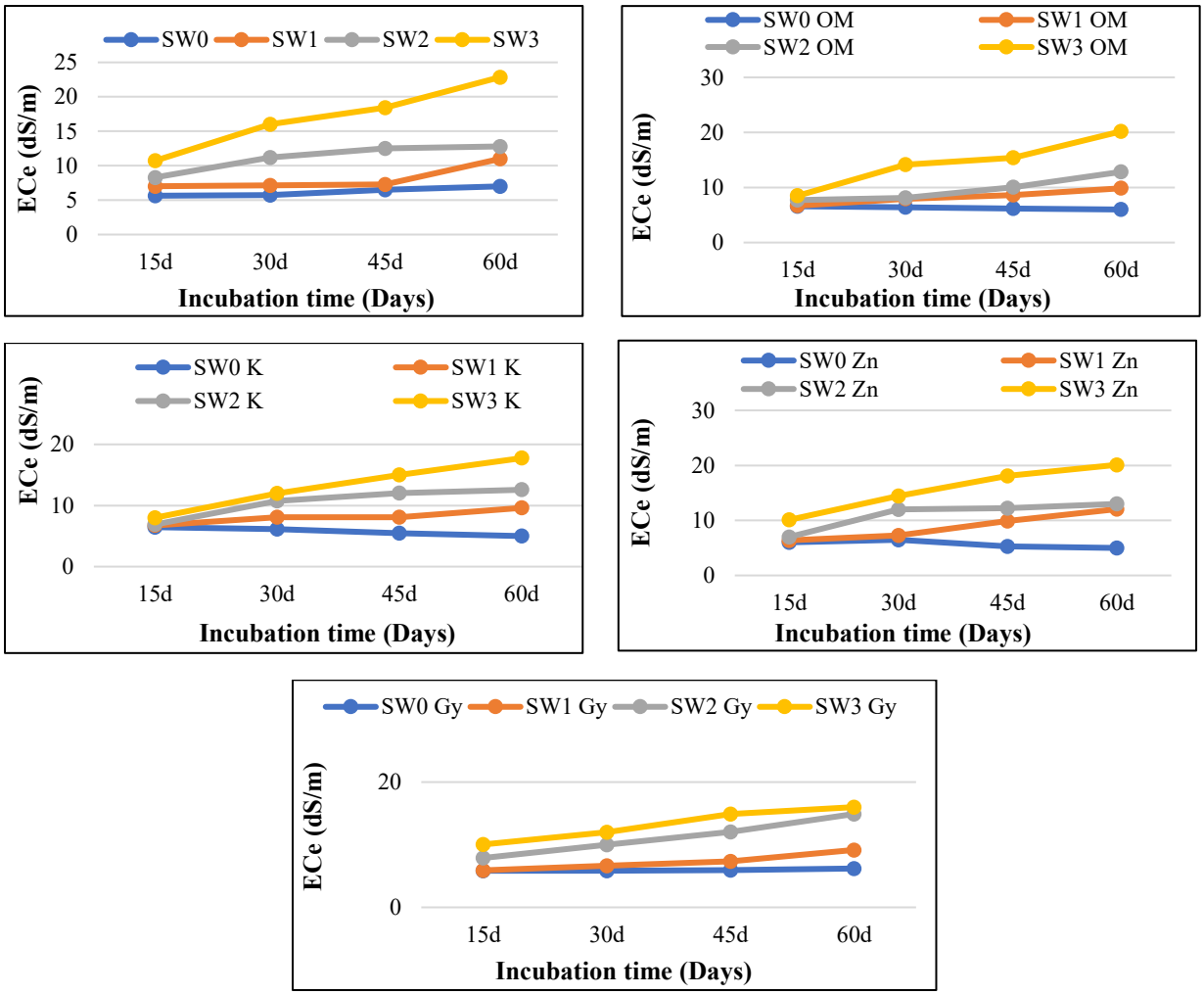


Fig 3. Effects of salinity levels (SW) and amendments on soil ECe during the incubation period

Further, the mean ECe (averaged over salinity and incubation period) decreased significantly by 9% in OM, 12% in K, 3% in Zn and 12% in Gy treatments over amendments control (C) (**Fig. 4b**). Previous reports also indicate that K reduces ECe by mitigating Na^+ toxicity (Alomar & Jena, 2024). Organic amendments enhance soil porosity, promoting Na^+ leaching and lowering salinity (Zhang *et al*., 2015; Tejada *et al*., 2008). Gypsum enriches soils with Ca^{2+}, replacing exchangeable Na^+ and improving soil structure, porosity, hydraulic conductivity, and infiltration (Mahmoodabadi *et al*., 2013; Murtaza *et al*., 2009). Zn addition improves soil porosity and decreases exchangeable sodium, alleviating salinity effects (Ali & Mahmoud, 2013). The interaction effect of salinity × amendments, salinity × incubation period and salinity × amendments × incubation period is significant at 1% level of significance (**Table 2**).

