Cow Manure Compost Promotes Maize Growth and Ameliorates Soil Quality in Saline-Alkali Soil: Role of Fertilizer Addition Rate and Application Depth

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Abstract: Soil salinization and alkalization is a global problem restricting agricultural production. This study compared different fertilizer regimes (addition rate and application depth) on maize growth and soil quality in saline-alkali soil. Cow manure compost was applied with addition rates of 6, 12, 18 and 24 t·ha⁻¹, and application depths of 5 and 20 cm, along with 0.6 t·ha⁻¹ mineral fertilizer, and compared to a control treatment with only mineral fertilizer application. Results indicated that cow manure compost application could promote maize growth and ameliorate soil quality better than alkalinility, while increasing compost application depth could reduce soil alkalinity. Increasing cow manure compost addition rate improved soil salinity, while increasing compost application depth could reduce soil salinity more effectively than salinity content. Moreover, increasing cow manure compost addition rate improved soil organic matter and soil nutrient content, thus promoting shoot growth and maize yield. However, increasing cow manure compost application depth could promote root growth, and further absorbed more nutrients to promote maize yield. Cow manure compost application increased maize yield by 6.0% to 28.4% with a maximum yield of 8.14 t·ha⁻¹ in a treatment with compost addition rate of 24 t·ha⁻¹ and application depth of 20 cm. Comprehensive evolution of soil quality, maize growth and maize yield, cow manure compost addition rate of 24 t·ha⁻¹ and application depth of 20 cm along with 0.6 t·ha⁻¹ mineral fertilizer application is suggested for use in saline-alkali soil.

Keywords: compost addition rate; compost application depth; maize growth; soil quality; saline-alkali soil

1. Introduction

Soil salinization and alkalization is a global problem restricting agricultural production. Salinized soil accounts for 10% of total arable land with an area of 1 billion ha in the world [1,2], and is increasing at a rate of 1–2% annually [1,3]. The Yellow River Delta, a typical coastal saline-alkali soil area of China, is a regressive area formed by land-sea interactions [4,5]. Unreasonable agricultural activities and saltwater intrusion may magnify soil degradation in this coastal delta, resulting in high soil salinity, nutrient deficiencies, degradation of soil structure, decreased microbial activity and limited land use efficiency [1,6]. Therefore, various countermeasures have been carried out to ameliorate soil quality and thus promote plant growth by either engineering improvement or application of additives [1,7].

Analysis of the literature demonstrates that organic amendment has been an effective practice in agricultural management, particularly in barren soil such as saline-alkali soil [6,8,9]. Organic matter can improve soil structure, increase microbial activity, promote nutrient cycling and enhance crop yield [5,10,11]. Moreover, Li et al. discovered that compost addition achieved maximum vegetable yield with lowest environmental risk of nitrate pollution compared with other organic fertilizers such as biogas residue [12]. However, an excessive amount of fertilizer application may decrease nutrient use efficiency and
increase environmental pollution risk, i.e., greenhouse gas emissions, nitrate leaching and soil degradation [13–15]. Thus, there is an urgent need for optimizing organic amendment application rate to ameliorate saline-alkali soil and promote plant yield.

Much research has been conducted to contrast different fertilizer management practices with respect to soil properties, plant growth and nutrient use efficiency [16–19]. Among these, fertilizer placement depth is a vital factor influencing nutrient uptake efficiency and plant growth [19–22]. Traditional surface broadcasting fertilization leads to massive nutrients loss and environmental pollution [21,23]. Deep fertilizer placement could be an excellent alternative method to alleviate the adverse consequence of nutrient runoff and gas emission [23]. Guo et al. demonstrated that controlled-release urea application depth of 15 cm produced a higher nitrogen use efficiency and maize yield by reducing nitrogen runoff compared with 5 cm and 10 cm fertilization [17]. Chen et al. discovered that ammonia bicarbonate fertilization at 12 cm soil depth yielded greater nitrogen agronomic efficiency, enzyme activities, root growth and rice grain production than other lower fertilization depths [16]. Moreover, the improvement effects of deep fertilizer placement increased under the drought and/or high temperature stresses [18,22]. Hence, suitable fertilizer placement depth may depend on various factors such as soil classification, fertilizer property, plant type and environment conditions.

