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Leaching of salt-affected soil amended by leonardite

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ABSTRACT

Salt-affected soils are widely distributed in arable croplands worldwide with potential productivity so that it is important to develop and utilize these soils. This study investigated the effects of leonardite at the application dosage of 0 (CK), 1% (T1), 3% (T2), and 5% (T3) on amending salt-affected soils under intermittent leaching. Results showed that leaching effectively reduced the electrical conductivity (EC) in soil at CK/T1/T2/T3 with 67.4%/70.9%/75.7%/ 75.6% of salt discharged. As the dominant cation in leachates, Na⁺ removed accounted for 75.1% (CK), 79.7% (T1), 72.6% (T2), and 71.5% (T3) of the total cation in soil. Sodium adsorption ratio of soil column for CK/T1/T2/T3 treatment decreased by 61.1%/68.1%/ 50.0%/44.9%. Organic matters in the soil reached 9.74/17.20/31.41/ 42.88 g/kg for CK/T1/T2/T3 treatment at the end of the experiment, indicating a fertile prospect for reclamation of the salt-affected soils. Soil pH increased with leonardite dosage after leaching in a similar pattern as the decline of EC. The results would provide practical assistance for amending salt-affected soil in the Yellow River Delta.

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Introduction

Salt-affected soils have been widely distributed in more than 100 countries, especially in arid and semi-arid regions of the world (Saifullah et al., 2018). Approximately 36 million hm² land is evaluated as saline soil in China (Liu et al., 2015). The cultivated land per capita in China was only 0.09 ha in 2008, much lower than the world average land of 0.236 ha (Huang et al., 2011). Therefore, it is urgent to find more lands suitable for agriculture in China since China possesses the largest population in the world. The rehabilitation and utilization of saline soil have become a very important practice to alleviate the contradiction between the shortage of land resources and increased population in China and other countries with a large quantity of salt-affected lands.

One obstacle of culturing on salt-affected soil is the excessive salts accumulated in the soil profile occupied by root systems (Diacono & Montemurro, 2015). In addition, salt-affected soil is usually deteriorated in soil structure and inefficient in nutrient availability, land use rate and productivity of crops. Thus, many amelioration methods including

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drainage facilities, chemical amendments, and phytoremediation have been applied for amending salt-affected soils (Ghafoor et al., 2012; Mau & Porporato, 2016). Leaching is a typical method for removing soluble salts from the topsoil by water and plays an important role in reclaiming salt-affected soils (Shaygan et al., 2018).

Low organic matter content is another factor restricting the productivity of salt-affected soil. Salt content and poor soil structure inhibit plant growth, which causes less accumulation of organic carbon in plant residues and accelerates organic matters to be leached out with precipitation (Lakhdar et al., 2009; Raychev et al., 2001). It is important to retain organic matter in soil, especially salt-affected soils (Srivastava et al., 2016). Leonardite, a kind of oxidized shallow coal with low combustion value, contains a lot of humic substances that provide huge adsorption and buffer ability to promote seed germination and root growth (Barone et al., 2019; Dobrzanski & Anyszka, 2008). In addition, the market price of leonardite in China is about 30 USD/t at present, far lower than that of the current emerging soil improvement materials such as biochar whose average price is 2650 USD/t globally (Ahmed et al., 2016). The effects of soil improvement will last for years after application and only a fraction of ameliorator is initially degraded to make it available for plants and soil microorganisms (Gao et al., 2012). The grain yield of the study area is only one-third to half of that in the normal soil due to the excessive salt retained in the topsoil. Therefore, the cost-efficient leonardite will become a potentially useful material for amelioration of salt-affected soil.

The study area, the Yellow River Delta, has 78% of the precipitation in summer to readily leach soluble salts and dissolved organic materials (DOM) from soils due to large amount of rainfall. Therefore, the main aim of this study is to determine the influence of leonardite on salt-affected soil under the simulation of summer rainfall. The final goal of this study is to understand the leaching behaviors of cations and organic matters so as to predict the consequences of the organic ameliorator for amending the salt-affected soils.

