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Responses of soil organic and inorganic carbon to organic and phosphorus fertilization in a saline – alkaline paddy field

Xiujun Wang[1*†], Haonan Zheng[1†], Lipeng Wu[1], Xiaodong Ding[2] and Tongping Lu[1]

Abstract

There is evidence of increased soil organic carbon (SOC) and inorganic carbon (SIC) under fertilization in dry croplands of arid and semi-arid areas. However, not much is known about the responses of SOC and SIC in coastal saline – alkaline paddy soils that undergo flooding – draining cycles. Here, we assess the impacts of various combinations of organic and phosphorus fertilization on SOC and SIC and other soil properties in a saline – alkaline paddy field of the Yellow River Delta. Our study showed that organic fertilization resulted in an increase of SOC by 11.9% over 0 – 20 cm and 13.3% over 20 – 100 cm (i.e., 140 – 250 g C $m^{-2}y^{-1}$ over 0 – 100 cm) whereas phosphorus fertilization only led to a significant increase of SOC in subsoils (or ~ 75 g C $m^{-2}y^{-1}$ over 0 – 100 cm). There were little differences in SIC over 0 – 20 cm among the treatments; but SIC showed a significant decrease over 20 – 100 cm under organic fertilization combined with lower rate of phosphorus fertilization. However, high rate of phosphorus fertilization combined with organic amendment led to an increase in SIC stock, but a decrease in SOC stock in the subsoil. There was a significant negative relationship between SIC and SOC stocks in this paddy soil. This study demonstrated that fertilization practices could have complex influences on SOC and SIC in saline – alkaline paddy fields due to the flooding – draining cycles that lead to changes in soil conditions.

Keywords Organic amendment, Phosphorus fertilization, Soil organic carbon, Soil inorganic carbon, Saline – alkaline soil, Paddy field

Introduction

Saline – alkaline soils often have low fertility due to their poor physicochemical conditions (Wong et al. 2010). Although the purpose of ameliorating saline – alkaline soils is to reduce soil pH and/or salinity, and to increase crop production, the practice can have influences on soil carbon storage (Amini et al. 2016; Wang et al. 2014b). However, our understanding is uncompleted in terms of the response of soil carbon to amelioration practices in agricultural ecosystems.

A large number of studies have demonstrated that organic amendment is an effective means for amelioration of saline – alkaline soils (Amini et al. 2016; Tejada et al. 2006; Yang et al. 2018). In particular, applying organic materials can improve soil physical and chemical conditions, e.g., decreasing exchangeable Na^{+}, soil pH, and/or other salt contents (Oo et al. 2015; Tejada et al. 2006), and/or increasing exchangeable Ca^{2+}, cation exchange capacity (CEC), soil microbial activities, aggregate stability, and permeability (Tejada et al. 2006; Yang et al. 2018). On the other hand, organic amendments, as a means to increase soil fertility, can also lead to higher

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levels of both soil organic carbon (SOC) and nutrients (Mi et al. 2018).

The majority of the land in the Yellow River Delta (YRD) is characterized as some degree of saline – alkalization due to the shallow water table and high levels of salts in the groundwater (Kong et al. 2015). High-salinity lands are often used for growing rice in the YRD, and one of the effective amelioration practices is periodical salt-leaching. Although salt-leaching in paddy fields can reduce soil salinity, leaching can also remove nutrients and organic materials from soil profile (Chi et al. 2012; Xiao and Meng 2020), which may lead to soil degradation thus low crop production. Thus, organic and chemical fertilizers are often applied in saline – alkaline soils, which could result in an increase of SOC due to enhanced crop growth and subsequent more inputs of crop residue. There is evidence that phosphate anion (from fertilizer) could be absorbed on soil minerals, which reduces the holding capacity for organic matter (Mahmood and Ali 2015), thus causes less protection of SOM and subsequent losses of SOC through desorption/leaching (Amini et al. 2016). Indeed, an earlier study reports that phosphorus application in wetland can increase the fraction of dissolved organic carbon in total organic carbon (Liu et al. 2014).

On the other hand, phosphorous fertilization also has influences on soil inorganic carbon (SIC). For example, Wang et al. (2014b) reported that long-term phosphorous fertilization enhanced SIC accumulation in dry cropland, which was partly due to extra Ca^{2+} from fertilizer. Limited studies showed that organic amendment led to an increase in both SOC and SIC stocks in the dry cropland of North China (Bughio et al. 2016; Wang et al. 2015, 2014b), and there was a positive relationship between SOC and SIC stocks in most cropland of arid and semi-arid regions (Guo et al. 2016; Shi et al. 2017; Wang et al. 2015). Here, we test the hypothesis that similar phenomena (i.e., a positive SIC – SOC relationship, and enhancement of SOC and SIC under fertilization) exist in saline – alkaline paddy soils of semi-humid regions of north China. Our study is based on the 4-year field experiment established in a saline – alkaline paddy field of the YRD, which consists of eight different combinations of chemical and organic fertilization. We analyze the vertical distributions of main salts, SOC and SIC over 0 – 100 cm. The objective of this study is to evaluate the impacts of organic amendment and phosphorus fertilization on the dynamics of SOC and SIC, and to examine the relationship between SOC and SIC in the saline – alkaline paddy of YRD.