Recently, deep fertilizer placement has been applied as an effective fertilizer regime in agricultural production, but with limited studies of saline-alkali soil amelioration. Especially, little information is available on the interactive effect of organic amendment and deep fertilizer placement in rehabilitation of saline-alkali soil and promoting crop growth. To address these knowledge gaps, an organic amendment (cow manure compost)-saline-alkali soil-maize system was established, which aimed to (1) evaluate the interactive effect of compost addition rate and application depth on soil quality and maize growth in a saline-alkali soil, and (2) reveal whether compost can be applied to ameliorate soil and promote maize growth, and ascertain the best fertilizer regime (addition rate and application depth) of compost in the saline-alkali soil. Thus, the novelty of this research is the precise study of compost addition rate and application depth on reclamation of saline-alkali soil and promoting crop growth, and further clarification of the relationship among fertilizer regime, soil properties and crop growth parameters. Results obtained from this study provide useful guidance for the application of organic amendments with respect to the promotion of crop growth and reclamation of saline-alkali soil.

2. Materials and Methods

2.1. Site Description

A field experiment was conducted on the saline-alkali soil at Bohai farm of Linjin country, Dongying city, Shandong province, China (37°47'24” N, 108°37'54” E). This region has a typical warm temperate continental monsoon climate zone. The average annual temperature is about 13.5 °C with seasonal variation. The average annual precipitation amount is around 486.5 mm, occurring mainly in the summer from June to August. The soil in this area is derived from alluvial loess materials, mostly of saline flavo-aquic soil and coastal saline soil. The initial properties of the soil were as follows: total nitrogen 1.41 g·kg⁻¹, available phosphate 10.21 mg·kg⁻¹, available potassium 270 mg·kg⁻¹, soil organic matter 13.84 g·kg⁻¹, pH 8.25, and electrical conductivity 1.24 dS·m⁻¹.

2.2. Experimental Design and Crop Management

To assess the ecological and agronomic effect of organic ameliorant, cow manure compost was used as an organic modifier. The properties of the cow manure compost are as follows: organic matter 409.52 g·kg⁻¹, total nitrogen 18.26 g·kg⁻¹, total phosphate 9.21 g·kg⁻¹, total potassium 11.39 g·kg⁻¹. Organic fertilizer addition rate and application depth are both vital factors influencing saline-alkali soil improvement, nutrient uptake efficiency and plant growth. Nine treatments, denoted as CK, L1, L2, L3, L4, H1, H2, H3 and H4, were performed in triplicate in the field experiment to assess the interactive effect
of compost addition rate and application depth on soil quality and maize growth in a saline-alkali soil (Table 1). The CK treatment only applied mineral fertilizer according to the fertilization habits of local farmers. Volfertile controlled release fertilizer with an N-P$_2$O$_5$-K$_2$O content of 28-8-8% was applied as mineral fertilizer.

Table 1. Design of experiment.

<table>
<thead>
<tr>
<th>No.</th>
<th>Treatment</th>
<th>Compost Addition Rate (t·ha$^{-1}$)</th>
<th>Compost Application Depth (cm)</th>
<th>Mineral Fertilizer Addition Rate (t·ha$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CK</td>
<td>-</td>
<td>-</td>
<td>0.6</td>
</tr>
<tr>
<td>2</td>
<td>L1</td>
<td>6</td>
<td>5</td>
<td>0.6</td>
</tr>
<tr>
<td>3</td>
<td>L2</td>
<td>12</td>
<td>5</td>
<td>0.6</td>
</tr>
<tr>
<td>4</td>
<td>L3</td>
<td>18</td>
<td>5</td>
<td>0.6</td>
</tr>
<tr>
<td>5</td>
<td>L4</td>
<td>24</td>
<td>5</td>
<td>0.6</td>
</tr>
<tr>
<td>6</td>
<td>H1</td>
<td>6</td>
<td>20</td>
<td>0.6</td>
</tr>
<tr>
<td>7</td>
<td>H2</td>
<td>12</td>
<td>20</td>
<td>0.6</td>
</tr>
<tr>
<td>8</td>
<td>H3</td>
<td>18</td>
<td>20</td>
<td>0.6</td>
</tr>
<tr>
<td>9</td>
<td>H4</td>
<td>24</td>
<td>20</td>
<td>0.6</td>
</tr>
</tbody>
</table>