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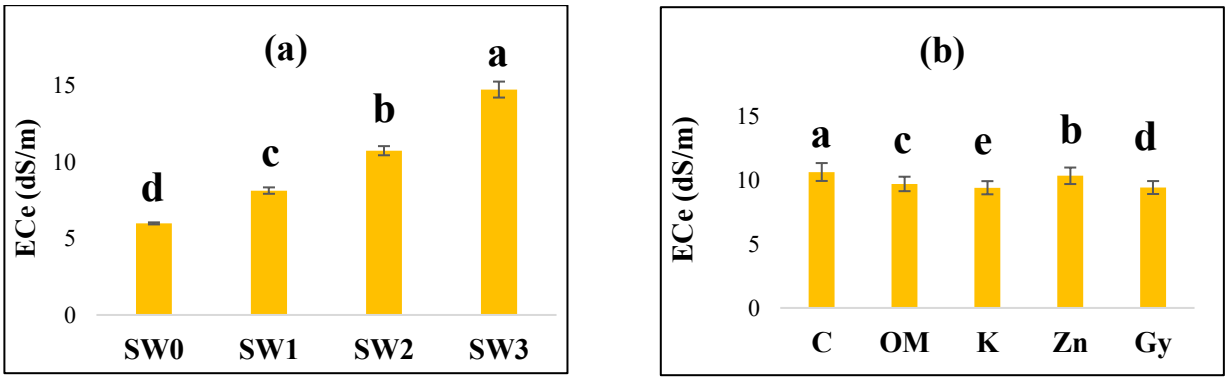


Fig 4. Effects of (a) salinity (n=20) and (b) amendments (n=16) on soil ECe.
Means followed by same letter (s) do not differ significantly

Effect of salinity, fertilizers and amendments on soil organic carbon content

The OC of initial soil was 1.03% and increased significantly in all treatments with passes of incubation period. In amendment control (C) treatments, application of saline water significantly increased the OC content by 60% in SW1 and SW2 and by 46% in SW3 treatments over SW0 at 60d. Further, averaged over the incubation period and amendments, the OC content was significantly increased by 18% in SW1 and SW2 and by 10% in SW3 over SW0 treatment (**Fig. 5a**), indicating that microbial activity declined at higher level of salinity (SW3). Low salinity can stimulate microbial population and OC content, whereas high salinity limits water availability and microbial activity (Liu *et al*., 2017; Chowdhury *et al*., 2011; Rath and Rousk, 2015).

Application of OM significantly increased the OC content by 50% in normal water (SW0 OM) and 60 to 62% in saline water treatments over control (SW0C). Organic matter decomposition releases CO_2, H^+ and organic acids contributing to soil OC (Kitila *et al*., 2020; Ontl and Schulte, 2012).

Effect of K fertilization was lower than OM application. The OC content at 60d of incubation period was significantly increased by 33% in SW0K and 48 to 55% in saline water treatments over control (SW0C), highest being in SW2K (1.27%) treatment. Potassium influences microbial community dynamics, affecting OM decomposition and stabilization (Zhou *et al*., 2024).

Zinc fertilization has tremendous effect on microbial activity resulting 45% higher OC content in SW0Zn, 67% in SW1Zn, 71% in SW2Zn and 1.35% in SW3Zn treatment over control (SW0C) at 60d of incubation period. Similarly, Tang *et al*. (2020) found that an appropriate level of zinc seemed to stimulate microbial activity and boost the functioning of enzymes in soil.

The OC in gypsum treatments were lower than the initial value (1.03%) up to 45d except SW1Gy treatment. However, at the end of 60d incubation there was build up in OC content by 26% in SW0Gy, 57% in SW1Gy, 62% in SW2Gy and 38% in SW3Gy treatments over control (SW0C). gypsum enhances soil chemical and physical properties, supporting CO_2 stabilization and inorganic carbon formation (Wang *et al*., 2017).

Further, it was observed that averaged over salinity and incubation period, the OC content in OM, K, Zn and Gy treatments was significantly increased by 16%, 13%, 8% and 6% respectively over amendment control (C) (**Fig. 5b**). The interaction effects of salinity × amendments and salinity × amendments × incubation period is significant at 1% level of significance (**Table 2**).

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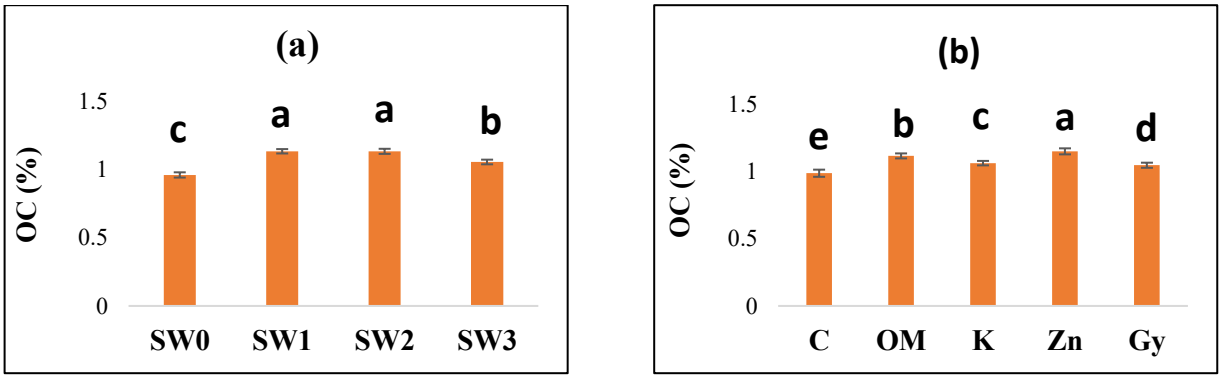


Fig 5. Effects of (a) salinity (n=20) and (b) amendments (n=16) on organic carbon content in soil.
Notes: Means followed by same letter (s) do not differ significantly

Effect of salinity, fertilizers and amendments on available K and Na

Available K in control (SW0C) at 15d was 250 mg/kg and significantly increased with level of salinity by 8% in SW1C, 44% in SW2C and 50% in SW3C indicating that saline water addition enhanced the release of non-exch.K into soil solution with passes of incubation period, similar trend was maintained in all saline treatments except SW2C treatment (**Fig. 6**). Further, the mean available K (averaged over incubation period and amendments) in SW0 was 275 mg/kg and significantly increased by 8% in SW1, 21% in SW2 and 38% in SW3 treatments (Fig. 7a).