Materials and method

Description of the experimental site

Our study area is located at the lower YRD (37°31′18″N, 188°33′31″E), which is characterized by a temperate monsoon climate zone. Average temperature is – 2.9 °C in January and 26.8 °C in July. Annual mean rainfall is approximately 600 mm, in which more than 70% falls during June – September. The groundwater table is generally 1 – 2 m below the surface. The experimental site was covered by native vegetation dominated by reed (*Phragmites australis*) prior to experiment. The soil was developed on alluvial loess and classified as Salic Fluvisols (FAO 1988), and contains 62% silt, 21% sand and 17% clay. Initial soil properties were determined for the 0 – 20 cm layer in 2014, which showed high salinity (0.29%) and pH (8.1). Soil organic matter, total nitrogen (TN), total phosphorus (TP), and available phosphorus (AP) were 8.4 g kg^{-1}, 0.59 g kg^{-1}, 0.34 g kg^{-1}, and 17.0 mg kg^{-1}, respectively.

Field experiment

The paddy field experiment was established in April 2014, which consisted of eight treatments (Table 1) with three replicates. In brief, there were two levels of fertilization

Table 1 Application rates of organic and chemical fertilizers for different treatments

Treatment	Organic fertilizer (kg ha^{-1})	Phosphorus fertilizer (kg ha^{-1})	Nitrogen fertilizer (kg ha^{-1})	Potassium fertilizer (kg ha^{-1})
CK	0	0	0	0
C_0P_0	0	0	255	229
C_0P_1	0	64	255	229
C_0P_2	0	128	255	229
C_1P_1	1000	64	255	229
C_1P_2	1000	128	255	229
C_2P_1	2000	64	255	229
C_2P_2	2000	128	255	229

* Organic fertilizer contains 45% C, 2.4% N, 1.6% P and 1.4% K. Phosphorus, nitrogen and potassium fertilizers are superphosphate, urea and potassium sulphate, respectively

for phosphorous (superphosphate, 64 and 128 kg ha^{-1}) and commercial organic fertilizer (containing 26.1% C, 2.4% N, 1.6% P and 1.4% K, 1000 and 2000 kg ha^{-1}), which were applied as base fertilizers. Urea application (255 kg ha^{-1}) was split as follows: 40% as the base fertilizer before seedling, 20% at tillering, 20% at panicle and 20% at granule stages. Potassium sulfate (229 kg hm^{-2}) was applied as the base fertilizer (50%) and at panicle stage (50%). Zinc fertilizer was applied (7.5 kg ha^{-1}) at tillering stage. The treatments were arranged randomly for each replicate, and there was a buffer zone (~ 30 cm in width) between plots. Each plot had a size of 3 m by 5 m, which was surrounded by PVC clapboard. The field was flooded in late May, and drained in mid-July, followed by one-week sunning/drying and then flooding. Rice was planted in mid-June and harvested in mid-October.

Soil sampling and analyses

Soil sampling was conducted in October 6 − 8, 2017, when the surface was almost dry. In each plot/treatment, we selected 4 − 5 spots randomly along a 'S-shape' line. We used a soil auger (38 mm in diameter) to collect soil samples from 0 − 20, 20 − 40, 40 − 60, 60 − 80 and 80 − 100 cm, and combined the subsamples into one for each layer. Soils were then air-dried, thoroughly mixed, and sieved through a 2 mm mesh for the measurements of soil pH, electric conductivity (EC), water soluble cations and AP.

Soil pH and EC in a soil − water (1:2.5) mixture were measured by a pH Meter and Conductivity Meter. We measured water soluble Ca^{2+}, Mg^{2+}, K^+ and Na^+ in a soil − water (1:5) mixture using an Atomic Absorption Spectrophotometer. AP was determined using the Olsen-P method, which was based on the extraction of phosphate from soil using 0.5 M $NaHCO_3$. Air-dried soil subsamples were crushed and passed through a 0.25-mm sieve for analyses of total soil carbon (TC), TN, TP and SOC. TC and TN were measured using an Elemental Analyzer (Euro EA). TP was determined after oxidative digestion with $H_2SO_4 - HClO_4$ (~ 15:1 vol:vol) followed using the colorimetric method with ascorbic acid. SOC was determined using the $K_2Cr_2O_7 - H_2SO_4$ oxidation method (Walkley and Black 1934). Content of SIC was calculated by subtracting SOC from TC.

Data calculation and statistical analysis

Sodium adsorption ratio (SAR) was calculated as follows:

$$SAR = \frac{[Na^+]}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}} \quad (1)$$

where $[Na^+]$, $[Ca^{2+}]$, and $[Mg^{2+}]$ were the contents of water soluble Na^+, Ca^{2+}, and Mg^{2+}, respectively.

The analysis of variance (ANOVA) was applied to assess the effects of treatment, depth and/or their interactions on soil properties. Multiple comparisons were conducted using the least significant difference (LSD) to determine the significance of differences in soil properties among layers or treatments. Linear regression was applied to examine the relationship between SIC stock and SOC stock over the 0 − 20 cm and 0 − 100 cm layers. All statistical analyses were conducted using SPSS 19.0, and all graphs were generated using SigmaPlot 12.5.