The field experiment consisted of 27 plots with a net individual plot area of 3 m $\times$ 5 m, and the plots were a split plot design in a complete randomized block with a 50 cm isolation ridge to eliminate interference. The summer maize cultivar of “Deng-hai 605” was planted on 29 May and harvested on 2 October. The planting density was 60,000 plants·ha$^{-1}$. Other management measures, such as irrigation, weed and insect control, complied with the farmer’s usual practice.

2.3. Analytical Methods

Surface soil (0–20 cm) samples were collected after harvesting of maize using a multipoint sampling method. All the soil samples were air-dried, milled, and passed through a 2-mm sieve for the measurement of pH, salt content, total nitrogen (TN), available phosphorus (AP), available potassium (AK) and soil organic matter (SOM) contents. Soil pH and salt content were measured using an aqueous extraction method with a water:soil ratio of 5:1, and following analysis using a pH meter and gravimetric method, respectively [4,24]. SOM and TN contents were measured with K$_2$Cr$_2$O$_7$ titrimetric and Kjeldahl methods, respectively. AP content was extracted using NaHCO$_3$, and then measured with a molybdenum vanadate colorimetric method [2]. AK was analyzed by flame photometry after extraction with NH$_4$OAc [2].

Ten maize plants were sampled from each plot at harvest for the measurement of maize growth (i.e., plant height, stem diameter, fresh weight of shoot and root) and yield index (ear length, ear diameter, number of kernels per ear and yield). Maize grains were dried at 70 °C to constant weight, then one hundred-grain weight was measured. The maize yield per hectare was calculated based on the one hundred-grain weight, number of kernels per ear and number of ears per hectare.

2.4. Statistical Analysis

The mean value and standard deviation of three replicates were recorded. Analysis of variance (ANOVA) was applied with SAS 8.2 for Windows at $p < 0.05$. Redundancy analysis (RDA) ordination from Canoco 4.5 for Windows was done to elucidate the relationship among fertilizer regime, soil properties, crop growth and maize yield parameters.

3. Results and Discussion

3.1. Effect of Cow Manure Compost on Saline-Alkali Soil Salt Content and pH

Cow manure compost application decreased soil salt content and soil pH in saline-alkali soil (Figure 1). Compost addition rates were significantly negative related with soil salt content ($R = 0.938$, $p = 0.002$). This could be explained by a report that found improve-
3. Results and Discussion

