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ORIGINAL PAPER

Integrated effect of nano-Zn, nano-Si, and drainage using crop straw–filled ditches on saline sodic soil properties and rice productivity

Ahmed Mohammed Saad Kheir[1] · Hesham Mahmoud Abouelsoud[1] · Emad Maher Hafez[2] · Osama Ali Mohamed Ali[3]

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Abstract

Soil salinity and sodicity issues due to limited water resources and arid climate are the main sources of land degradation in the North Nile delta. Moreover, burning rice and cotton straw is a very common practice in this region contributing to global warming and further polluting the environment. Improving saline sodic properties by biological drainage has received less attention so far. The study aimed to evaluate the effect of burying some crop residuals in field ditches and foliar application of nanoparticles on salt affected soil properties and rice productivity. The obtained results revealed that burying rice or cotton straw in field ditches prior to rice planting resulted in significant increase in rice yield and its components with superiority of cotton stalk–filled ditches to that filled by rice straw especially in the second season. Likewise, the incorporation of crop residual improved soil properties including soil fertility. The decomposition of rice straw or cotton stalk obviously decreased soil electric conductivity and soil compaction and slightly decreased bulk density. Also, soil hydraulic conductivity and organic matter content were positively responded to incorporation of crop residues. In addition, the availability of N and Zn in soil was increased due to the application of crop residues. The yield and yield components of rice were significantly affected by the foliar application of nano-Si and Zn with superiority of nano-Zn. Also, soil properties such as soil salinity, bulk density, soil compaction, hydraulic conductivity, organic matter, and available nitrogen were slightly affected by these nanoparticles while the available Zn was clearly increased.

Keywords Nanoparticles · Injection · Burying · Residual-filled ditches · Soil fertility

Introduction

Abiotic stresses due to salinization, drought, and climate change (Asseng et al. 2018; Kheir et al. 2019) are the current potential hazard in the irrigated land in the North Nile Delta. So, field drainage ditches are essential in poorly drained areas for sustainable crop production (Needelman et al. 2007). The quantity of residues in Egypt (i.e., rice straw, maize, and cotton stalk) reached 18.7–25 million ton/year (El-Berry et al. 2001). Therefore, the field ditches can be filled by un-grinded crop residuals to increase its efficiency and increase its life, raise the soil fertility, and dispose these wastes safely. The local ditcher can be used for getting a deep open drain for depositing un-grinded crop residuals (El-Ashry 2008).

Salt-affected soil suffers from low crop productivity due to the extreme osmotic potential (Powter 2002). In Egypt, salt-affected soils are concentrated in the Nile Delta region and occupy about 30% area of the delta lands (2.0 Mha) (Mohamed 2016). The main causes of salinity in salt-affected soils are vicinity of the Mediterranean coast, limited fresh water resources, high temperature and evaporation, and saline water logging (Kishk 1986; Shalaby et al. 2012). Many efforts have been paid to reclaim such soils, among of them used bagasse ash to improve soil physical properties (Seleiman and Kheir 2018a) and other organic and inorganic amendments (Seleiman and Kheir 2018b) as well as biochar (Azeem et al. 2019). Moreover, Geographic

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✉ Ahmed Mohammed Saad Kheir
drahmedkheir2015@gmail.com

[1] Soils, Water and Environment Research Institute, Agricultural Research Center, Giza, Egypt

[2] Department of Agronomy, Faculty of Agriculture, Kafrelsheikh University, Kafr-Elsheikh 33516, Egypt

[3] Crop Science Dept., Faculty of Agriculture, Menoufia University, Shebin El-Kom, Egypt

Information System (GIS) was used to determine the actual degradation status in North Nile delta (AbdelRahman et al. 2018). Notwithstanding, using nanomaterials in alleviating crop sensitivity to salinity stress has less attention so far, creating an urgent study need in this field. In addition, application of residual-filled ditches using rice and cotton straw could be used to improve soil properties and reduce pollution.

