LAND DEGRADATION & DEVELOPMENT
Land Degrad. Develop. **27**: 1595–1602 (2016)
Published online 9 October 2014 in Wiley Online Library (wileyonlinelibrary.com) **DOI**: 10.1002/ldr.2323

YELLOW RIVER SEDIMENT AS A SOIL AMENDMENT FOR AMELIORATION OF SALINE LAND IN THE YELLOW RIVER DELTA

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Received: 21 August 2014; Accepted: 29 August 2014

ABSTRACT

Soil salinization and sedimentation in the Yellow River Delta pose significant environmental concerns in China. This study demonstrated for the first time that the Yellow River sediment can be used as a soil amendment to remediate the salt-affected soil. Four treatments including the control (CK), Yellow River sediment application at 70 Mg ha^{-1} (S70) and 140 Mg ha^{-1} (S140), and crop residue application at 3 Mg ha^{-1} (P3) were replicated in two blocks in the field. Cotton, one of the most common crops in the Yellow River Delta, was planted. Soil physical properties and electrical conductivity (EC) were measured. The results indicated that mixing the Yellow River sediment, a poorly graded sand, with the clayed saline soil improved soil texture, macroporosity, and saturated hydraulic conductivity. Mean EC of treated soils was significantly lower than for the control. Improved cotton emergence and stand establishment were observed along with a significant treatment effect on cotton yield. The effects of S140 and P3 on soil macroporosity, hydraulic conductivity, soil EC, and cotton growth were comparable. This study concluded that applying Yellow River sediment in the saline land is a technically feasible and environmentally sustainable approach for saline soil remediation in the Yellow River Delta. Copyright © 2014 John Wiley & Sons, Ltd.

KEY WORDS: saline soils; sediment; soil physical properties; cotton; Yellow River Delta

INTRODUCTION

Soil salinity and sodicity are a global environmental problem seriously limiting the productivity of cultivated land (Ivits *et al*., 2013). Salt-affected land covers more than 1 billion hectares in the world, accounting for about 25% of irrigated land (Qadir *et al*., 2006; Wong *et al*., 2010). Deterioration of soil physical properties such as dispersion of soil particles (occurring largely on sodic soils), poor soil structure, and low hydraulic conductivity are among the leading causes of low productivity of salt-affected soils (Jayawardane & Chan, 1994; Qadir & Schubert, 2002; Brinck & Frost, 2009; Ganjegunte *et al*., 2014). Projections of global population growth and increased demand for food and fiber suggest that larger areas of salt-affected land will need to be cropped in the future (Qadir *et al*., 2006; Qadir *et al*., 2013). Over the past century, site-specific remediation practices or control measures for remediation of salt-affected land have been developed. Some of the common ones included water leaching, tillage and plant residue management, chemical remediation, organic amendments, and phytoremediation (Ahmad & Chang, 2002; Sharma & Minhas, 2005; Ravindran *et al*., 2007; Mahdy, 2011; Ghafoor *et al*., 2012; Oo *et al*., 2013; Srivastava *et al*., 2014). One of the most extensively used practices is to apply gypsum ($CaSO_4$ $2H_2O$) as a source of calcium (Ca^{2+}) to replace excess sodium (Na^+) at the cation exchange sites (Brinck & Frost, 2009; Ghafoor *et al*., 2012). However, the cost of gypsum has limited its wide applications (Hasnat *et al*., 2009). Natural zeolite was also reported for saline soil remediation (Noori *et al*., 2006). Yet the high cost still remains an issue, limiting its wide applications especially in developing countries. Aluminum and coal mining slags and fly ash were also used as soil additives to improve soil physical properties of saline soils. High levels of heavy metals in these byproducts have limited their use by farmers (Pandey *et al*., 2009). Organic amendments were found to be effective in improving soil physical properties and in reducing salt levels (Tejada *et al*., 2006; Oo *et al*., 2013; Srivastava *et al*., 2014).

In China, about 7% of cultivated land contains excessive levels of salts. These salt-affected soils are distributed mostly in northern China, especially in the Yellow River Delta, one of China's three largest river deltas. With the onset of the Yellow River Delta Compressive Development Plan of the Chinese Central Government, remediation of saline land, which covers about 70% of the total area, becomes a national priority for sustainable development in the region (Li *et al*., 2003; Wu *et al*., 2004; Yao & Yang, 2010; Fan *et al*., 2012). Traditional saline soil remediation in the Yellow River Delta relied mainly on the hydraulic engineering approach using freshwater from the Yellow River for water leaching. Its limitation has been greatly felt owing to the limited fresh water resources and large expansion of agricultural land. Returning crop residue is

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perhaps one of the most effective saline soil amelioration practices in the region; yet its application was limited owing to lack of crop residues (only maize and corn) and concerns about plant diseases. A holistic approach integrating the economic, social, and environmental considerations is greatly needed to develop site-specific soil amelioration options.