Results

Variations of soil pH, EC, and cations under different treatments

Soil pH showed a clear increase from 0–20cm (8.34–8.75) to 20–40cm (8.75–9.05), followed by little change below 40 cm (Fig. 1a). Overall, there was an increasing trend in EC below 20 cm (Fig. 1b). Both water soluble Ca^{2+} and Mg^{2+} showed a clear decrease from 0–20cm (80.1 and 29.3mg kg^{-1}, respectively) to 20–40cm (62.4 and 24.4 mg kg^{-1}, respectively), followed by little changes except under the C_2P_1 and C_2P_2 treatments (Fig. 1c, d). There was a homogeneous distribution over depth in water soluble K^+ (~10mg kg^{-1}) except under the C_2P_1 and C_2P_2 treatments (Fig. 1e). Water soluble Na^+ and SAR displayed a gradual increase from 0-20cm (140.1mg kg^{-1} and 2.1, respectively) to 80–100cm (226.6mg kg^{-1} and 3.7, respectively) (Fig. 1f, g).

Statistical analyses indicated that there were significant differences between layers in most parameters except Mg^{2+} and K^+ (Table 2). Although fertilization treatments showed no significant influences on soil pH, phosphorus fertilization alone (C_0P_1 and C_0P_2) resulted in the lowest pH in the 0-20cm (Fig. 1a). Clearly, fertilization treatment had a significant effect on EC, and water soluble cations (Table 2). High rates of organic amendment (C_2P_1 and C_2P_2) led to higher levels of water soluble cations, particularly Ca^{2+}, Mg^{2+}, and K^+ in the subsoils (Fig. 1c–e; Table 3). Most treatments (except C_1P_1) resulted in an increase in water soluble Na^+ and SAR.

Variations of soil nutrients under different treatments

There was a decreasing trend in TP and AP over depth particularly under organic amendments (Fig. 2). High rate of phosphorus application alone (C_0P_2) led to a significant increase in TP and AP in soil profile (Fig. 2a, b). Organic fertilization resulted in higher levels of TP (0.90–1.06g kg^{-1}) and AP (18.78-22.57mg kg^{-1}) particularly in topsoil (Fig. 2c, d), which was due to extra inputs of phosphorus in the organic fertilizer.

Soil C:N ratio showed a wide range (6.2−12.0) with no clear vertical variation (Fig. 3a and c). Phosphorus fertilization (C_0P_1 and C_0P_2) led to a decrease in C:N