3.1. Effect of Cow Manure Compost on Saline-Alkali Soil Salt Content and pH

Cow manure compost application increased soil organic matter (SOM) content and soil fertility (Figure 2). As organic matter is unstable and easily decomposed in saline-alkali soil, SOM deficiencies occur in most conditions [30]. In this study, the SOM contents were increased by 15–52% with compost rehabilitation compared to the control treatment after harvesting of maize (Figure 2a), and increasing compost addition rates clearly enhanced the SOM content in the surface soil ($p < 0.05$). This may be ascribed to the high organic matter contents of compost [27,31]. Compost contains many functional groups that can combine with soil organic molecules, boost polymerization to form soil aggregates, and eventually help to enhance stable soil organic matter content [11]. Moreover, the SOM contents were significantly enhanced with the increase of cow manure compost application depths ($p < 0.05$), as the deep fertilizer application decreased organic decomposition [16].
The environment of saline-alkaline is adverse to soil microorganism survival, leading to nutrient deficiency [30]. Compost application increased total nitrogen (TN), available phosphorus (AP), and available potassium (AK) content in the surface soil. Notably, increasing compost addition rates significantly elevated the TN, AP, AK contents ($p < 0.05$). This could be explained by findings that compost application enhanced soil physicochemical properties [6] and beneficial microbe activity for decomposing of soil nutrients [8], thus accelerated the decomposition and mineralization process of organic matter. Additionally, compost contains a large number of plant-available nutrients [31]. Similar nutrient increase trends were also discovered by He et al. with the addition of biochar [3], Oo et al. with compost and vermicompost application [31], and Zhang et al. using organic amendment as a soil conditioner in saline-alkaline soil [32]. TN contents in the surface soil changed slightly under different compost application depths with application rates of 6–12 t·ha$^{-1}$ ($p > 0.05$), while they increased obviously under deep compost placement of 20 cm compared with compost placement at 5 cm with application rates of 18–24 t·ha$^{-1}$ ($p < 0.05$). This observation may be attributed to the fact that deep placement can decrease ammonia volatilization [33] and cause the fertilizer to become closely integrated with soil particles [34] to decrease nitrogen losses. Instead, AP content decreased significantly with the increase of compost application depths ($p < 0.05$), which may be ascribed to the fact that deep compost application with more phosphorus absorption promoted plant growth (Figure 3), and improved maize yield (Figure 4), whereas AK contents varied differently with compost application depths under different application rates. The above results indicate that deep compost placement of 20 cm increased SOM and TN contents but decreased AP and AK contents in the saline-alkaline surface soil.
Figure 3. Cow manure compost promotes maize growth of plant height (a), stem diameter (b), fresh weight of shoot (c) and fresh weight of root (d).

Figure 4. Cow manure compost improves maize ear length (a), ear diameter (b), number of kernels per ear (c) and maize yield (d).
3.3. Cow Manure Compost Promotes Maize Growth of Plant Height, Stem Diameter, Fresh Weight of Shoot and Fresh Weight of Root

Cow manure compost application significantly promoted maize growth of plant height, stem diameter, fresh weight of shoot and fresh weight of root (Figure 3, Table 2). In particular, increasing compost addition rate noticeably increased plant height, stem diameter and fresh weight of shoots \((p < 0.01)\), but the increase effect of compost application depth was not statistically significant (Figure 3a–c). However, the fresh weight of roots was clearly positive related to compost application depth \((R = 0.758, p = 0.018)\) but not with compost application rate (Figure 3d, Table 2). The correlation coefficient of fertilizer regime, soil properties and crop growth parameters are presented in Table 2. Plant height, stem diameter and fresh weight of shoots were all significantly positive related to compost addition rate, SOM, TN, AK \((p < 0.01 \text{ or } p < 0.05)\), while they were strongly negative correlated with soil salt content and pH \((p < 0.01 \text{ or } p < 0.05)\), indicating that compost ameliorated high soil salinity and alkalinity as well as an improved soil nutritional environment, thus promoting plant growth. Similar results were also reported in several previous studies. For example, He et al. revealed that biochar application rehabilitated saline-alkali soil for plant growth [3]. Zhang et al. demonstrated that subsurface organic amendment plus plastic mulching was effective in mitigating salinity and promoting sunflower growth [32]. Oo et al. discovered compost and vermicompost could be used to alleviate soil salinity stress and stimulate maize growth [31]. However, fresh weight of roots was clearly positive related to compost addition depth, SOM, TN \((p < 0.05)\), and it was markedly negative correlated with soil pH \((p < 0.01)\). This is in line with Su et al. [18], who reported that deep placement of fertilizer promoted oilseed rape root length and biomass. Deep fertilizer placement can accelerate root growth, and further absorb more nutrients to promote plant growth [16].