The Yellow River, the most sediment-laden river in the world, carries about 1·6 billion tons of sediment yearly (Wu *et al*., 2004). Yet, the yellow River is also the only fresh water resource in the Yellow River Delta where irrigation accounts for 80% of the water consumed from the river, with the rest supplying industry and drinking water for cities along the river and outside of the basin. Sedimentation in Yellow River diversion and water conveyance systems has long been an outstanding issue in the Yellow River Delta (Wu *et al*., 2004). A significant amount of manpower and financial resources is spent to dredge and manage the sediment. To the local farmers, the dredged sediment is a waste, which can create off-site ecological concerns if not managed properly. For example, the amount of sediment routed from the Yellow River in Bin-Zhou and Dong-Ying Cities, located in the central area of the Yellow River Delta, totals 450 million tons per year. The cost to clean up this sediment in irrigation canals and sedimentation basins amounts to about 1 billion RMB. Existing regulations established by Chinese government apply only to the main channel of the Yellow River. No rules or regulations are established for management or disposal of the dredged sediment in the Yellow River Delta. Conventionally, the Yellow River sediment is piled along the bank of the diversion canals or stocked in a central location. If not managed properly, the sediment may be washed away, creating further ecological problems. No research has been conducted to explore ways of utilizing the sediment. This study serves as the first attempt to demonstrate, through field trials, that Yellow River sediment can serve as a soil amendment to remediate saline soils in the region. Specifically, the objectives of the study are (i) to compare and contrast the physical properties and electrical conductivity (EC) of saline soils treated with and without Yellow River sediment; and (ii) to examine the effect of sediment treatment on the growth and yield of cotton, a salt tolerant crop that is commonly planted in the region.

MATERIALS AND METHODS

Study Area

The study area, located in Bin-Zhou City, Shandong Province (37°17′–38°03′N and 117°42′–118°04′E), is a major agricultural area of the Yellow River Delta (Figure 1). With the temperate continental monsoon climate, the area is characterized with strong seasonality with respect to rainfall, evaporation, temperature, and wind. The rainfall averages 564 mm per year, of which 78% falls from June to September, leading to seasonal drought from October to May. Annual evaporation averages 1,806 mm, with the maximum occurring in May and June (accounting for about 40% of the annual evaporation). The temperature averages 12·3 °C annually, ranging from −22·7 to 40·8 °C. Owing to the shortage of fresh water resources in the region, the Yellow River is the only source of water for irrigation and domestic use.

Saline Soils

The Yellow River Delta is characterized by low and level terrain with shallow groundwater tables containing high mineral contents. The groundwater table in the area is generally 1 to 2 m below the ground surface, containing about 10 to 30 g L^{-1} minerals. The capillary rise of water during the dry season can rapidly salinize the soils in the region (Fan *et al*., 2012). These salt-affected soils are typically classified as “saline soils” with pH < 8·5 and the ratio of exchangeable Na^+ to total cations <30%, although the sodium content is relatively high (Table I). Saline soils in Bin-Zhou and Dong-Ying Cities totals 9,212 km^2 (Figure 1), accounting for about 53% of the total land area according to the Second Soil Survey of Shandong Province. The majority of the saline soils are classified as Saline Fluvo-aquic Soil, occupying about 30% of the total land area. This soil is clayey and poorly drained. Excessive accumulation of salts especially Na^+ in the soil leads to deterioration of soil physical properties (Table I). Owing to the proximity to irrigation source water (Yellow River), the saline soil is commonly used for agriculture (cotton and maize) in the region. Poor soil physical properties and high salt contents of the saline soils are the major factors limiting crop production in the area.

Yellow River Sediment

The Yellow River is infamous for its high sediment content. Sedimentation becomes a concern when the Yellow River water is diverted for irrigation and domestic use. In the study area, a total of 2,731 million m^3 of water was diverted from 1999 to 2008. The sediment amounted to 1,251 million tons, most of which was deposited in the settling basin and irrigation canals. The sediment needs to be dredged each year, incurring huge cost in labor and large areas of land for storage. When land for storage is not available, dredged sediment is simply piled up along irrigation canals, creating further adverse ecological impacts. Secondary pollution by organic and inorganic contaminants in the sediment is rarely reported. The sedimentation basin built in the study area is located about 51 km away from the Yellow River, serving as an ideal site for large-scale application of Yellow River sediment. The field trials in this study utilized the dredged sediment from main canals, which was 4 km away from the test plots (Figure 1). The sediment is typically fine sand, containing very little salts. Depending on the location and the age of the sediment piles, some salts could migrate into the sediment from adjacent land (Table I). As the Yellow River sediment originates mostly from soils in the Loess Plateau, its available K content can be higher than in the saline soil (Table I).