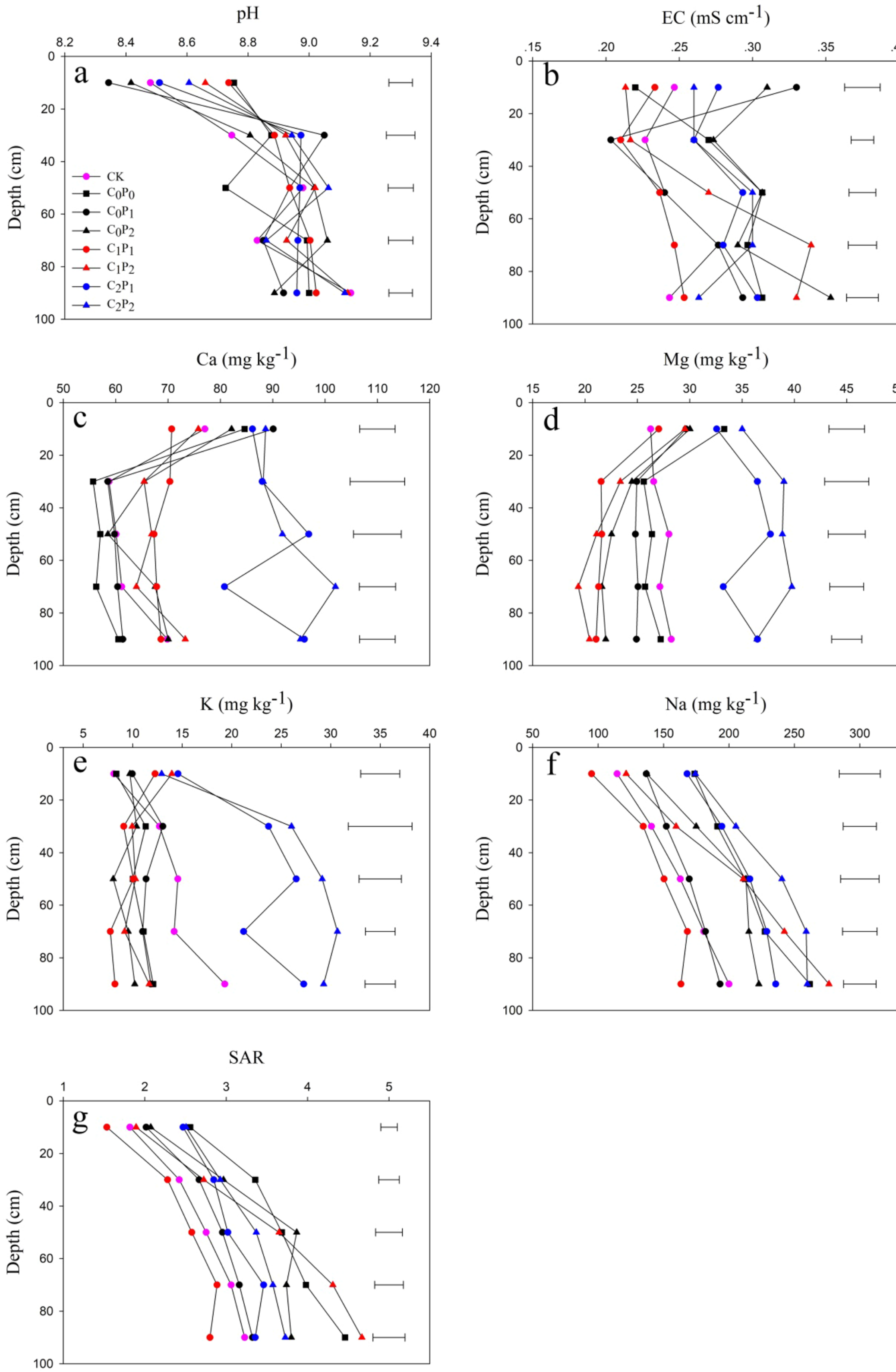

Fig. 1 Vertical distributions of soil pH (**a**), EC (**b**), water-soluable cations (**c-f**) and SAR (**g**) under different treatments

Table 2 P values from two-ways ANOVA for soil pH, EC, water soluble cations, SOC and SIC

Factors	n	pH	EC	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	SOC	SIC
Treatment	8	> 0.05	< 0.01	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.05
Depth	5	< 0.001	< 0.01	< 0.01	> 0.05	> 0.05	< 0.001	< 0.001	< 0.05
Treatment × depth	40	> 0.05	> 0.05	> 0.05	> 0.05	> 0.05	> 0.05	< 0.05	> 0.05

ratio (Fig. 3a). Compared with low rates of organic fertilization, high rates of organic fertilization (C_2P_1 and C_2P_2) resulted in a decrease (by 1.2) in C:N ratio (Fig. 3c). Figure 3b and d showed a sharp decline in TN from topsoil (0.48−0.65g kg^{-1}) to subsoil (0.13–0.34g kg^{-1}). There was a small increase of TN in the 0−20cm (<15%) under phosphorus and organic fertilization, but a considerable increase of TN over 20−80cm (>30%) under phosphorus fertilization and high rate of organic fertilization. Overall, higher C:N ratios were associated with lower TN values, e.g., CK and CP treatments showing the lowest TN and highest C:N ratio.

Variations of SOC and SIC under different treatments

SOC content revealed a sharp decline from 0–20 cm (4.35–5.85 g C kg^{-1}) to 20–40 cm (1.61–2.81 g C kg^{-1}) and little change over 40–100 cm (Fig. 4a and c). SIC content showed a small decrease from 0–20 cm (11.2–12.2 g C kg^{-1}) to 20–40 cm (10.9–11.2 g C kg^{-1}), and then an increase over 40–100 cm under no organic amendments (Fig. 4b). However, with organic fertilization, SIC content displayed a little vertical variation, with a range of 10.7 − 11.8 g C kg^{-1} (Fig. 4d). Statistical analyses indicated that there were significant differences between layers in SOC and SIC (Table 2).

SOC and SIC stocks were significantly influenced by organic and/or phosphorus fertilization (Table 2). There was a significant increase of SOC under higher rate of organic fertilization (C_2P_1 and C_2P_2) in the topsoil, but under all fertilization treatments in the subsoil (Table 3). Although phosphorus fertilization caused an increase of SOC stock (by > 0.28 kg C m^{-2} or 17%) over 20–100 cm, SOC stock was 13% lower under higher rate of phosphorus fertilization than under lower fertilization rate. Fertilization had nonsignificant effects on SIC in the 0 − 20 cm layer, but there was a significant reduction in SIC over 20 − 100 cm under lower rates of phosphorus fertilization combined with organic fertilization. Our analyses demonstrated that SIC stock was significantly negatively correlated with SOC stock in both 0 − 20 cm ($P < 0.01$) and 0 − 100 cm ($P < 0.001$) layers (Fig. 5).

Discussion

Effects of organic amendment on soil pH/salinity

Generally, soil amelioration would lead to improvements in soil physical and chemical conditions (Tejada et al. 2006). There is evidence that organic amendment can effectively reduce soil pH and EC in saline − alkaline soils, e.g., in paddy field of Songnen Plain, Northeast China (Chi et al. 2012), and in uncultivated soil of Subei Coast, Southeast China (Yang et al. 2018), which is caused by a reduction of salts especially Na^{+} and/or formation of inorganic/organic acids produced by the organic materials. However, our study showed no decrease in soil pH and EC under organic fertilization in the paddy field of the YRD (Fig. 1), there were even some degrees of increase in soil pH and EC in the topsoil under high rates of organic amendments, which was probably due to the supply of basic cations from the organic fertilizer (Wang et al. 2014a). In addition, the lack of decreases in soil pH and/or EC in the YRD's paddy might reflect the strong influences of hydrological processes such as the movement of underground waters that contained a large amount of salts (Fan et al. 2012), which could lead to desorption and removal of SOC (Mavi et al. 2012; McDonald et al. 2017) and thus make amelioration less effective.