Addition of OM significantly increased available K both in normal and saline water treatments and the values were higher over control at all stages of incubation and at all salinity levels. It was 284 mg/kg in SW0 OM at 15d and significantly increased by 8% in SW1OM, 44% in SW2OM and 50% in SW3OM treatment. The same trend was maintained up to 60d in SW0 OM and SW1OM whereas there was decline in available K in SW2OM and SW3OM treatment at 45d and 60d might be due to K fixation.

Available K in potassium treatments were higher than OM, Zn and Gy treatments at all stages of incubation period. It was 290 mg/kg in SW0K at 15d and significantly increased by 34% in SW1K, 39% in SW2K and 52% in SW3K treatments. With increasing the incubation period there was decline in available K in all saline treatments because of change of exchangeable K to non-exchangeable form.

The magnitude of available K in Zn treatments was similar to OM treatments but lower than K treatments. Available K in SW0Zn treatment at 15d was 284 mg/kg and significantly increased by 4 to 43% in saline treatments highest being in SW3Zn treatment. The available K in all Zn treatments increased up to 30d and thereafter declined up to end of incubation period.

Application of Gy significantly decreased the available K at 15d and 30d as compared to OM, K and Zn treatments whereas it was increased at 45d and 60d of incubation. Comparing the effects of different amendments, it is observed that the mean available K (over salinity and incubation period) was significantly ($P < 0.01$) increased by 18% in K followed by 13% in Zn and 11% in OM treatment over control. On the other hand, there was 6% reduction in available K with application of gypsum might be due to increased K-fixing capacity of soil (**Fig. 7b**).

Irrespective of treatments, there was reduction in available K with increasing in incubation period might be due to K fixation. Reduction in 3 to 5% available K during 45d-60d of incubation period explained the amount of K was fixed by clay lattice at favorable pH range.

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Application of saline water significantly increased available Na with level of salinity and incubation period. It was 2901 mg/kg at 15d in control (SW0C) and significantly increased by 2% in SW1C, 12% in SW2C and by 34% in SW3C treatments.

With passes of incubation time, the available Na in control (SW0C) reduced from 2901 mg/kg to 1540 mg/kg whereas it was significantly increased at all salinity levels (Fig. 8). Averaged over the incubation period and amendments, the mean available Na in SW0 treatments was 2024.99 mg/kg and significantly increased by 48% in SW1, 98% in SW2 treatments (**Fig. 9a**). Application of K, Zn and Gy significantly reduced the available Na at all levels of salinity and incubation period as compared to control. Whereas, there was buildup of available Na in OM treatments might be due to binding and retention of Na^+ ion.

Averaged over the incubation period and salinity levels, highest reduction (8%) was recorded in K and Gy treatments followed by 5% in Zn treatment over control (**Fig. 9b**). Accumulation of Na increased with passes of time over the incubation time. It was 2966 mg/kg soil at 15d and significantly ($P < 0.01$) increased by 23% at 30d, 27% at 45d and 48% at 60d of incubation. As per the Anova, all the interaction combinations are significant at 1% level of significance (**Table 2**).

Organic matter increased available K, likely through mineralization and improved cation exchange capacity (Walker and Bernal, 2008; Liang *et al*., 2003). Potassium application further increased K availability while reducing Na due to cation antagonism (Gul *et al*., 2016). Zn application increased available K and reduced Na supporting cation balance and nutrient uptake (El-Sharkawy *et al*., 2022). Gypsum and K effectively reduced Na accumulation by providing Ca^{2+} and enhancing water infiltration (Sharma and Singh, 2017).