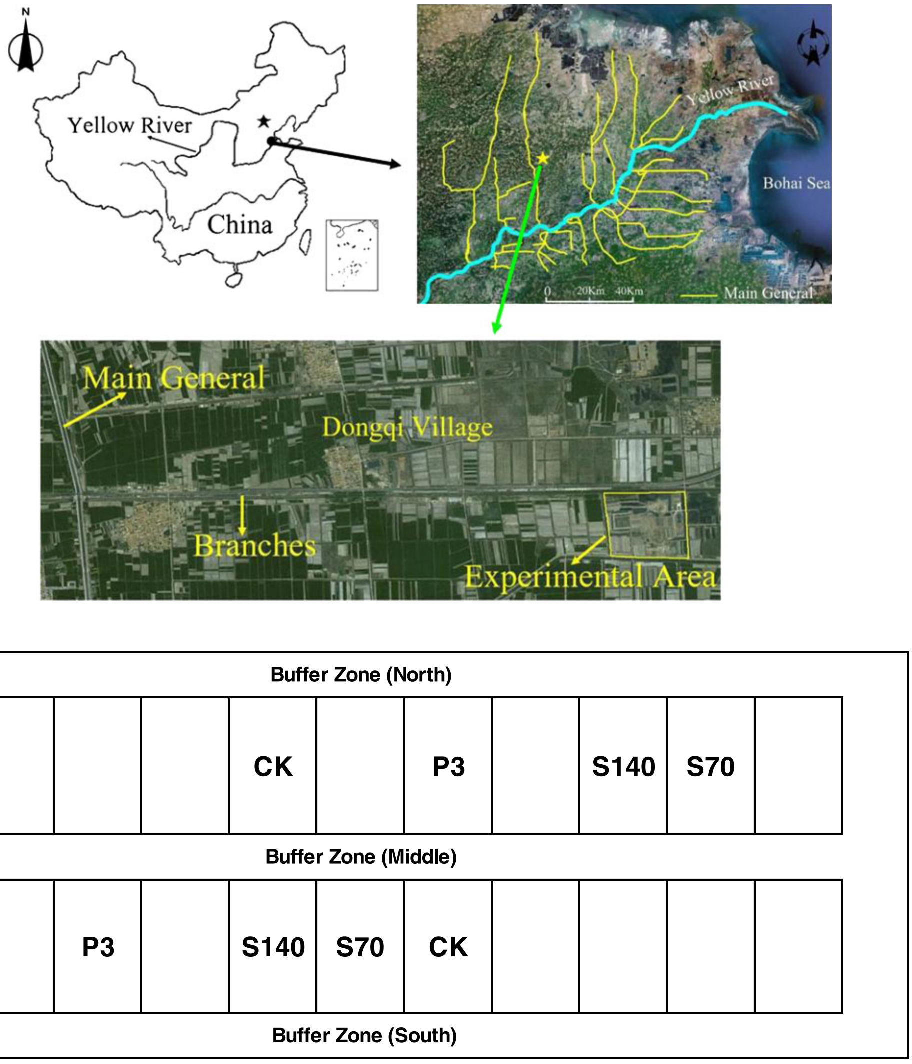

Figure 1. Location map of the Yellow River Delta and the experiment site. The middle panel shows the proximity of test plots to irrigation canals, and the lower panel shows the layout of the treatment plots. This figure is available in colour online at wileyonlinelibrary.com/journal/ldr

Field Trials and Treatments

In this study, the effectiveness of Yellow River sediment as a soil amendment for remediation of the low-yielding saline soil was compared with that of commonly used crop residues. Four treatments were replicated in two blocks (north and south) separated with a 2-m buffer zone (Figure 1). Each treatment is named in accordance with the amount of sediment or crop residues added: the control with no application of Yellow River sediment or plant residue (CK), sediment application at the rate of 70 Mg ha^{-1} (S70), sediment application at the rate of 140 Mg ha^{-1} (S140), and crop residue application at the rate of 3 Mg ha^{-1} (P3). The P3 treatment represented one of the most effective saline soil amelioration practices; yet its application was limited owing to lack of crop residues and concerns about plant diseases. The application rate and method for the crop residues treatment (P3) were consistent with what were commonly used for saline soil improvement in the region. Crop residues were evenly chopped to less than 1 cm in length. For the ease of agricultural machinery in the field, each plot was designed to be 3 m × 15 m, and cotton was grown as the crop. Prior to sowing, sediment and crop residues were spread on land surface and then tilled into the soil (about 20 cm in depth) using rotary disc. All plots received the same tillage. After sowing, the fields were irrigated in the end of April. The seeding rate, tillage, irrigation, and fertilization were consistent with local farming practices. Field trials began in April 2012, and cotton was harvested in November 2012.