Recently, the applications of nanofertilizers show a critical role in global food production (Servin et al. 2015). Nanomaterials are being developed for slow release and efficient fertilizers (Singh 2012), so nanosizing makes nutrients more available to nanoscale plant pores and therefore result in efficient nutrient use (Suppan 2013). In addition, nanofertilizers may be absorbed by plants more rapidly and completely than traditional fertilizers (Mousavi and Rezaei 2011). Consequently, nanopowders fertilizers can be successfully used in very small amounts to improve productivity of several crops (Batsmanova et al. 2013) including rice (Lemraski et al. 2017).

Zinc (Zn) being an essential micronutrient for plant acts as the metal component of enzymes (Khan et al. 2004). The foliar application of nano-ZnO to rice at 20 ppm improved its salt tolerance yield and yield attributes and it can be used as future fertilizers (Elamawi et al. 2016). Also, the exposure of rice to nano-Zn (up to 50 mg/L) caused positive changes in its yield (Upadhyaya et al. 2017). The application of nano-Zn to rice under moisture stress conditions improved its stress tolerance, plant height, chlorophyll content, and biomass yield (Rameshraddy et al. 2017).

Silicon is needed for normal rice growth, where it absorbs quantity of Si greater than other cereals by 10–20% (Adhikari et al. 2013), as it might enhance its root length, root volume, and shoot and root weight. It could enhance crop yield under special crop/soil agriculture conditions, by promoting several desirable physiological processes (Korndörfer and Lepsch 2001). Furthermore, it can decrease transpiration of rice, gas exchange modifications, nutrient homeostasis, and compatible solutes regulations; decrease sodium uptake and increase potassium translocation (Rizwan et al. 2015); and increase the oxidizing power and promote its root activities.

Straw incorporation into the furrow bottom could increase infiltration rate in sandy loam soils. Rice straw is commonly incorporated into rice fields to maintain soil fertility (Sugano et al. 2005). The anaerobic decomposition of agricultural wastes like rice straw led to bioethanol emission in paddy fields without any inhibition on rice growth (Takakai et al. 2017). Burying rice straw is a common practice to increase soil nutrient contents (Fores et al. 1988). Also, the total yield of maize and wheat were significantly increased by mole drains filled with shredded rice straw, maize stalk or cotton stalk, with superiority of cotton stalk moles (Abd El-Aziz 2013). Therefore, returning crop straw back to the field is highly recommended to increase soil fertility and soil organic carbon storage (Singh et al. 2004; Tirol-Padre et al. 2005), protecting the environment from a potential pollution.

Nevertheless, integrating impacts of nano-Zn and Si with crop residuals-filled ditches on soil properties and crop production not studied before in salt affected soils. Therefore, the main objective of this study is to evaluate the effect of crop residuals burying in field ditches and foliar nanoparticles on salt affected soil properties and rice productivity.

Materials and methods

Field site and experimental treatments

The experimental field was established under saline poor drained soils at El-Serw Agricultural Research Station Farm, Damietta, Egypt (38° 32′ 28.1° N, 27° 25′ 31.1E). The study aimed to evaluate the effect of crop residuals burying in field ditches and nanoparticles on salt-affected soil properties and rice productivity. Prior to the experiment, the shredded rice straw or cotton stalk was buried in narrow field ditches at 0.9 m depth, 1.0 m width, and 2 m spacing at a rate of 12 and 8 t ha^{-1} for rice and cotton respectively. Accordingly, 3 ditches were installed manually in each plot. Gypsum requirements were calculated based on initial soil ESP and added with tillage for all treatments The field was cultivated by rice (*Oryza sativa*, L.), variety Giza 178 during two successive summer growing seasons 2017 and 2018. Rice seedlings were transplanted on June 11 and harvested on October 20. The management practices for rice cultivation were followed according to Rice Research and Training Center, ARC. Foliar spray of nano-Zn (30 nm) with 50 mg/L or nano-SiO_2 (25 nm) with 2.5 mg/L were applied three times to rice plants 3, 5, and 7 weeks after transplanting. The dosages of foliar applications were based on previous tests.