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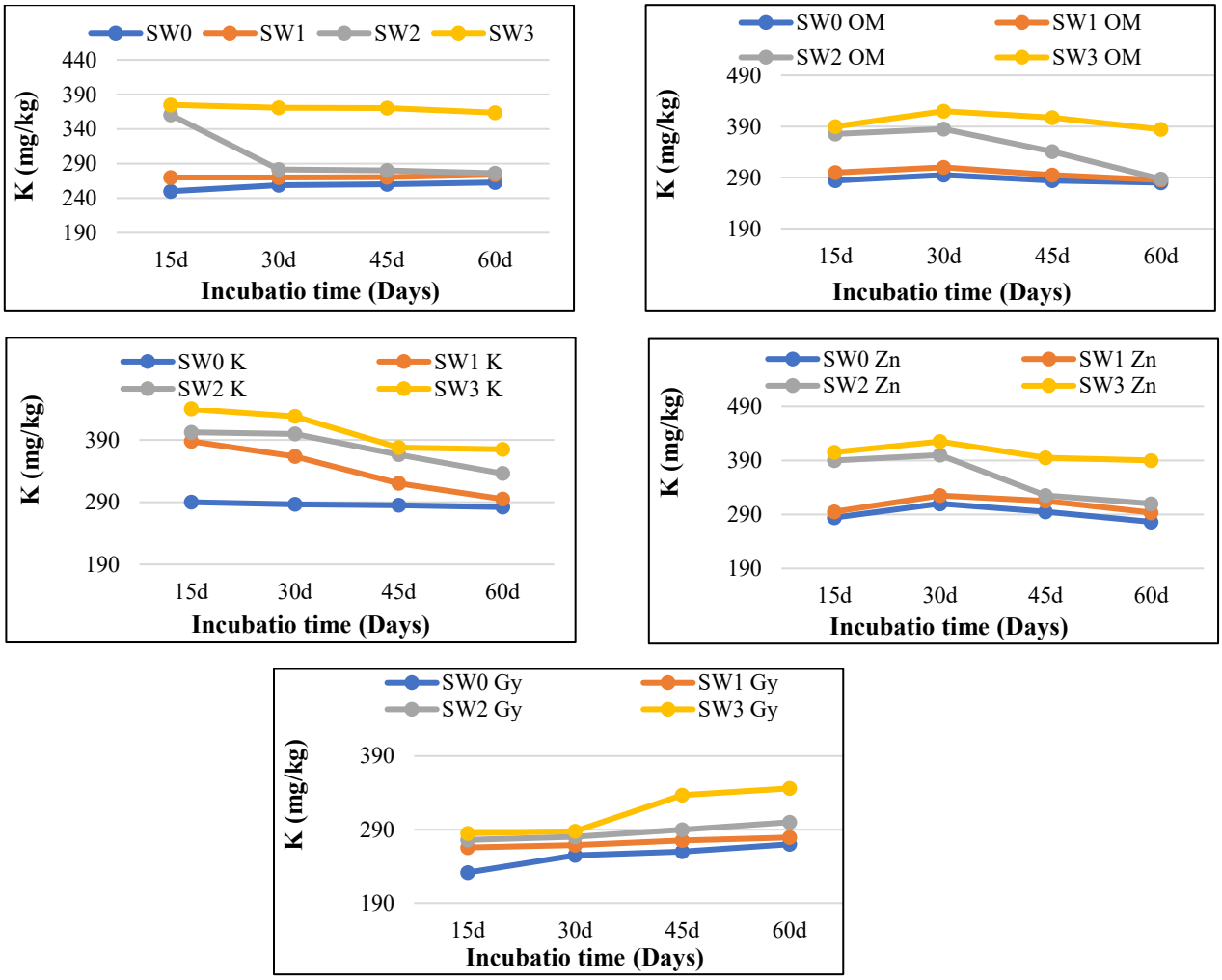


Fig 6. Effects of salinity levels (SW) and amendments on available K during the incubation period

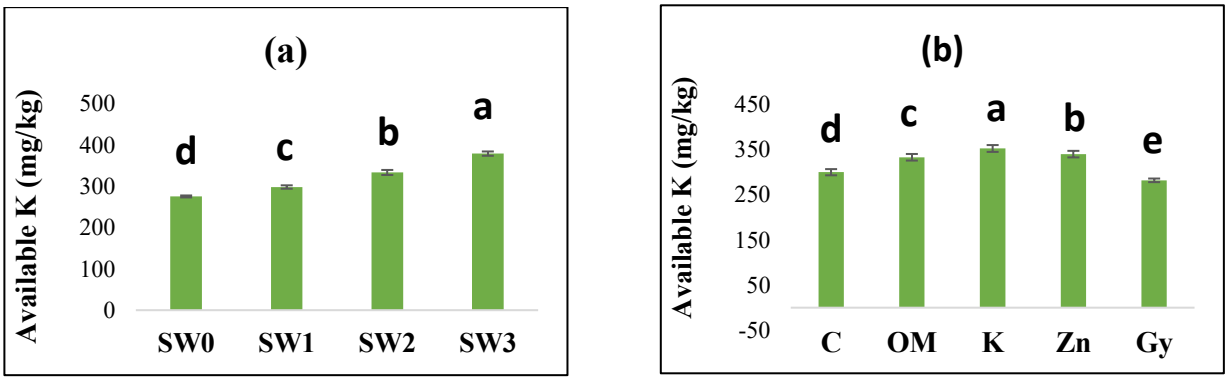


Fig 7. Effects of (a) salinity (n=20) and (b) amendments (n=16) on available potassium in soil.
Notes: Means followed by same letter (s) do not differ significantly