<table>
<thead>
<tr>
<th>Table 2. Correlation coefficient of fertilizer regime, soil properties and crop growth parameters.</th>
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<tbody>
<tr>
<td><strong>Compost Addition Rate</strong></td>
</tr>
<tr>
<td>---------------------------</td>
</tr>
<tr>
<td>Plant height</td>
</tr>
<tr>
<td>Stem diameter</td>
</tr>
<tr>
<td>Fresh weight of shoot</td>
</tr>
<tr>
<td>Fresh weight of root</td>
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</table>

\* \(p < 0.05\); \** \(p < 0.01\).

3.4. Cow Manure Compost Improves Maize Yield

Cow manure compost application significantly improved maize yield and its components of ear length, ear diameter and number of kernels per ear (Figure 4, Table 3). Particularly, with increased compost addition, ear length, ear diameter, number of kernels per ear and maize yield clearly increased \((p < 0.01 \text{ or } p < 0.05)\), while increasing compost application depth only significantly increased maize yield \((p < 0.05)\). Cow manure compost application increased maize yield by 6.0% to 28.4% compared with CK and, more importantly, a maximum yield of 8.14 t·ha\(^{-1}\) was achieved in the H4 treatment with cow manure compost addition rate of 24 t·ha\(^{-1}\) and application depth of 20 cm. The correlation coefficient of fertilizer regime, soil properties, crop growth parameters and maize yield are presented in Table 3. Maize yield and its components of ear length, ear diameter and number of kernels per ear were all strongly positive correlated with compost addition rate and compost application depth, soil properties of SOM, TN, AK and crop growth parameters of plant height, stem diameter, and fresh weight of shoot and root \((p < 0.01 \text{ or } p < 0.05)\), while they were significantly negatively related to soil salt content and pH \((p < 0.01 \text{ or } p < 0.05)\), indicating that cow manure compost application ameliorated soil salinity and alkalinity as well as improved soil nutrient contents, thus promoting plant growth and improving maize yield. These results are consistent with previous research. For example, Oo et al. discovered that compost and vermicompost effectively increased...
maize growth and dry matter yield [31], while Zhang et al. demonstrated that organic amendment promoted sunflower yield [32]. The reasons for this yield increase may be due to the following three aspects. First, the cow manure created a highly fertile soil layer that provided more nutrients for maize growth (Figure 2) [8]. Second, cow manure compost increased soil organic matter and the number of beneficial microbes, thus improving soil structure and enhanced plant resistance [6,8]. Lastly, cow manure compost addition regulated the soil salt content and pH, hence alleviating the inhibition of saline-alkali stress on maize growth (Figure 1) [6,11,31]. Moreover, the maize yield increased with increased manure compost application depth, as deep fertilizer placement can boost root growth and plant growth [16,18]. This is in line with Giehl et al. [35] and Zhang et al. [32], who showed that 10 to 30 cm depth represents an optimal nutrient placement depth for plant root growth.

Table 3. Correlation coefficient of fertilizer regime, soil properties, crop growth and maize yield parameters.

<table>
<thead>
<tr>
<th>Compost Application Rate</th>
<th>Compost Application Depth</th>
<th>Salt Content</th>
<th>pH</th>
<th>Soil Organic Matter</th>
<th>Total Nitrogen</th>
<th>Available Phosphorus</th>
<th>Available Potassium</th>
<th>Plant Height</th>
<th>Stem Diameter</th>
<th>Fresh Weight of Shoot</th>
<th>Fresh Weight of Root</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ear length</td>
<td>0.792 *</td>
<td>−0.801 **</td>
<td>−0.775 *</td>
<td>0.828 **</td>
<td>0.788 *</td>
<td>0.507</td>
<td>0.832 **</td>
<td>0.777 *</td>
<td>0.759 *</td>
<td>0.876 **</td>
<td>0.728 *</td>
</tr>
<tr>
<td>Ear diameter</td>
<td>0.918 **</td>
<td>−0.815 **</td>
<td>−0.917 **</td>
<td>0.933 **</td>
<td>0.861 **</td>
<td>0.748 *</td>
<td>0.940 **</td>
<td>0.959 **</td>
<td>0.686 *</td>
<td>0.803 **</td>
<td>0.686 *</td>
</tr>
<tr>
<td>Number of kernels per ear</td>
<td>0.980 **</td>
<td>−0.916 **</td>
<td>−0.947 **</td>
<td>0.946 **</td>
<td>0.950 **</td>
<td>0.791 *</td>
<td>0.950 **</td>
<td>0.976 **</td>
<td>0.804 **</td>
<td>0.901 **</td>
<td>0.737 *</td>
</tr>
<tr>
<td>Maize yield</td>
<td>0.935 **</td>
<td>−0.913 **</td>
<td>−0.932 **</td>
<td>0.919 **</td>
<td>0.939 **</td>
<td>0.653</td>
<td>0.905 **</td>
<td>0.926 **</td>
<td>0.864 **</td>
<td>0.978 **</td>
<td>0.834 **</td>
</tr>
</tbody>
</table>