Our data showed that water soluble Ca^{2+} and Mg^{2+} were significantly higher in subsoil under high rates of organic fertilization than under other treatments (Table 3, Fig. 1). Other studies also reported an increase of water soluble Ca^{2+} and Mg^{2+} under organic amendments such as with poultry manure and waste compost (Walker and Bernal 2008). Although organic amendment could provide some Ca^{2+} and Mg^{2+} (Yang et al. 2018), there was no clear increase in these water soluble cations under lower rate of organic fertilization, implying that other processes were responsible for the increases of water soluble Ca^{2+} and Mg^{2+} (under high rates of organic fertilization). On the one hand, high rates of organic fertilization could cause more CO_2 production in the topsoil, which would lead to dissolution of SIC (Wang et al. 2014a) and release of Ca^{2+}/Mg^{2+}, which resulted in more Ca^{2+}/Mg^{2+} in subsoils due to downward water movement. On the other hand, high rates of organic fertilization would be more effective in improving soil physical and chemical conditions (e.g., CEC) and stability of soil

Table 3 Stocks of water soluble cations, SOC and SIC over 0–20 cm and 20–100 cm under different treatments

Treatment	Ca^{2+} (g m^{-2})		Mg^{2+} (g m^{-2})		K^{+} (g m^{-2})		Na^{+} (g m^{-2})		SOC (kg Cm^{-2})		SIC (kg Cm^{-2})	
	0–20 cm	20–100 cm	0–20 cm	20–100 cm	0–20 cm	20–100 cm	0–20 cm	20–100 cm	0–20 cm	20–100 cm	0–20 cm	20–100 cm
C_0P_0	20.3 ab	62.0 c	7.99 ab	28.4 b	2.00 def	12.0 bc	41.7 a	242.3 ab	1.20 bc	1.62 cd	2.65 a	12.51 a
C_0P_1	21.6 a	64.9 c	7.11 bc	26.9 b	2.39 bcd	12.7 bc	32.8 ab	189.1 ab	1.19 bc	1.90 bc	2.85 a	12.26 a
C_0P_2	19.7 abc	70.6 c	7.20 abc	24.4 b	2.33 cde	10.3 bc	32.9 ab	224.3 ab	1.16 cd	1.91 bc	2.72 a	12.16 ab
C_1P_1	17.0 cd	73.9 bc	6.49 cd	23.1 b	2.94 abc	9.5 cd	22.8 b	167.2 b	1.22 bc	2.33 a	2.74 a	11.75 b
C_1P_2	18.2 bc	72.8 bc	7.09 bc	22.7 b	3.35 a	11.1 bc	29.1 ab	242.6 ab	1.29 abc	2.01 ab	2.75 a	12.12 ab
C_2P_1	20.7 ab	97.8 ab	7.82 ab	38.8 a	3.50 a	26.7 ab	40.3 a	237.3 ab	1.40 a	2.30 a	2.62 a	11.76 b
C_2P_2	21.3 ab	102.1 a	8.40 a	41.6 a	3.10 ab	31.2 a	41.8 a	261.9 a	1.35 ab	1.99 bc	2.74 a	12.22 a

Values followed by the same letter are not significantly different at $P < 0.05$ based on LSD test