Soil Sampling and Analysis

Prior to planting cotton, soil samples were taken on 1 April 2012 in each plot to establish the pre-treatment condition. Soil EC samples was taken at six locations from depths of 0–20, 20–40, and 40–60 cm in each plot using an hand auger, and EC measurements were conducted with 1:5 mixture of soil and water ($EC_{1:5}$). This method has been increasingly used as an alternative for EC measurement using saturated

Table I. Characteristics of the saline soil and Yellow River sediment

Source of variation	Saline soil	Yellow River sediment
pH	8·3	7·8
EC ($dS\,m^{-1}$)[a]	1·74	0·20
Soluble salt ($g\,kg^{-1}$)	4·22	0·69
CO_3^{2-}	0	0
HCO_3^-	0·07	0·04
SO_4^{2-}	1·08	0·13
Cl^-	1·76	0·14
Ca^{2+}	0·20	0·04
Mg^{2+}	0·16	0·02
K^+	0·94	0·31
Na^+	0·49	0·11
Organic matter ($g\,kg^{-1}$)	19·20	6·85
Total N ($g\,kg^{-1}$)	1·82	0·21
Available P ($mg\,kg^{-1}$)	11·2	2·28
Available K ($mg\,kg^{-1}$)	114	186

[a]Soil EC was measured using 1:5 mixture of soil and water, roughly 1/10 of EC using saturated soil paste.

soil paste extract (EC_e) (He *et al.*, 2012). Laboratory trials indicated that for the soil studied, $EC_{1:5}$ was roughly one-tenth of EC_e. On 8 May 2012, shortly after cotton emergence, and on 27 May 2012, before the rainy season started in June, $EC_{1:5}$ was surveyed in a similar manner at six locations in each plot.

After cotton was harvested in November 2012, five samples were taken in each treatment for particle size distribution analysis using a combination of sieving (>0·053 mm) and hydrometer (<0·053 mm) methods. Soil macropores and saturated hydrologic conductivity were measured at three locations for each treatment. Soil macropores (pores > 0·03 mm) were estimated with volumetric displacement of water under the soil water matric potential of 10 kPa of undisturbed soil samples. Soil saturated hydraulic conductivity (Kf) was measured using the Hood Infiltrometer (manufactured by Umwelt-Geräte-Technik GmbH) in the field. Calculation of saturated soil hydraulic conductivity was based on Wooding's (1968) solution for infiltration from a circular source with a constant pressure head at the soil surface and the exponential function of unsaturated hydraulic conductivity given by Gardner (1958).

Statistical Analysis

All statistical analyses were conducted using SPSS 15·0. Analysis of variance (ANOVA) was conducted to evaluate the treatment effect on soil properties and cotton yield. When the treatment effect was significant, differences of means among the treatments were tested using Turkey's test. The significance level at $\alpha = 0{\cdot}05$ was applied to all statistical analyses.

RESULTS AND DISCUSSION

Particle Size Distribution

Soil particle size distribution or texture is the most fundamental soil physical property that controls water, nutrient, and oxygen exchange, retention, and uptake (Letey, 1985; Osman, 2013). For a given soil, its particle size composition is often difficult to change through time. In the Yellow River Delta, water diversion from the Yellow River created a significant amount of sediment, which originates from soils in the Loess Plateau. During the course of transport, change in particle gradation results in a poorly graded fine sand in the lower reach of the river. With about 90% fine and very fine sand (0·1–0·05 mm) and virtually no clay, the sediment has a distinct particle size distribution compared with the saline soil in the study area (Figure 2). The difference in particle size distribution between the Yellow River sediment and the saline soil suggests that the sediment can be used to improve soil texture of the clayey saline soil in the region. This is similar to the principle of addition of clays to light textured degraded soils reported by Qadir *et al.* (2013).

The extent to which the particle size distribution of the saline soil can be changed depends on the quantity of the sediment added and how well they are mixed. The result of ANOVA with samples of the top 20 cm of the soil indicates a significant treatment effect of sediment application in increasing the 0·1–0·05 mm fraction and decreasing the <0·001 mm fraction (Figure 3). Although the difference between the means is significant only for the <0·001 mm fraction of CK and S140, the percentage of the 0·1–0·05 mm fraction of S70 and S140 was marginally higher than that of CK, and the percentage of the <0·001 mm fraction of S70 was marginally lower than that of CK. This is partly due to the obvious spatial variability as shown in Figure 3, which is inherent in the soil. In addition, uniform mixing between the soil and the sediment can hardly be reached in the field application, and this may have contributed to the variability in the data (Figure 3). The P3 treatment had no significant influence on soil particle size distribution.