Measurements

Soil salinity, bulk density, hydraulic conductivity, soil compaction, organic matter, available N, available Zn, chlorophyll content, panicle length, plant height, 1000-grain weight, grain number/panicle, grain yield, and straw yield were measured. Representative soil samples were taken before planting and after harvesting from 0–30 cm depth and subjected to chemical and physical analysis according to (Piper 1950; Black 1983; Page 1982; Klute 1986; Jackson 1973; Garcia 1978; Richards 1954). Available Zn was estimated by an atomic absorption spectrometer (AAS) using the DTPA-extractant (Lindsay and Norvell 1978) as shown in Table 1.

Experimental design and statistical analysis

The experiment was designed in split plot with completely randomized block design in three replicates. The burial treatments were arranged in main plots (i.e. control, rice ditches and cotton ditches), while foliar applications of nano-Si or -Zn were arranged in sub-plots (i.e., control, nano-Zn, and nano-Si). The obtained data were analyzed statistically using analysis of variance (ANOVA) according to Gomez and Gomez (1984). Treatment means were compared using the least significant difference test (LSD) at 5% level.

Results and discussion

Effect of the treatments on growth parameters and rice yield

The yield and yield components as well as the chlorophyll content of rice leaves grown under saline condition were significantly affected by the foliar application of nanoparticles in both growing seasons Table 2. The yield and its components in the 2nd season were higher than that in the 1st season especially with cotton-filled ditches. Foliar application of Zn-NPs was better than Si-NPs in all parameters under this study particularly with cotton stalk–filled ditches (Fig. 1). For Si-NPs treatment, rice grain and straw yields as the mean values of both growing seasons showed 15% and 4.7% increases, respectively over the control (Fig. 1). Concerning the yield components, Si-NPs application increased all yield components in both seasons. In this regard, Si-NPs treatment caused an increase in plant height, number of grain/panicles, panicle length, 1000-grain weight, and chlorophyll content by 8.2%, 11.3%, 9.3, 4.1, and 3.9%, respectively, compared with the control. The increase in biomass and growth parameters confirms the need of rice to Si for its growth under salinity stress (Epstein 1999). Also, the foliar application with nano-Si fertilizers can facilitate the penetration to leaves leading to higher utilization by rice (Liu et al. 2009), improving the growth and the contents of chlorophyll in rice under abiotic stress (Wang et al. 2015). Consequently, the application of Si may increase plant resistance to salinity stress (Kardoni et al. 2013) creating its importance in enhancing the growth and yield of rice particularly under biotic and abiotic stresses.

Table 1 Some physical and chemical properties of top soil layer of the experimental field before cultivation

Chemical properties		Physical properties	
EC (soil paste, dS m^{-1})	7.60	Bulk density (Mg m^{-3})	1.4
SAR	14.0	Compaction (N cm^{-2})	220
ESP	22.5	Hydraulic conductivity (cm/d)	3.0
OM (%)	1.51	Sand (%)	22.5
Available Zn(ppm)	100	Silt (%)	26.4
Available N(ppm)	63	Clay (%)	51.1
Available P (ppm)	18	Soil texture	Clayey

EC, soil electrical conductivity; *SAR*, sodium adsorption ratio; *OM*, soil organic matter

Foliar application of Zn-NPs to rice showed significantly positive effect on its growth under saline soil in both growing seasons (Table 2 and Fig. 1). The Zn-NPs application significantly influenced the rice yield, where the grain and straw yields were increased comparing with the control by 27.1 and 7.7%, respectively. These positive effects on rice yield may be attributed to that Zn application improved K^+ uptake that improves grain filling (Sims 1986). Likewise, application of Zn-NPs significantly influenced the yield component. Therefore, plant height, number of grain/panicle, panicle length, 1000-grain weight and chlorophyll content were increased by 14.0, 26.6, 21.1, 11.6, and 6.3%, respectively, over the control due to application of Zn-NPs at the selected concentration. The improvement of the growth parameters of rice may be related to the upward movement of Zn-NPs which resulting in regulating the plant growth (Lin and Xing 2008; Khan et al. 2009; Shehata et al. 2009; Elamawi et al. 2016; Upadhyaya et al. 2017; Rameshraddy et al. 2017; Torabian et al. 2016).