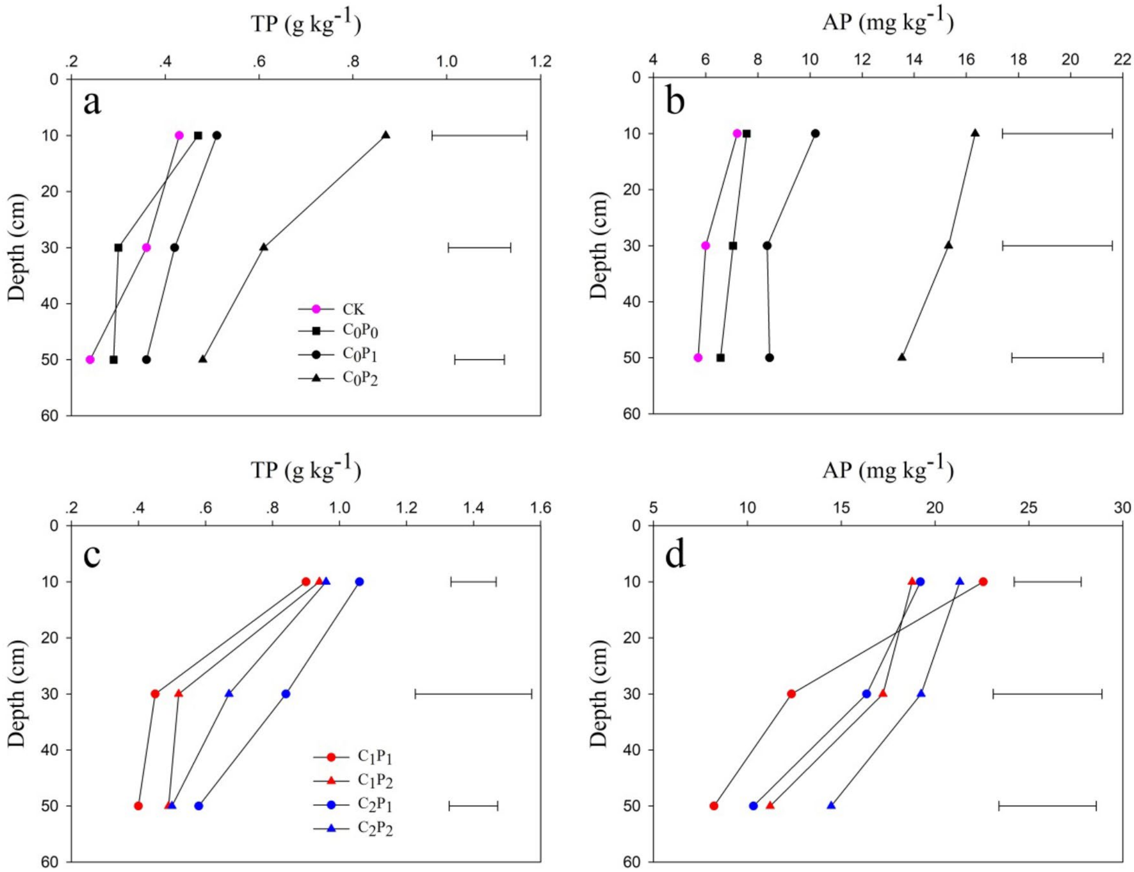

Fig. 2 Vertical distributions of TP (**a** and **c**) and AP (**b** and **d**) under different treatments

aggregates (Oo et al. 2015), which could lead to more absorption of exchangeable cations (Zhang et al. 2015); thus, less removal of Ca^{2+}/Mg^{2+} in saline – alkaline paddy field.

Influences of organic amendment and phosphorus fertilization on SOC

A large number of studies have demonstrated that organic amendment can increase SOC levels in dry cropland (Kou et al. 2012; Zhang et al. 2010) and paddy field (Pan et al. 2004). SOC content in the topsoil of this study (4.2–6.2 g C kg^{-1}) was slightly higher than those (3.17–4.82 g C kg^{-1}) in saline-alkaline paddy soil of the northeast China (Wang et al. 2017). Although SOC content over 0–20 cm was slightly higher than the initial value of 4.9 g C kg^{-1} after 3.5 years of organic amendment, organic fertilization led to a significant accumulation of SOC (140–250 g C m^{-2} y^{-1}) over 0–100 cm. The main reason for the low levels of surface SOC in saline – alkaline paddy soils was associated with the procedure of salt-leaching and drainage, which could result in enhanced desorption and removal of dissolved organic carbon (DOC) (Mavi et al. 2012) and subsequent reduction of SOC in topsoil.

In general, chemical fertilization could also lead to an increase in SOC in cropland because of enhanced crop growth thus more inputs of crop residues (Brar et al. 2013). There was evidence that phosphorus fertilization led to an increase in SOC content in the topsoil of paddy field in yellow–brown soil of south China (Zhang et al. 2018). Although our study showed that phosphorus fertilization alone did not result in a significant increase in SOC in topsoil, a significant increase of SOC occurred in subsoil (Table 3), which led to an accumulation of ~ 75 g C m^{-2} y^{-1} over 0–100 cm (relative to nonfertilization). Interestingly, our study showed that the combination of high rates of phosphorus with organic fertilization resulted in a small reduction of SOC in the subsoil (Table 3), which was probably attributed to improvement of soil physical and chemical conditions (including soil texture, pH/salinity and nutrient availability) that could stimulate microbial activities (Liu et al. 2014). There was evidence that high rate of phosphorus fertilization increased the abundance of