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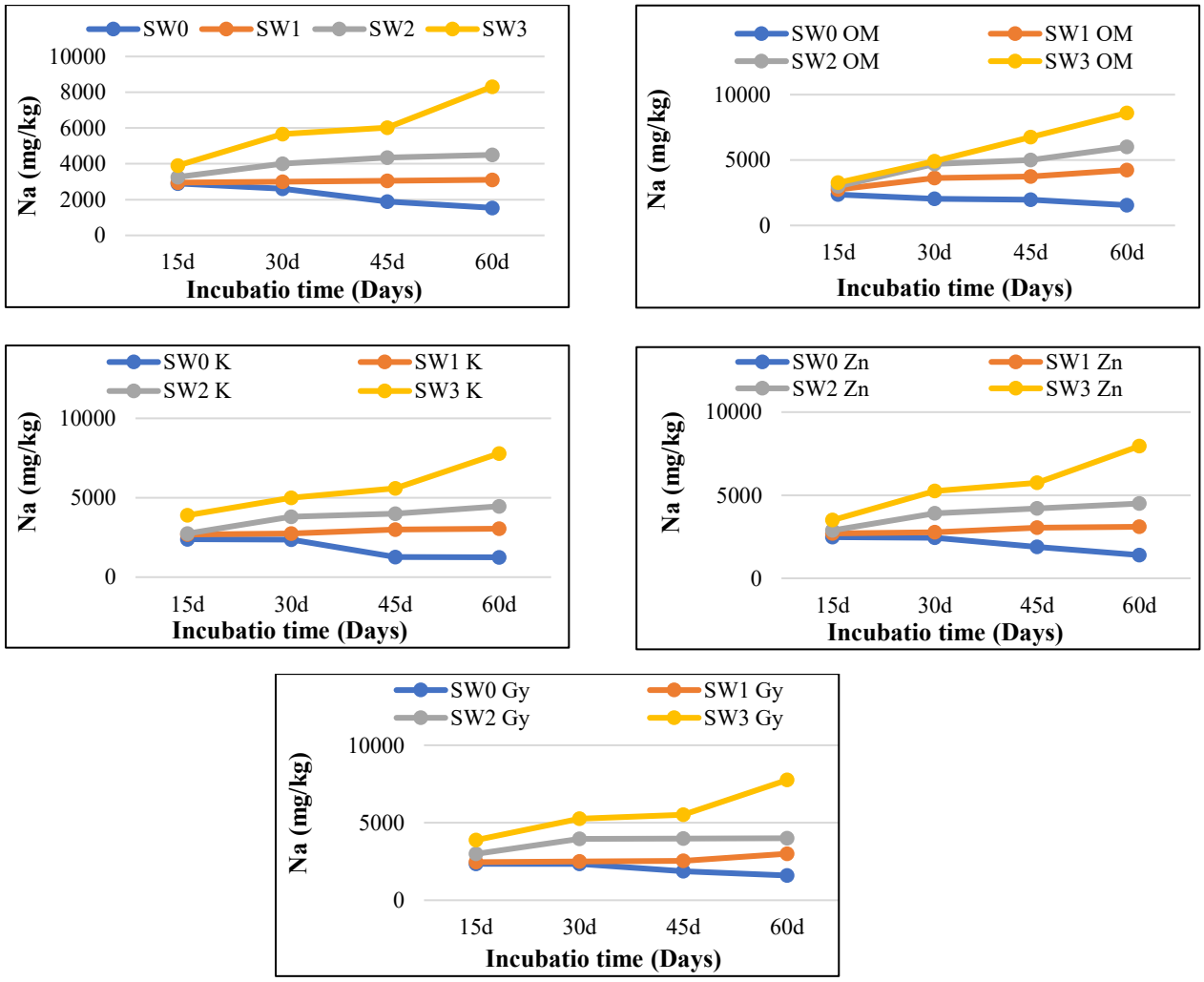


Fig 8. Effects of salinity levels (SW) and amendments on available Na during the incubation period

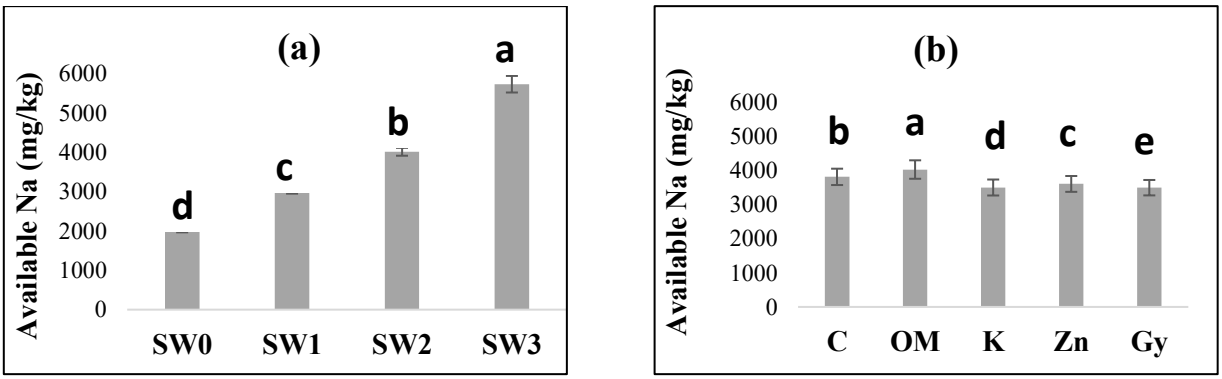


Fig 9. Effects of (a) salinity (n=20) and (b) amendments (n=16) on available sodium in soil.
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Effect of salinity, fertilizers and amendments on available Ca

Saline water irrigation has negative effect on available calcium in soil. Available Ca in normal water treatments (SW0) was higher than saline water treatments at all stages of incubation period in OM, K and Zn treatments. However, when Gy was applied, it was higher up to 30d of incubation and declined at 45d and 60d (**Fig. 10**). Averaged over the incubation period and amendments, highest value of 0.078% was recorded in SW0 and significantly ($P < 0.01$) decreased by 10% in SW1, 18% in SW2 and 28% in SW3 treatment (**Fig. 11a**). This indicated that soil salinity suppressed the available Ca in soil. High Na^+ concentrations compete with Ca^{2+}, Mg^{2+}, K^+ and NH_4^+ for uptake and exchange sites (Mindari e*t al*., 2013).