The obtained data indicated that rice yield and its components were significantly affected by filled-ditch treatments especially in the 2nd growing season. This may be due to higher decomposition rate of crop waste in the 2nd season and in sequence increases the soil fertility (Fores et al. 1988). Also, the cotton stalk–filled ditches were more effective on all studied rice growth parameters than that filled by rice straw in both growing seasons (Table 2 and Fig. 1). Regarding the differences in rice growth parameters, the mean values of rice yield in the two growing seasons indicated that the injection of rice straw in narrow ditches increased the grain and straw yields by 12.2 and 6.1%, respectively. The corresponding increases in both parameters with cotton stalk–filled moles were 18.1 and 13.4%, respectively (Table 2). Concerning the yield components, the rice straw–filled ditches caused increases in plant height, number of grain/panicles, panicle length, 1000 grain weight, and chlorophyll content by 7.4, 7.5, 9.4, 5.7, and 1.3%, respectively. While with cotton stalk–filled ditches, the corresponding increases were 13.7, 13.9, 23.8, 12.8, and 1.9 %, respectively.

Table 2 Statistical analysis of rice yield and its components as affected by nanoparticles and crop straw–filled ditches

Treatments	GY (t/ha)	SY (t/ha)	PH (cm)	NGP	PL (cm)	1000 GW (g)	CC (SPAD)
Drainage (D)							
Control	3.7	7.0	66.9	51.6	17.1	23.1	39.4
Rice	3.8	7.4	71.2	55.0	18.3	24.7	40.1
Cotton	4.1	7.9	76.2	59.0	20.2	26.8	40.3
S.E.M	0.120	0.271	2.687	2.119	0.912	1.071	0.276
Foliar nanomaterials (N)							
Control	3.9	7.5	71.4	55.2	18.5	24.8	39.9
Nanosilica	4.5	7.8	77.3	61.5	20.3	25.8	41.5
Nano-zinc	5.1	8.0	81.4	70.2	22.5	27.7	42.4
S.E.M	0.357	0.164	2.904	4.347	1.144	0.835	0.734
ANOVA							
D	**	**	**	**	**	**	**
N	**	**	**	**	**	**	**
Drainage × nanomaterials	*	NS	**	*	NS	*	NS

GY, grain yield; *SY*, Straw yield; *PH*, plant height; *NGP*, number of grains in panicle; *PL*, panicle length; *GW*, grain weight; *CC*, chlorophyll content. Data are average of two growing seasons

On the other hand, there were positive interaction effects between the nanoparticles and residual–filled ditches in most of the growth parameters except of straw yield, panicle length and chlorophyll content (Table 2). The highest values of rice yield and its components were achieved by the application of Zn-NPs with cotton stalk–filled ditches in both growing seasons. These trends may be attributed to that the incorporation of crop residuals with the soil increased its fertility (Sugano et al. 2005), improved its infiltration (Miller and Aarstad 1971), increased its organic carbon content, and increased its nutrient contents (Fores et al. 1988). So, recycling the crop residuals back to the field is highly recommended to increase soil fertility and soil organic carbon (Tirol-Padre et al. 2005).