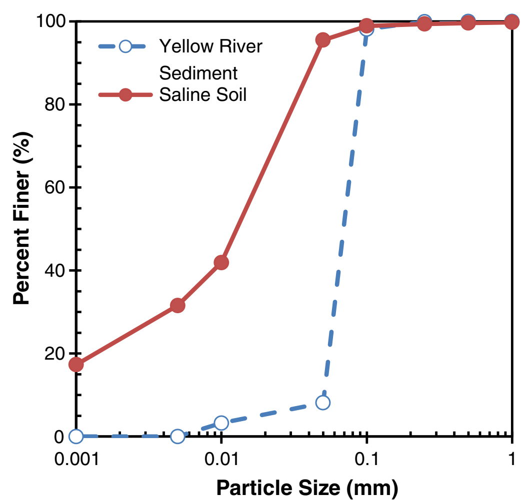

Figure 2. Particle size distribution of the Yellow River sediment and saline soil. This figure is available in colour online at wileyonlinelibrary.com/journal/ldr

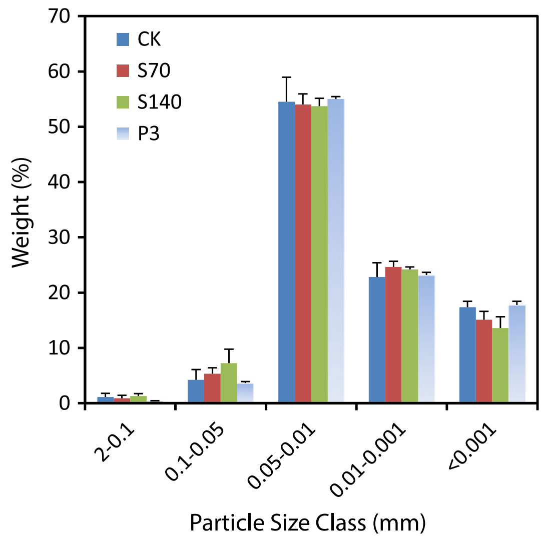

Figure 3. Particle size composition of surface layer in the treatment plots. Error bars represent the standard deviation. This figure is available in colour online at wileyonlinelibrary.com/journal/ldr

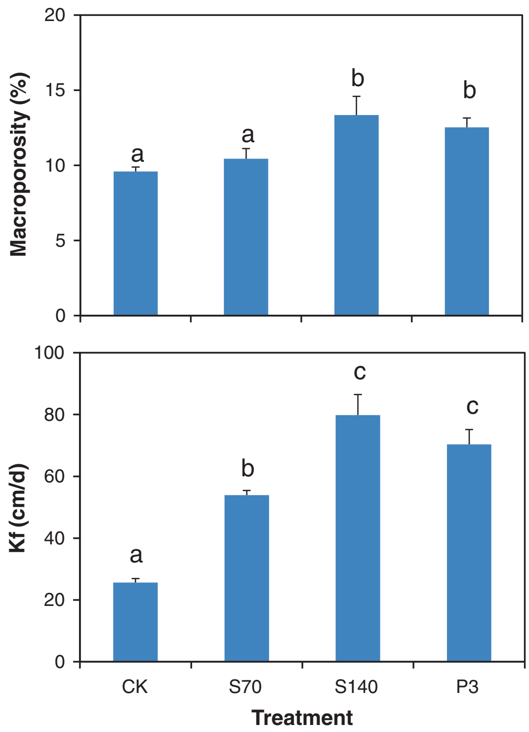

Figure 4. Comparison of macroporosity (top panel) and saturated hydraulic conductivity (Kf) (bottom panel) between treatments. Error bars represent the standard deviation. Mean values labeled with the same letter were not significantly different at $\alpha = 0{\cdot}05$. This figure is available in colour online at wileyonlinelibrary.com/journal/ldr

Soil Macroporosity and Hydraulic Conductivity

Soil porosity characteristics are fundamental to soil physical behavior, root penetration, and water movement (Sasal *et al.*, 2006). The treatment effect on the amount of macropores (>0·03 mm) measured using undisturbed soil columns (10-kPa displacement) was significant with one-away ANOVA ($p < 0{\cdot}01$). Compared with CK, all treatments resulted in an increase in macropores in the surface layer (Figure 4). The macroporosity was 9·6% for CK, 10·4% for S70, 13·4% for S140, and 12·5% for P3. Compared with CK, the increase for S140 and P3 was significant ($p < 0{\cdot}05$), accounting for about 2–3% increase.