Materials and methods

Soil sampling and leonardite

The study area is located in the Yellow River Delta of China (N37°55'14.17", E118°48' 59.14"). The mean annual precipitation in the study area is only 564 mm with 78% of rainfall occurring from June to September (Mao et al., 2016). The top tilled soils with 20 cm depth were obtained from the field before winter wheat sowing (in October 2017). After air drying, the soil samples were crushed to pass through the 1 mm sieve. The soil used in this study was silty clay according to American soil texture standard to represent the soil texture of the surface horizon. The physicochemical properties of the soil are present in Table 1. Salt content of the salt-affected soil was measured as 2.6‰ (Bao, 2005) and the soil organic matter was 11.01 g/kg.

Leonardite used in this study was purchased from Shandong Innovation Company (Shandong, China). Leonardite was rich in organic matters with 44.21% of carbon and 23.7% of ash (Table 1). The content of functional groups including carboxyl (-COOH) and phenolic (-OH) was 2.01 and 1.75 mol/kg, respectively. These functional groups were involved in cation exchange capacity, absorption, and complexation (Saifullah et al., 2018) and further affected soil properties and physiological properties of plants (Abiala et al., 2018;

| | | | | | | Sand | Silt | Clay |
|------------|------|-----------|-------------|----------|-----------------|-------|-------|-------|
| | | | CEC | | Organic matters | | | |
| Sample | рН | EC (dS/m) | cmol/kg | Salinity | g/kg | | (%) | |
| Soil | 7.56 | 0.89 | 16.22 | Slightly | 11.01 | 10.55 | 39.76 | 49.70 |
| | | | | -COOH | phenol-OH | Ash | С | Ν |
| Material | pН | EC (dS/m) | CEC cmol/kg | _ | (mol/kg)— | _ | (%) | |
| Leonardite | 3.84 | 7.84 | 163.72 | 2.01 | 1.75 | 23.70 | 44.21 | 0.91 |

Table 1. Basic characters of soil and leonardite.

EC (electrical conductivity) and pH were determined at the liquid-soil ratio of 5:1. CEC (cation exchange capacity) was determined using a sodium acetate – flame photometry method; the organic matter in the soil was by potassium dichromate heating method (Bao, 2005). -COOH and phenol-OH were determined through the titration method provided by the International Humic Substances Society (http://humic-substances.org/).

Olaetxea et al., 2018). The pH and electrical conductivity (EC) of leonardite in water extraction were measured at 1:5 solid-liquid ratio and shown in Table 1.

Leaching experiment

Leaching columns used in this study were made of polypropylene with an internal diameter of 5 cm. The cylinders were filled with clean gauze at the bottom to prevent soil loss with leachate. A hole was drilled at the end caps while drain tubes were attached to the bottom of each column by a rubber. Every 5 cm soil was compacted to finally form a 20 cm soil column. All columns were packed to the bulk density of 1.31 g/cm³ according to the field measurement. Before columns filling, a predetermined amount of leonardite was mixed fully with the dried soil to obtain the final leonardite content of 0/10/30/50 g/kg for CK (control)/T1/T2/T3. Each treatment had three replicates. Deionized water was simulated as the rainfall in summer with a volume of 50 ml that was determined according to the rainfall amount of heavy rain. Each leaching was dripped drop by drop and accomplished within 24 h for every 3 days. The experiment was completed after seven leaching events. Leachate from each column was collected in a 100 ml polyethylene bottle and weighed as the weight difference of empty bottle and bottle containing leachate. The leachate volume could be calculated using leachate weight divided by the density of 1.0 g/cm³. EC, pH, soluble cations (Na⁺, Ca²⁺, Mg²⁺, and K⁺) and total organic carbon (TOC) of the leachate were determined. The ratio of absorbance of DOM solution at 250 and 365 nm (E_2/E_3) as well as 465 and 665 nm (E_4/E_6) was measured.

Soil chemical analyses

The initial soil solution before leaching was obtained. Soil or soil-leonardite mixtures (weight of 8 g) with the soil-liquid ratio of 1:5 were distributed in 50 ml centrifugal tubes before leaching for extraction. Afterwards the tubes were put on the shaking table at the rate of 300 rpm/min for 7 days. Soil extract was filtered by 0.45 μ m membrane. EC, pH, soluble cations (Na⁺, Ca²⁺, Mg²⁺, and K⁺) at a 1:5 solid-liquid ratio were measured and soil organic matter (SOM) was also measured according to the method documented in Soil Agricultural Chemistry Analysis (Bao, 2005). In order to evaluate the differences of

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soil property before and after leaching, columns were dismantled after the leaching process was finished and the soil samples were analyzed after air-drying and passing 1 mm sieve.