Effect of the treatments on some soil properties

Data in Fig. 2 revealed that soil properties except the available Zn were slightly affected by the application of Si-NPs and Zn-NPs, while residual-filled ditches clearly affected all these parameters. Also, the values of selected parameters in 1st season were slightly different with that in the 2nd season. The application of Si-NPs and Zn-NPs caused a slight decrease in soil salinity in respect to the ECe mean values in both growing seasons (2 and 6%, respectively) comparing with the control. Also, application of Si-NPs and Zn-NPs slightly reduced bulk density by 0.4 and 1%, respectively and soil compaction by 2.2 and 4.4 %, respectively as compare with control. On the other hand, both nanoparticles slightly increased soil hydraulic conductivity by 1.7 and 2.2%, respectively and OM contents by 0.4 and 1.8%, respectively as compared with the control. In addition, the availability of N in soil was slightly increased while the availability of Zn was clearly enhanced because of Si-NPs and Zn-NPs application. Therefore, the application of Si-NPs and Zn-NPs increased the available N by 0.6 and 2.7%, respectively while the available Zn was increased by 6.0 or 30.5%, respectively over that achieved in the control (González-Melendi et al. 2008) as the high mobility of the nanoparticles ensures the nutrient to reach all plant parts (González-Melendi et al. 2008). In addition, application of the nano-Zn to plants enhances its uptake (Prasad et al. 2012) causing an increase of nutrient's availability in the soil (Watts-Williams et al. 2014).

The incorporation of crop residual in the soil improved soil properties and raised soil fertility with superiority of cotton stalk over rice straw especially in the second season. The mean results of the two seasons indicated that the decomposition of both rice straw and cotton stalk obviously decreased soil electrical conductivity (12.0%) and soil compaction (20.2%) and slightly decreased bulk density (2.3%). With the incorporation of cotton stalks, the corresponding decreases in soil salinity, soil compaction, and bulk density were 25.1, 19.2, and 4.0%, respectively. On the other hand, soil hydraulic conductivity and organic matter content positively responded