*p < 0.05; **p < 0.01.

3.5. Redundancy Analysis of Relationships among Fertilizer Regime, Soil Properties, Maize Growth and Maize Yield Parameters in Saline-Alkali Soil

Redundancy analysis was performed to discern relationships among fertilizer regime, soil properties, maize growth and maize yield parameters in saline-alkali soil (Figure 5). Maize yield was affected by the fertilizer regime and soil physicochemical parameters. Cow manure compost application had an obviously positive correlation with SOM, soil nutrients of TN, AP and AK contents in the surface soil, maize growth of plant height, stem diameter, fresh weight of shoot and fresh weight of root and also maize yield and its components of ear length, ear diameter and number of kernels per ear, while it was negative correlated with soil salt content and pH. Soil salinity and alkalinity of saline-alkali soil led to nutrient deficiency, which greatly reduced plant growth [11]. Cow manure compost application can alleviate soil salinity and pH. Especially, increasing fertilizer addition rate alleviated soil salinity better than alkalinity, while increasing compost application depth can reduce soil alkalinity better than soil salt content. Moreover, increasing cow manure compost addition rate improved SOM and soil nutrient content, thus promoting plant growth and improving maize yield. These results are similar to findings by Oo et al. with compost and vermicompost application [31], to the results of Zhao et al. with biochar addition [11]. However, compost application depth stimulated maize growth and evaluated yield by enhancing nutrient uptake with increasing fresh weight of roots, in line with results from Chen et al. [16]. In addition, cow manure compost application directly affected microbial community structure, nutrient transformation and plant uptake [2,3,8]. Thus, further study is required to investigate the effect of cow manure compost application on the microbial community structure in saline-alkali soil.
Figure 5. Redundancy analysis of relationships among fertilizer regime (cow manure compost addition rate and application depth), soil properties, maize growth and maize yield parameters in saline-alkali soil. Addition rate: cow manure compost addition rate; Application depth: cow manure compost application depth; SC: soil salt content; pH: soil pH; SOM: soil organic matter; TN: total nitrogen; AP: available phosphorus; AK: available potassium; Height: plant height; SD: stem diameter; FWS: fresh weight of shoot; FWR: fresh weight of root; EL: ear length; ED: ear diameter; NK: number of kernels per ear; Yield: maize yield.

4. Conclusions

Results reported here indicate that cow manure compost application can promote maize growth and ameliorate soil quality in saline-alkali soil. Increasing cow manure compost addition rate alleviated soil salinity better than alkalinity, while increasing compost application depth reduced soil alkalinity more effectively than soil salt content. Moreover, increasing cow manure compost addition rate improved soil organic matter and soil nutrients contents, thus promoting shoot growth and maize yield. However, increasing cow manure compost application depth can boost root growth, resulting in increased nutrient absorption to promote maize yield. Cow manure compost application increased maize yield by 6.0% to 28.4% and, more importantly, the maximum yield of 8.14 t·ha\(^{-1}\) was achieved with cow manure compost addition rate of 24 t·ha\(^{-1}\) and application depth of 20 cm.

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Data Availability Statement: The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest: The authors declare no conflict of interest.
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