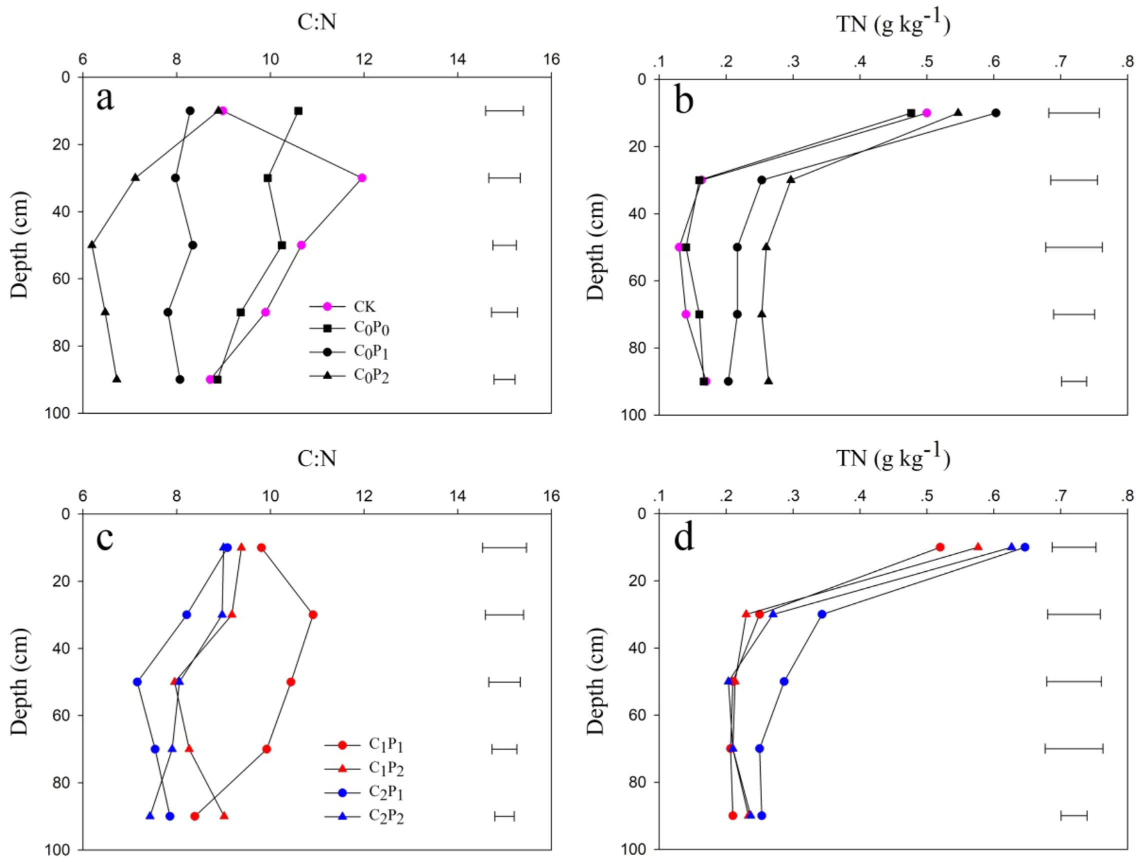

Fig. 3 Vertical distributions of C:N (**a** and **c**) and TN (**b** and **d**) under different treatments

the carbon-degrading bacteria, such as *Rhodocyclates*, *Xanthomonadales*, and *Myxococales* (Li et al. 2014). As a result, enhanced microbial activity would lead to an increase in decomposition of SOM in paddy soils.

Influences of organic amendment on SIC and the SIC – SOC relationship

Previous studies demonstrated that organic amendment led to enhanced SIC stock in dry cropland, and higher application rates resulted in a greater increase in SIC, particularly in the subsoil (Bughio et al. 2016; Wang et al. 2014b). However, this study showed no increase in SIC under organic amendments in the saline – alkaline paddy of YRD; moreover, application of organic fertilizer led to a decrease of SIC stock in the subsoil (Table 3). Previous studies reported negative SIC – SOC relationships, including in paddy soil of the Northeast China (Tang et al. 2016) and under other land uses (such as shrub, grassland, and forest) in the Loess Plateau of China (Han et al. 2018; Zhao et al. 2016). Similarly, our study also showed a significant negative relationship between SIC and SOC stocks (Fig. 5). However, there were other studies showing positive SIC – SOC relationships in 0–100 cm layer of north China, e.g., in the dry cropland of the North China Plain (Guo et al. 2016; Shi et al. 2017) and under various land uses in salt-affected dryland of the Yanqi Basin, northwest China (Wang et al. 2015).

The inconsistent relationships may be attributed to the differences in soil and environmental conditions that regulate the precipitation and dissolution of SIC, which are mainly associated with the following reactions:

$$CO_2 + H_2O \leftrightarrow HCO_3^- + H^+ \qquad (2)$$

$$Ca^{2+} + 2HCO_3^- \leftrightarrow CaCO_3 + CO_2 + H_2O \qquad (3)$$

In general, organic fertilization can enhance crop growth, in addition to the supply of organic materials, which lead to an increase in both autotrophic and heterotrophic respirations (Chang et al. 2012; Han et al. 2018) thus an increase in CO_2 production. For dryland, increased CO_2 in soil profile (under organic amendments) would promote the creation of HCO_3^- and subsequently the precipitation of SIC (Wang et al. 2015). However, in saline – alkaline paddy field, salt-washing could transport and remove the newly formed HCO_3^-,