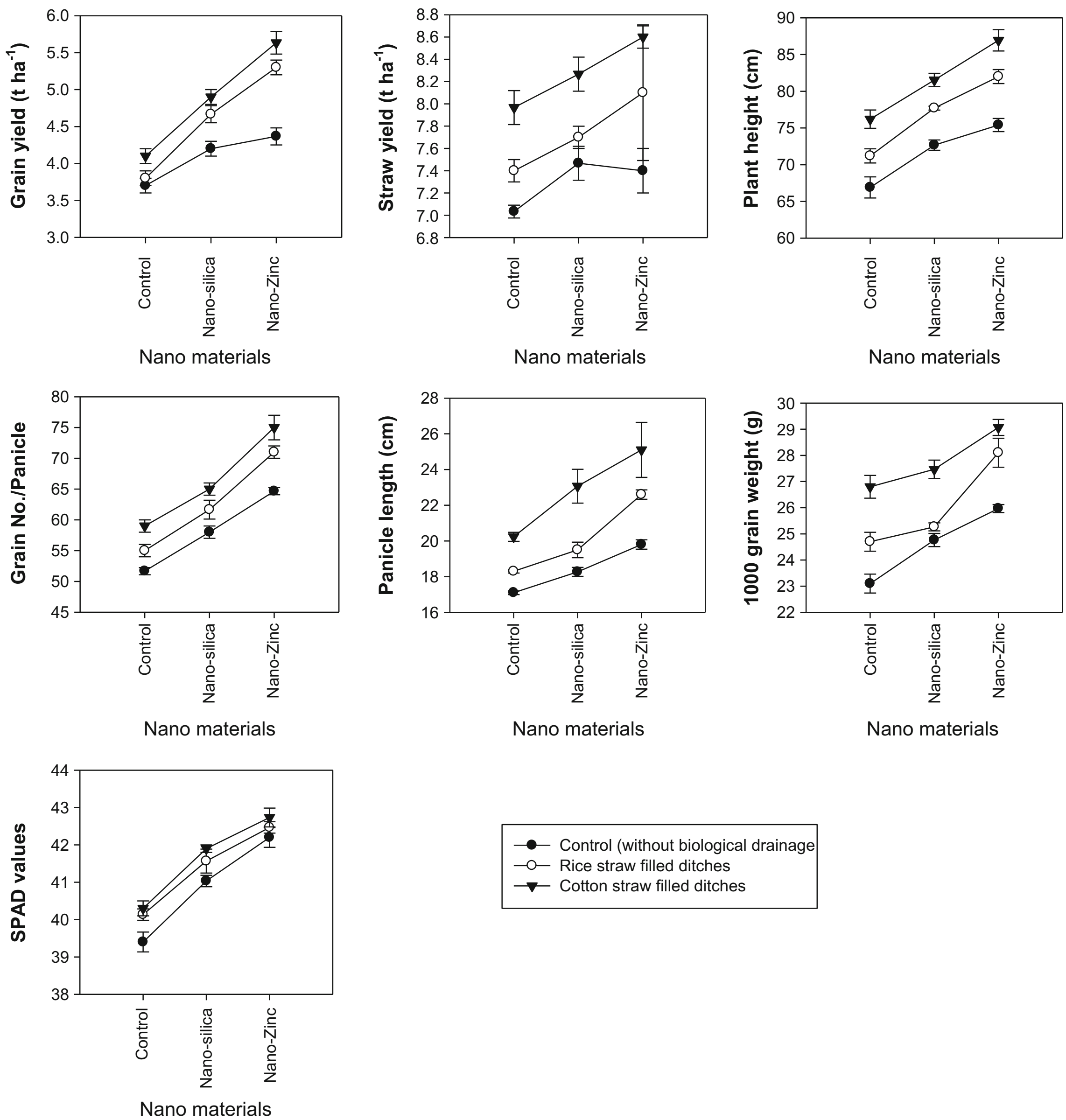

Fig. 1 Effect of biological drainage with rice and cotton straw and foliar application of nanomaterials on rice productivity, other attributes and chlorophyll content. The data is average of two growing seasons 2017 and 2018

to injection of crop residuals. Consequently, these parameters were increased by about 8.2 and 7.0%, respectively with the rice straw–filled ditches, while they were increased by about 22.4 and 15.6%, respectively with the cotton stalk–filled ditches. These advantages may be related to that the incorporation of crop residuals in soil improves its drainage efficiency, increases its infiltration rate and in sequence increase salt leaching (Miller and Aarstad 1971). Also, the decomposition of rice in paddy soils increases its organic carbon content according to (Singh et al. 2004) who reported that 21–33% of carbon in the decomposed straw remained in paddy soils.

On the other hand, the availability of N and Zn were relatively less affected by rice straw injection while they clearly responded with cotton stalk injection. So, the availability of N and Zn were increased with rice straw–filled ditches by 1.1 and 3.9%, respectively, while they increased with cotton stalk–filled ditches by 7.6 and 7.2%, respectively. These results are corresponding to (Sugano et al. 2005) who reported that rice straw incorporated into rice fields maintain soil fertility. Also, burying rice straw in a rice field increases soil nutrients contents, where it furnished 33% N and 8% P of their amounts provided by man (Fores et al. 1988).