Soluble salt content of the soil extract solution was determined by the residual drying method. CEC (cation exchange capacity) was determined using a sodium acetate – flame photometry method. The organic matter in the soil was by potassium dichromate heating method. The total mass of Na⁺, Ca²⁺, Mg²⁺, and K⁺ in digestion extract was determined according to the HNO₃-HClO₄-HF method. All the above-mentioned methods referred to Bao (2005). EC was measured by Rex DDS-11A conductivity meters (Shanghai INESA Scientific Instrument Co., Ltd, China). Soluble cations (Na⁺, Ca²⁺, Mg²⁺, and K⁺) were analyzed by Ion Chromatography, Dionex ICS3000 (Dionex Corporation, USA). The contents of -COOH and phenol -OH in biochar and peat were determined through titration method provided by the International Humic Substances Society (http://humic-substances.org/). The ratios of E₂/E₃ (Peuravuori & Pihlaja, 1997) and E₄/E₆ (Chen et al., 1977) were obtained by the Genesys 10S UV–Vis Spectrophotometer (Thermo Fisher Scientific, USA) in a 1-cm quartz cuvette.

Statistical analyses

Origin 8.1, Excel 2003 and SPSS 9.0 were employed in data analysis. One-way ANOVA was performed to determine the difference of means for the soil analysis results, followed by Duncan's multiple comparison test (P < 0.05).

Sodium adsorption ratio (SAR) $[(mmol/l)^0.5]$ was calculated by the following equation (Miller et al., 2017):

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

where [Na⁺], [Ca²⁺] and [Mg²⁺] in solution were expressed in mmol/l.

Cumulativeleachateofcations =
$$\sum_{i=1}^{n=7} Ci * Vi$$
 (2)

where Ci (mmol/l) and Vi (L) represent the concentration and volume of cation during the *i*th leaching event (e.g. when i = 2, it means the second leaching event), respectively.

Results and discussion

Variation of EC and pH in leachate and soil

The breakthrough curve of EC for each leaching event was presented in Figure1(a). EC in the leachate of each leaching event increased with the addition dosage of leonardite. The peak value of EC occurred at the third leaching event for CK (control) and T1-3, and then the EC gradually decreased during the following leaching processes to reach a relatively stable status. It coincided with previous observations that the mountain-like variation of EC might be caused by the movement of soluble salts to the upper part of the soil column along with the wetting front while the columns were initially saturated from the bottom



Figure 1. Variation of EC, pH, and In-organic carbon in leachate of different treatments throughout the leaching process (a–c) as well as the comparison of EC or pH between before and after leaching in soil columns (d–e). (a: the variation of EC in the leachate by different treatments; b: the variation of pH in the leachate by different treatments; c: the variation of inorganic carbon in the leachate by different treatments; d: comparison of EC in the soil columns by different treatments between before and after leaching; e: comparison of pH between before and after leaching in the soil columns by different treatments). Note: CK was the control; T1 was the treatment of 10 g/kg leonardite dosage; T2 was the treatment of 30 g/kg leonardite dosage; T3 was the treatment of 50 g/kg leonardite dosage. Different lower case letters indicated significant differences among different treatments at p < 0.05. The EC and pH in the soil columns were determined through the extract obtained at soil-water ratio of 1:5.

(Chaganti et al., 2015). A similar phenomenon that EC of leachate increased during the initial leaching was also observed (Jalali & Ranjbar, 2009). Great changes in EC and pH occurred at the end of leaching experiments. Figure 1(d) shows that the initial EC in the soil solution was correlated to application dosage due to the soluble salt leonardite contained ($R^2 = 0.997$). Final EC of the soil achieved great declination to a level suitable for growing plants after leaching. The EC of CK/T1/T2/T3 was 0.29/0.32/0.34/0.40 dS/m with 67.4%/70.9%/75.7%/75.6% of salt discharged compared with that before leaching. The decreased EC demonstrated that the reduction of salt and the soil desalination took place. A relatively lower salt content was one of the critical aspects of reclaiming salt-affected soil, which could improve plant growth and microbial activities (Abiala et al., 2018; Jesus et al., 2015).