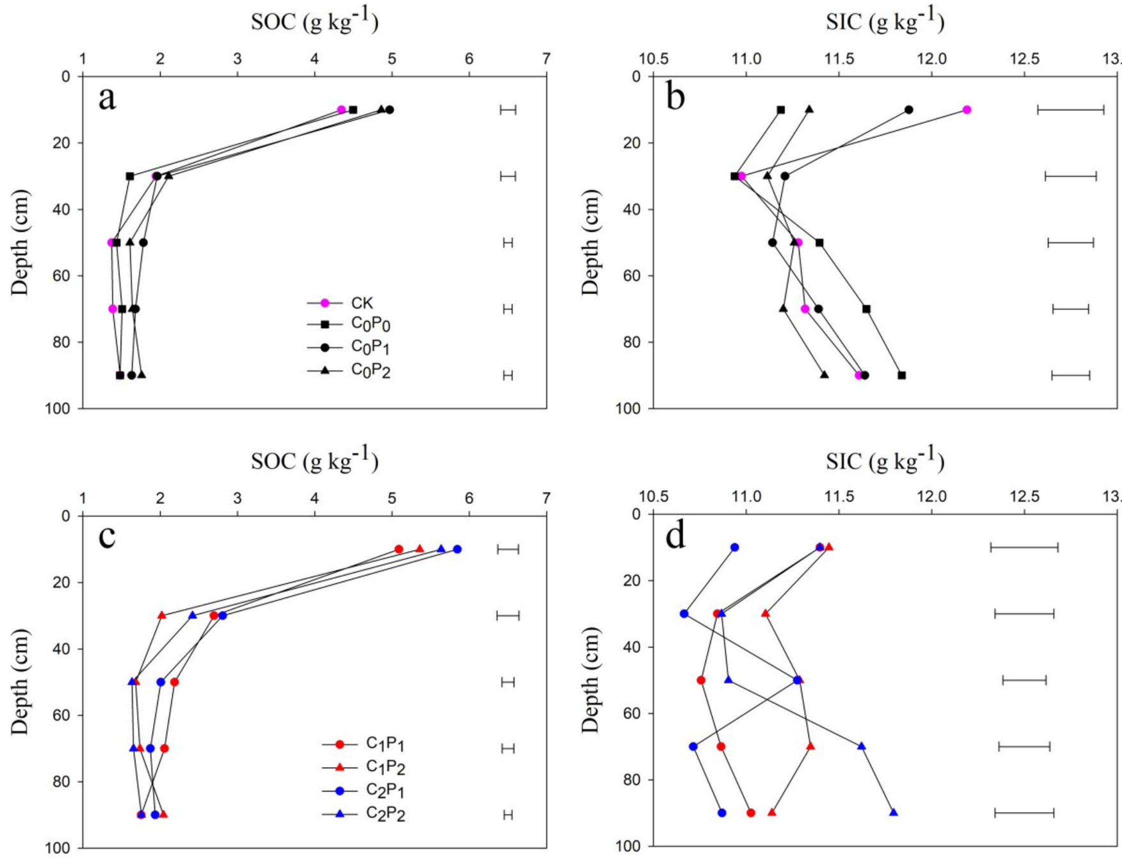

Fig. 4 Vertical distributions of SOC (**a** and **c**) and SIC (**b** and **d**) under different treatments

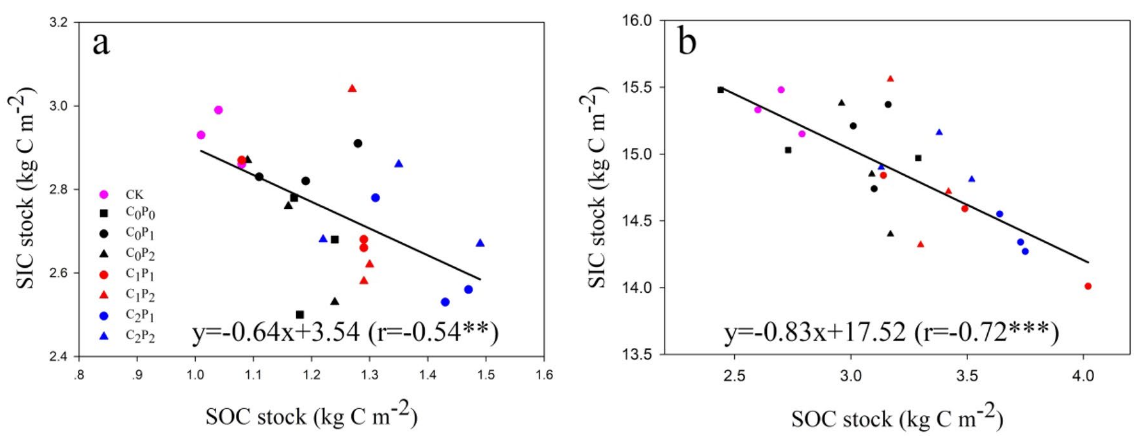

Fig. 5 Relationship between SIC and SOC stocks in the 0 – 20 cm (**a**) and 0 – 100 cm (**b**) soil layers

and higher levels of CO_2 in water-logged condition would promote the dissolution of SIC (according to Eq. 3), leading to lower levels of SIC.

Both SOC and SIC stocks are lower in the saline – alkaline paddy of YRD (3.2 and 14.9 kg Cm^{-2}, respectively) relative to those in the low-salinity dry cropland of North China Plain (7.5 and 16.5 kg Cm^{-2}, respectively) over 0–100 cm (Shi et al. 2017), despite of the same or similar parent materials. There is evidence that the presence of SIC can provide protection for SOM in saline – alkaline soils (Rowley et al. 2018), implying that there may be interactions between SIC and SOC in the saline – alkaline paddy of YRD. These analyses indicate that the SIC – SOC relationship is complex, and there are many processes regulating the formation and transformation of SIC (Monger et al. 2015), which are influenced by soil and climatic conditions, and also land use/management practices.

Conclusion

This study addresses the responses of SOC and SIC to different combinations of organic and phosphorus fertilization in a saline – alkaline paddy soil of the YRD. Overall, most of the fertilization practices could not significantly reduce soil pH, EC, Na^+, and SAR. High rate of organic fertilization resulted in an increase in water soluble cations, AP, TP and TN in the topsoil. Phosphorus fertilization led to an increase in SOC below 20 cm whereas organic amendment caused an increase of SOC in both topsoil and subsoil. Increasing the rate of organic fertilization only resulted in an increase of SOC above 20 cm when lower rate of phosphorus fertilization was applied. Fertilization had little influence on SIC in the topsoil, but resulted in a significant decrease in SIC in subsoil under lower rates of phosphorus fertilization combined with organic fertilization. Our data showed a significant negative relationship between SOC and SIC stocks in saline – alkaline paddy of YRD. More studies are needed to assess the impacts of soil managements on the dynamics of SOC and SIC and their relationships in various cropping systems spanning from arid to semi-humid regions.

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Author contributions
XW provided financial support for this study, and corrected all the versions of the manuscript. HZ conducted laboratory measurement, data analyses, and prepared for the manuscript. XD and LW conducted the field experiment. LW and TL collected soils, and commented on earlier versions of the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials
The research data of this study can be obtained upon by requesting the corresponding author.

Declarations

Competing interests
All authors declare that they have no conflict of interests.

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