Because pores in soils are fluid conduits, soil porosity are perhaps the most fundamental soil property affecting soil hydraulic conductivity (Strudley *et al.*, 2008). The treatment effect on saturated hydraulic conductivity was significant using one-away ANOVA ($p < 0{\cdot}01$). Compared with CK, all treatments resulted in a significant increase in saturated hydraulic conductivity (Figure 4). The mean saturated hydraulic conductivity was 25·6 cm day^{-1} for CK, 53·9 cm day^{-1} for S70, 79·8 cm day^{-1} for S140, and 70·3 cm day^{-1} for P3. The saturated hydraulic conductivity was strongly correlated with the amount of macropores in the soil ($r = 0{\cdot}88$).

Improvements in macroporosity and drainage characteristics are probably one of the most notable effects for saline soil amelioration with soil amendments and tillage (Jayawardane & Chan, 1994; Strudley *et al.*, 2008). Although Borresen (1999) indicated that the effects of tillage and straw treatments on total porosity and pore size distribution were not significant, the literature generally supports that crop residue returning is effective in increasing the total porosity of soil (Lal, 1980). Jayawardane & Chan (1994) argued that low macroporosity and macropore instability of salt-affected soils can be improved by tillage techniques combined with addition of chemical ameliorants and organic matter. The increased macroporosity with sediment treatments in this study may be partly due to the improved macropore stability associated with the added sand and enhanced leaching of salt (next section). Sahin *et al.* (2011), in a laboratory study, found that saturation hydraulic conductivity of saline–sodic soils increased about 68% with microbial applications. Our results were, in general, consistent with the literature, indicating that mixing Yellow River sediment with saline soils can achieve a comparable effect in increasing macropores as with plant residue management (Figure 4).

Electrical Conductivity

Spatial variations in soil $EC_{1:5}$ were not significant among the plots before treatment (Table II). Mean $EC_{1:5}$ was 2·17 dS m^{-1} for the surface layer (0–20 cm), 1·17 dS m^{-1} for the subsurface layer (20–40 cm), and 0·87 dS m^{-1} for the bottom layer (40–60 cm). For the 8 May survey, which was conducted shortly after cotton emergence, mean soil $EC_{1:5}$ ranged from 0·37 to 0·93 dS m^{-1} (Table III), which was significantly lower than for the 1 April measurement, reflecting the effect of leaching induced by irrigation supplied in the end of April and a major rainfall event on 1 May 2012. Also note that for the 8 May survey, mean $EC_{1:5}$ of S70, S140, and P3 was significantly lower than that of CK. However, mixing with low EC sediment itself was relatively insignificant in reducing soil EC at the mixing rates examined in this study. The major mechanism for reduced EC in the soil treated with Yellow River sediment is through the enhanced soil hydraulic characteristics (Figure 4). Salts accumulated in the soil were more easily

Table II. Two-ways ANOVA of soil $EC_{1:5}$ under the pre-treatment and post-treatment conditions

Source of variation	Degree of freedom	Sum squares	Mean square	F statistic	p
		Pre-treatment—measured on 1 April 2012			
Plot	3	0·55	0·18	0·42	0·7426
Depth	2	14·81	7·40	16·91	<0·0001
Plot × Depth	6	0·76	0·13	0·29	0·9381
Residual	36	15·76	0·44		
Total	47	31·87			
		Post-treatment—measured on 8 May 2012			
Treatment	3	1·06	0·35	41·81	<0·0001
Depth	2	0·61	0·31	36·02	<0·0001
Treatment × Depth	6	0·05	0·01	1·01	0·4255
Residual	60	0·51	0·01		
Total	71	2·23			
		Post-treatment—measured on 27 May 2012			
Treatment	3	9·96	3·32	33·52	<0·0001
Depth	2	3·20	1·60	16·15	<0·0001
Treatment × Depth	6	0·18	0·03	0·30	0·9364
Residual	60	5·94	0·10		
Total	71	19·28			

leached out with the sediment than without the sediment. The lower EC helped germination and stand establishment as observed in the field and demonstrated by Dong *et al.* (2009). The treatment effect was significant in changing soil EC (Table III). In all three layers, $EC_{1:5}$ of S70, S140, and P3 was significantly lower than that of CK (Table IV). The lower EC was important as cotton plants are more sensitive to salt stress at emergence and young seedling stages than at other stages of growth in saline conditions (Dong, 2012).