However, a reverse trend was observed in amendments treatment. With application of K, OM, Zn and Gy the Ca availability increased by 10, 16, 20 and 43% respectively, over control (**Fig. 11b**). Maximum availability of Ca in Gy treatment showed that, addition of Ca through gypsum enhanced the release of Ca from exchange complex to solution phase. In SW3 treatment, available Ca was increased with Gy addition over control by 75%, 50%, 60% and 33.33% at 15d, 30d, 45d and 60d of incubation, respectively.

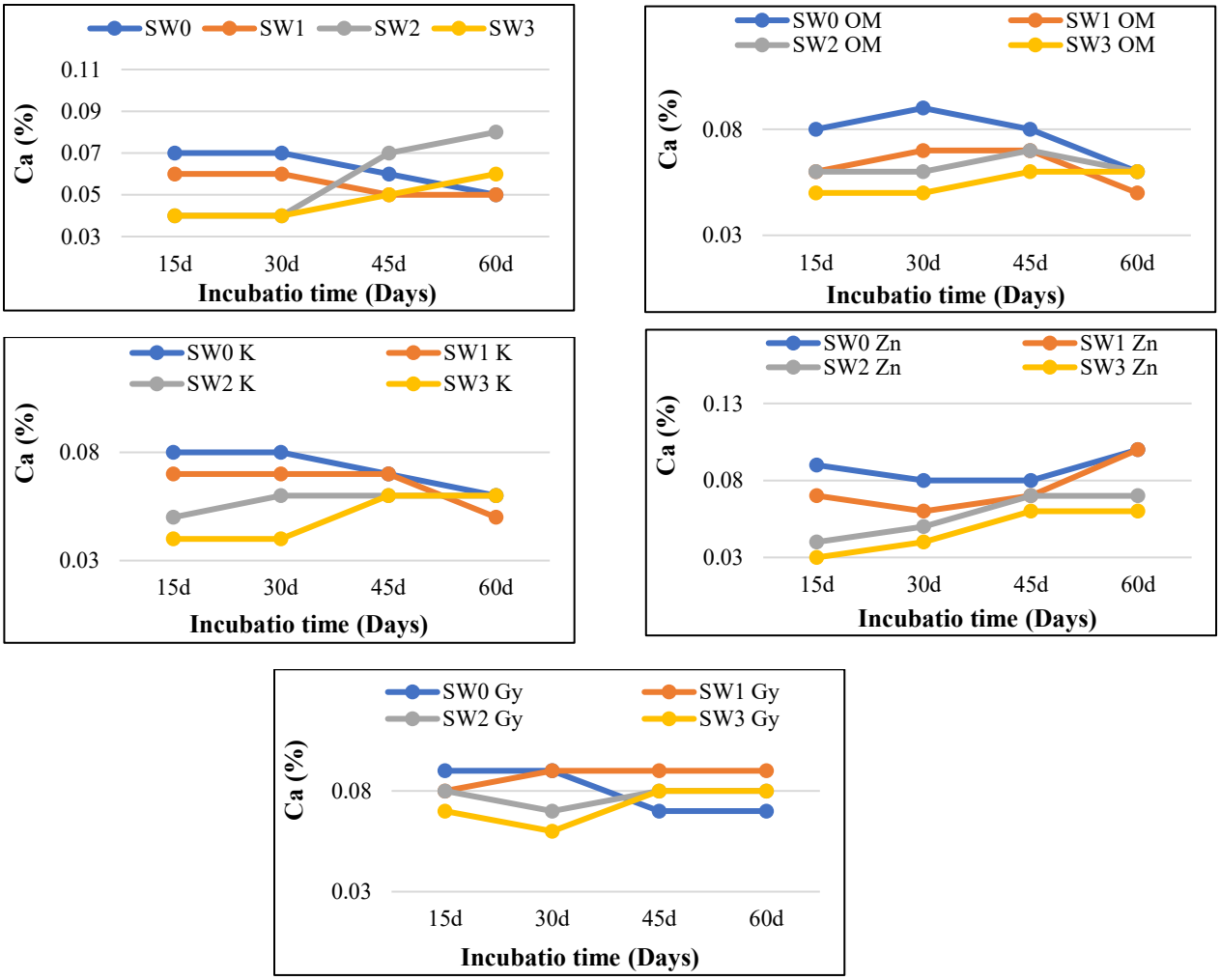


Fig 10. Effects of salinity levels (SW) and amendments on available Ca during the incubation period

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Organic matter increased available Ca and Mg, likely via organic acids promoting cation solubilization and chelation (Wong *et al*., 2009; Tejada *et al*., 2006). Gypsum and organic matter increase soil Ca^{+2} and Mg^{+2}, which interact with Na^{+} on soil colloids, reducing the Exchangeable Sodium Percentage (ESP) (Mahmoud *et al*., 2018). Further, the Anova showed that the interaction effects of all treatment combinations are statistically insignificant (**Table 2**).