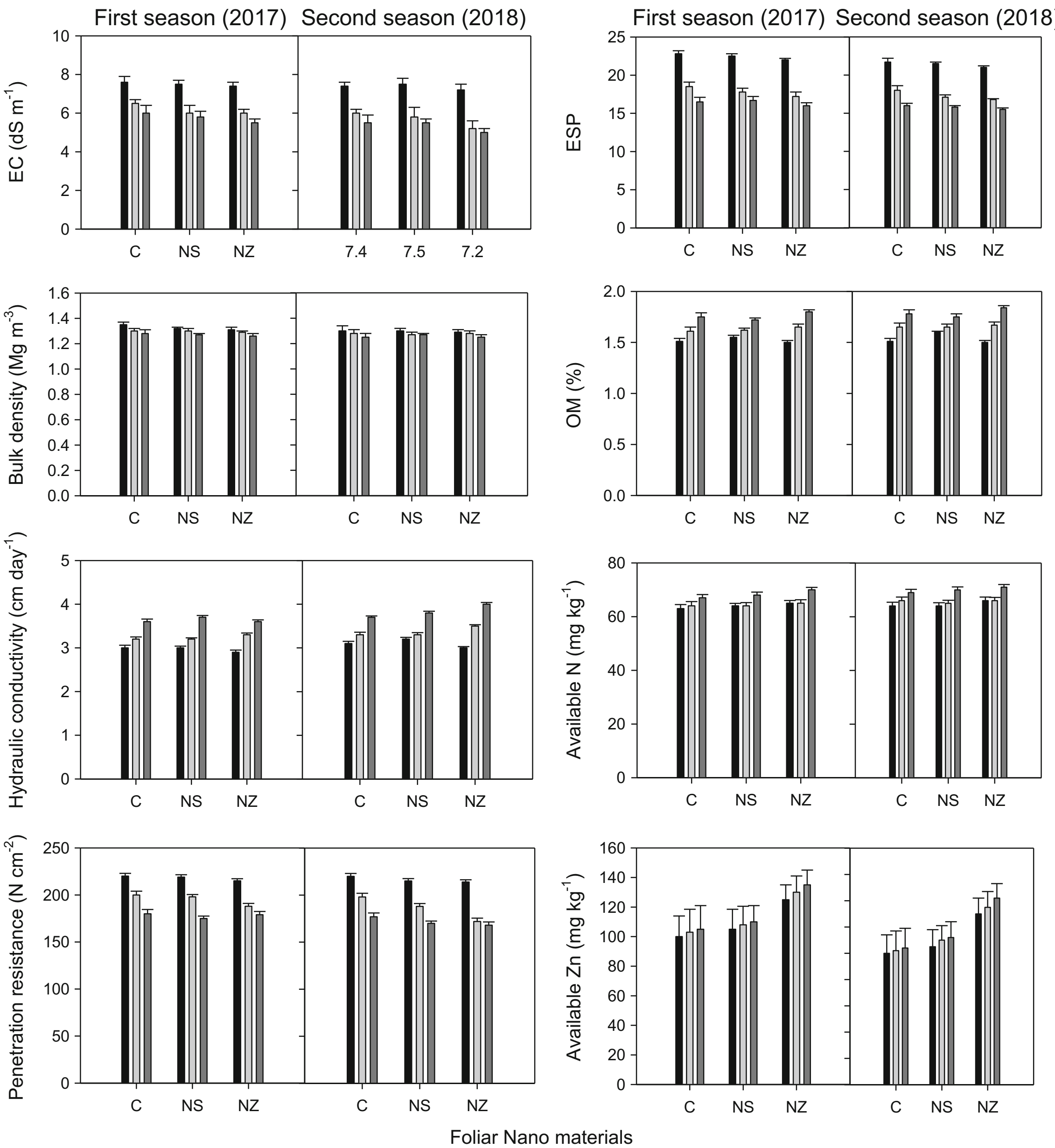

Fig. 2 Soil physical, chemical, and nutritional properties subjected to biological drainage using rice and cotton straw and foliar application of nanomaterials following two growing seasons of rice. Bars colored with black, light gray, and dark gray are control (without using crop residuals). Rice straw filled ditches and cotton straw–filled ditches respectively. Symbols C, NS, and NZ represent control, nanosilica, and nano-zinc application respectively

Conclusion

The positive effects of nanoparticles on rice productivity cultivated in saline sodic soils can be concluded from this study. It could be recommended that the foliar application of Zn or Si nanoparticle (Zn-NPs or Si-NPs) is proper for rice growing under saline and alkaline soils and improves its tolerance to abiotic stresses. The nanoparticles from both elements improved rice growth and yield with superiority of Zn-NPs than Si-NPs. Improvement of drainage efficiency with crop straw–filled ditches is interested to improve soil characteristics especially under salinity and water logging stress. Therefore, burying the crop residuals in field ditches resulted in raising drainage efficiency, improving soil fertility, increasing nutrient contents, and enhancing salt leaching and rice yield particularly with cotton stalk–filled ditches. Finally, the recycling of rice straw and cotton stalk to the field by burying in drainage ditches is a safer way for disposing of crop residues and improving the soil's chemical and physical properties.

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Compliance with ethical standards

Conflict of interest The authors declare that there are no conflicts of interest.

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