For the 27 May survey, mean $EC_{1:5}$ ranged from 0·69 to 2·11 dS m^{-1}, significantly higher than the 8 May survey for the corresponding treatment and depth (Table III). Note that during 8–31 May 2012, there was no rainfall or irrigation; thus, strong evapotranspiration facilitated the accumulation of salts (Fan *et al.*, 2012). Adding Yellow River sediment and plant residue into the saline soil effectively slowed down salt accumulation. This is most likely due to enhanced salt leaching as shown by the significantly improved soil hydraulic conductivity of the treated soil (Figure 4). In all three layers, soil $EC_{1:5}$ of S70, S140, and P3 was significantly lower than that of CK (Table III). Although not significantly different, S140 and P3 exhibited slightly more effectiveness in reducing EC than S70.

Table III. Mean soil $EC_{1:5}$ measured on 8 and 27 May 2012

	EC (dS m^{-1})		
Treatment	0–20 cm	20–40 cm	40–60 cm
	Measured on 8 May 2012		
CK	0·93 (0·18) a	0·71 (0·11) a	0·63 (0·09) a
S70	0·62 (0·03) b	0·55 (0·10) b	0·43 (0·10) b
S140	0·60 (0·04) b	0·42 (0·11) b	0·37 (0·07) b
P3	0·54 (0·05) b	0·45 (0·06) b	0·37 (0·05) b
	Measured on 27 May 2012		
CK	2·11 (0·53) a	1·84 (0·47) a	1·51 (0·42) a
S70	1·50 (0·26) b	1·25 (0·23) b	0·86 (0·19) b
S140	1·18 (0·29) b	1·00 (0·38) b	0·74 (0·13) b
P3	1·07 (0·21) b	0·81 (0·13) b	0·69 (0·20) b

Values in parentheses are standard deviation from the means. The statistics used was one-way ANOVA followed by the Turkey test. For each measurement, means with the same letter in a depth (column) are not significantly different at $\alpha = 0{\cdot}05$.

Cotton Growth and Yield

Salt damage to cotton plants can be externally manifested through the inhibited seed germination and emergence, decreased seedling growth, and finally reduced biomass and economic yield (Khorsandi & Anagholi, 2009; Dong, 2012). Improved growth conditions in the treatment plots were visually observed in the field (Figure 5, pictures taken in June 2012). Dong *et al.* (2009), using potted saline soils, found that emergence and stand establishment were normal when EC_e was lower than 5 dS m^{-1} (equivalent to about 0·5 dS m^{-1} $EC_{1:5}$ for the soil tested in this study) but reduced to 60–78% and 45–55%, respectively, when soil EC_e was 5–7·5 dS m^{-1}. A two-way ANOVA was conducted on cotton yield with factors of the treatment and block (Table IV), both of which were significant ($p < 0{\cdot}01$). Although the yield for S70 (1,278 kg ha^{-1}), S140 (1,344 kg ha^{-1}), and P3 (1,343 kg ha^{-1}) was higher than for CK (1,156 kg ha^{-1}), pair-wised comparison using Turkey's test did not show a statistically significant difference between them (Table V). This is possibly because regional precipitation in the study area was about 48% more than normal during June to

Table IV. Two-way ANOVA of cotton yield

Source of variation	Degree of freedom	Sum squares	Mean square	F statistic	p
Block	1	0·45	0·45	361	0·0003
Treatment	3	0·96	0·32	257	0·0004
Residual	3	0·00	0·00		
Total	7	1·42			