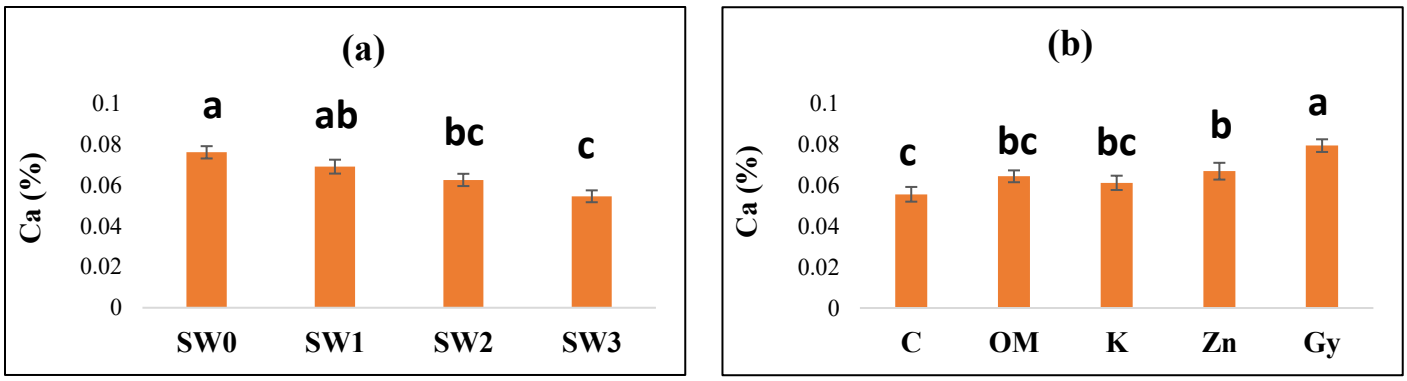


Fig 11. Effects of (a) salinity (n=20) and (b) amendments (n=16) on available calcium in soil.
Notes: Means followed by same letter (s) do not differ significantly

Effect of salinity, fertilizers and amendments on DTPA Zinc

Brackish water irrigation significantly decreased the DTPA-Zn content in soil in all amendment treatments and at all stages of incubation period (Fig. 12). Highest mean Zn content (1.95 mg/kg) was recorded in SW0 and decreased by 6% in SW1,16% in SW2 and 7% in SW3 treatments (Fig. 13a). High concentration of Na^{+} increases soil pH, limiting the availability of Zn and other micronutrients (Neina, 2019). Excessive Na^{+} also causes soil dispersion, which reduces the contact of roots with soil-bound Zn.

On the other hand, applications of Zn, OM and Gy significantly increased the DTPA-Zn by 285%, 23% and 11%, respectively over control. Application of K depresses the Zn availability by reducing the Zn content by 9% over control (Fig. 13b). Zn enhances microbial and enzymatic activities critical for nutrient cycling (Liu *et al*., 2020). Organic matter decomposition releases acids that reduce Zn fixation, improving its availability (Lekasi *et al*., 2003). Gypsum improves Zn availability by replacing Na^{+} on soil surfaces, enhancing drainage and reducing ESP (Singh and Singh, 2014).

Averaged over the salinity and amendment treatments, highest DTPA-Zn content was recorded at 15d (2.56 mg/kg) and thereafter decreased by 9% at 30d, 53% at 45d and 55% at 60d of incubation. The interaction effect of all treatment combinations is significant at 1% level of significance (Table 2).

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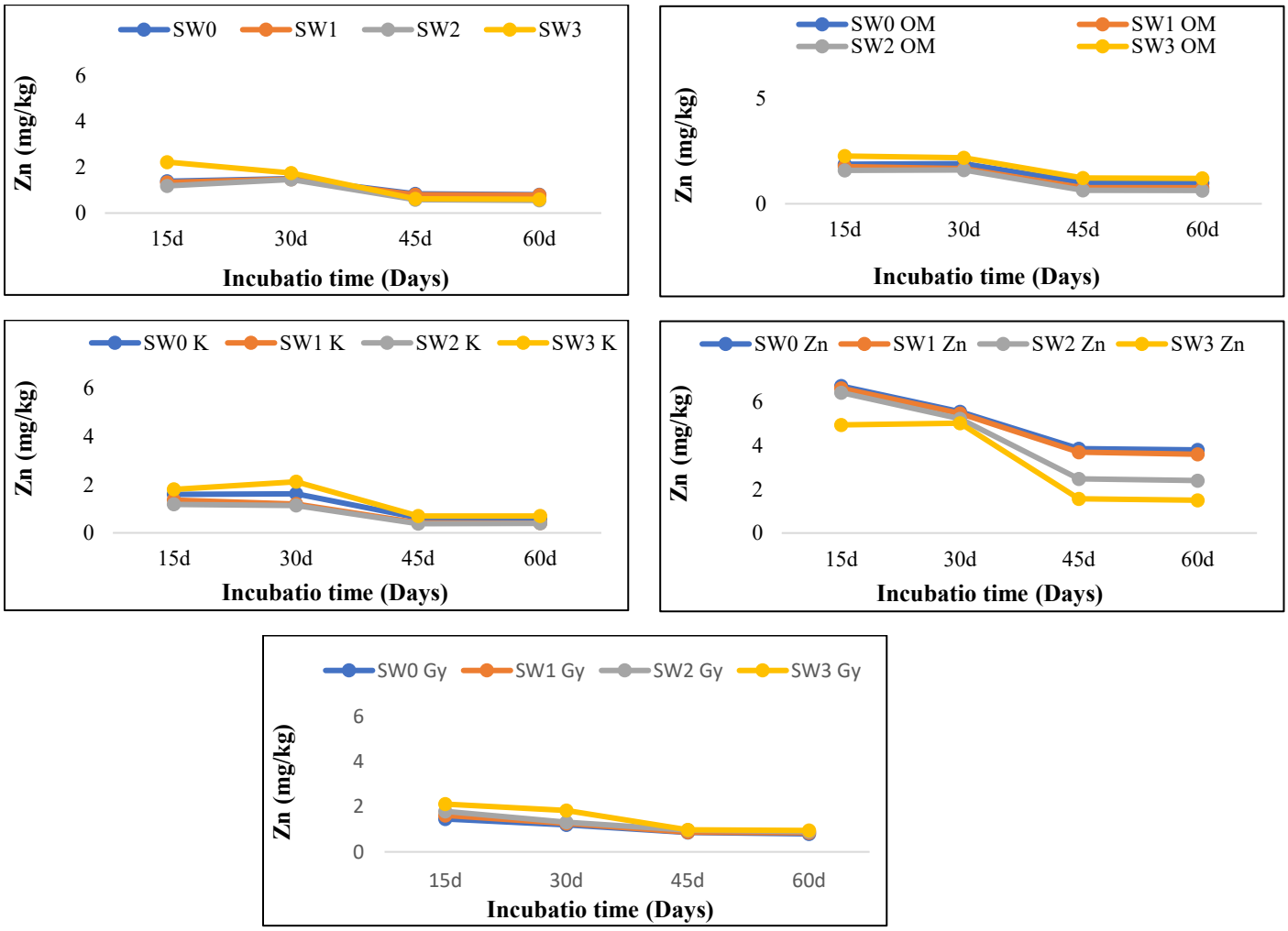