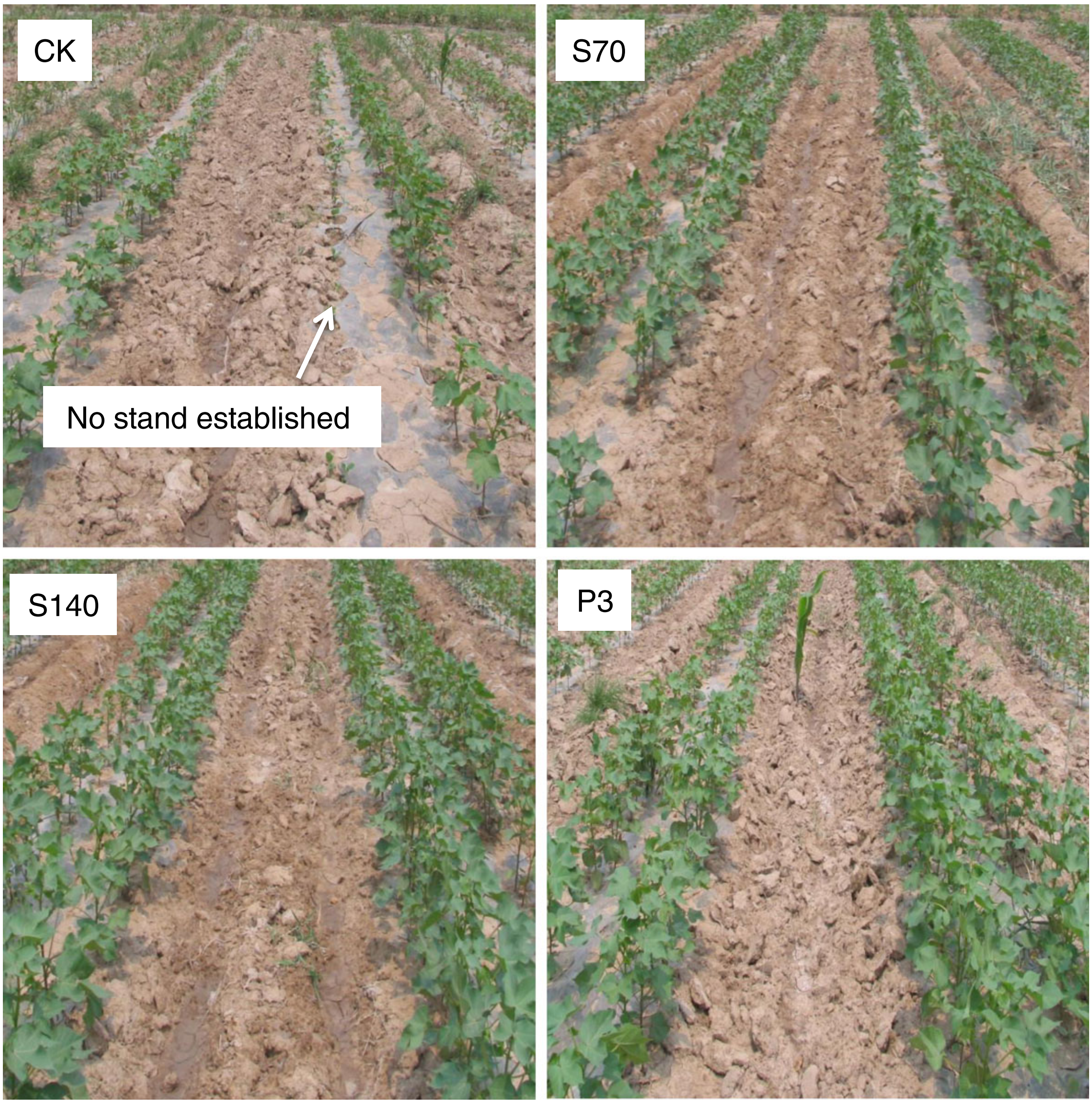

Figure 5. Photos taken in June 2012 showing the treatment effect on cotton stand establishment. This figure is available in colour online at wileyonlinelibrary.com/journal/ldr

September 2012. The study area received 157 mm of rainfall from 31 July to 1 August 2012, causing widespread waterlogging. The extremely wet condition negatively impacted the production of cotton in all the test cells. Cotton yield in the south block was lower than in the north block (Table V) for the same treatment owing to more pronounced waterlogging conditions.

Table V. Cotton yield averaged based on block and treatment

		Yield (kg ha^{-1})
Block	North	1,333 (94) a
	South	1,228 (84) a
Treatment	CK	1,156 (63) a
	S70	1,278 (79) a
	S140	1,344 (79) a
	P3	1,343 (79) a

Values in parentheses are standard deviation from the means. The statistics used was one-way ANOVA followed by the Turkey test. Means of block or treatment with the same letter are not significantly different at $\alpha = 0{\cdot}05$.

CONCLUSIONS

Soil salinization and sedimentation have long been outstanding issues in the Yellow River Delta. This study, for the first time, demonstrated that the Yellow River sediment can be used as a soil amendment to improve the physical properties of saline soils in the Yellow River Delta. The sediment is a poorly graded fine sand. When mixed with the saline soil, which is clayed in nature, the sediment helps changing soil texture. For the saline soil, the most prominent feature is its low macroporosity and infiltration rate. The saline soil treated with Yellow River sediment exhibited a significant increase in macroporosity and hydraulic conductivity, thereby enhancing salt leaching during irrigation and rainfall events. Soil EC surveys indicated significantly lower $EC_{1:5}$

values in the treated soil than the control. As a result, improved emergence and stand establishment in the treatment plots were observed. The treatment effects in enhancing cotton yield were significant in spite of regional flooding during the field trials. Amelioration of saline soils using Yellow River sediment provided an innovative approach for sustainable management of the sediment and the saline soils in the Yellow River Delta.

ACKNOWLEDGEMENTS

We gratefully acknowledge the public service sector special funds from the Water Resources Department of China (project number: 201001073) and the Xiaokaihe Yellow River Irrigation Authority of Bin-Zhou City for their support of this study.

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