Fig 12. Effects of salinity levels (SW) and amendments on DTPA-Zn during the incubation period

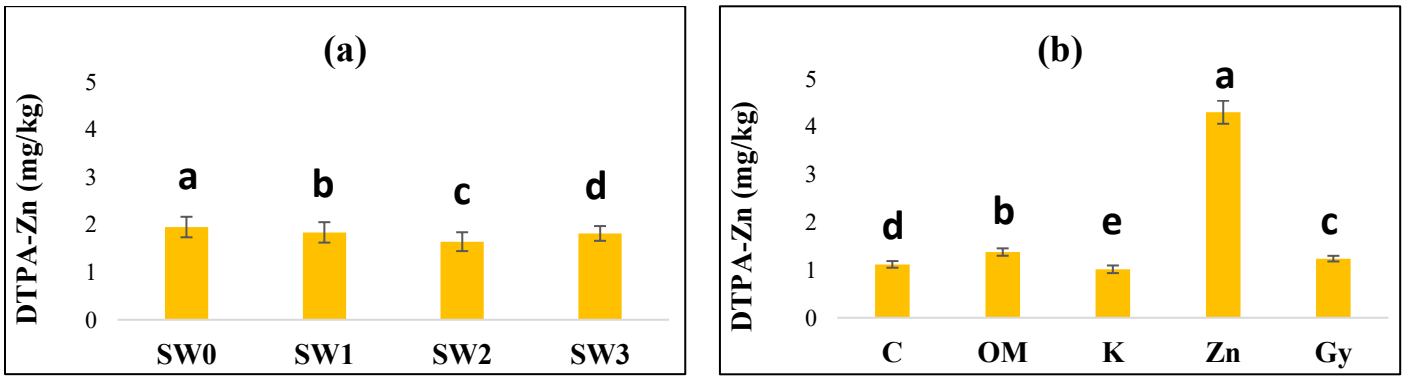


Fig 13. Effects of (a) salinity (n=20) and (b) amendments (n=16) on DTPA-Zn in soil.
Notes: Means followed by same letter (s) do not differ significantly

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Table 2. Interaction effects of treatments on nutrient availability (Anova table)

Sources of variation	Significance							
	pH	ECe (dS/m)	Av.K (mg/kg)	Av.Na (mg/kg)	OC (%)	Ca (%)	Mg (%)	DTPA-Zn (mg/kg)
Salinity (SW)	**	**	**	**	**	**	**	**
Amendments (A)	**	**	**	**	**	**	**	**
Incubation period(D)	**	**	**	**	**	ns	*	**
SW × A	**	**	**	**	**	ns	**	**
SW × D	**	**	**	**	**	ns	ns	**
A × D	**	**	**	**	**	ns	ns	**
SW × A × D	**	**	**	**	**	ns	ns	**

**- ($P < 0.01$), *- ($P < 0.05$); ns- non significant

CONCLUSION

Based on the findings, soil salinity reduced pH and increased electrical conductivity, highlighting its adverse effects on soil chemical properties. Individual amendments effectively alleviated these negative impacts. Organic manure and Zn significantly increased soil organic carbon, enhancing fertility in saline environments. Potassium fertilization notably raised available K, while gypsum substantially improved Ca availability and reduced sodium content, indicating their role in managing salt stress. The positive effects of amendments became more pronounced over the 60-day incubation period, reflecting gradual improvements in nutrients availability over time. Among the treatments, potassium under high salinity (SW3K) was most effective in mitigating salinity stress, whereas organic manure and Zn were particularly beneficial for enhancing organic carbon. These results indicate that careful selection of appropriate amendments can improve soil fertility and nutrient availability under saline stress conditions.

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CONFLICT OF INTEREST

Authors have declared that no competing interests exist either financial or otherwise.

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