Soil pH is an essential indicator to show land arability because it is hard for most of the plants to live in the soil with pH >9.0 or <2.5. In addition, the pH also affects the element speciation of nutrients (Lehmann & Rillig, 2015). The acid leonardite might potentially benefit to neutralize high pH of salt-affected soil. Figure 1(b) shows that the leachate pH initially decreased to reach a minimum value at the third leaching event and then

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increased during the following leaching events. The variation pattern of pH was just opposite to that of EC in the whole leaching process. The pH of CK at the first three leaching events was significantly higher than that of columns with leonardite addition, indicating that leonardite played an important role in adjusting soil pH. The pH of CK/ T1/T2/T3 reached the lowest of 7.54/7.30/7.30/7.33 at the thirdleaching event. When soil salinity reduced gradually, pH was found to rise steadily with increased additional dose of leonardite. The similar variation trend of pH during leaching process was observed in many studies (Cui et al., 2018; Kaschl et al., 2002) and explained as a byproduct brought by leaching or dissolution balance of CaCO₃ precipitation (CaCO₃ + CO₂ + H₂O \leftrightarrow Ca²⁺ + 2HCO₃⁻) in the soil. HCO₃⁻/CO₃²⁻ moved more slowly than other anions such as Cl⁻ or SO₄²⁻. HCO₃⁻/CO₃²⁻ retained in the soil column and hydrolyzed to produce OH⁻, which resulted in the increase of soil pH. An interesting phenomenon showed that pH was corresponding to the inorganic carbon content (Figure 1(c)), indicating that inorganic carbon in the solution resulted in the increase in pH. In addition, variation pattern of $pH_{CK} < pH_{1\%} < pH_{3\%} < pH_{5\%}$ might be explained by that the acid leonardite activated $CaCO_3$ of the soil to promote more soluble Ca^{2+} and HCO_3^{-} or CO_3^{2-} . This might benefit to the amendment of salt-affected soil since Ca²⁺ could replace Na⁺ by the process of Soil_ Na^{-Na} + + Ca²⁺ \leftrightarrow Soil - Ca + 2Na⁺.

At the beginning of leaching, the initial pH of soil column for CK and T1-3 was around 7.6 (Figure 1(e)). The abundant humic acid contained in leonardite led to a decline of soil pH with the application dosage. Along with the process of desalination, the pH increased about 1.0 unit in all treatments. Some researchers once reported that a sodic soil may be produced resulting from leaching saline soils (Rengasamy & Olsson, 1991), which was similar in this study. However, soil pH of leonardite treatments was slightly lower than that of CK which demonstrated the ability of neutralization.

Variety of cations (Na⁺, Ca²⁺, Mg²⁺, and K^+) in leachate and soil

The impact of electrolyte effects and cation exchange can be revealed by the leaching process (Reading et al., 2012). Na⁺ was the dominant cation in the water extraction of leonardite to account for 90% of total digestion cation mass (Na⁺, Ca²⁺, Mg²⁺, and K⁺) (Table 2). Content of Ca²⁺, Mg²⁺ or K⁺ in acid digestion of leonardite was almost tenfold higher than that of in water extraction. Leaching was considered to be one of the most efficient method of reducing soil salt. Soluble salt was continuously discharged from columns and Na⁺ was the dominated salt in the leachate (Figure 2(a–d)). A good relationship existed between the accumulation amount of Na⁺ in the leachate and the addition dose of leonardite (R² = 0.999). The cumulative mass of Na⁺ that leached out in CK/T1/T2/T3 was 5.40/7.16/10.52/

| | Na ⁺ | K ⁺ | Ca ²⁺ | Mg ²⁺ | | | | | |
|--|-----------------|----------------|------------------|------------------|--|--|--|--|--|
| ltem | | (mg/g) | | | | | | | |
| Water extraction of leonardite | 7.23 | 0.33 | 0.28 | 0.20 | | | | | |
| Water extraction of soil | 0.30 | 0.05 | 0.33 | 0.12 | | | | | |
| Digestion of leonardite by HNO ₃ -HClO ₄ -HF | 11.46 | 2.00 | 7.12 | 1.69 | | | | | |

Table 2. Cations mass of leonardite and soil.

The water extraction of Na⁺, K⁺, Ca²⁺, Mg²⁺ was determined at the liquid-soil/leonardite ratio of 5:1. The digestion of leonardite was determined according to the HNO₃-HCIO₄-HF method (Bao, 2005).



Figure 2. Cumulative cations (Na⁺, Ca²⁺, K⁺, Mg²⁺) (a–d) and SAR (i) in the leachate, comparison of Na⁺, Ca²⁺, K⁺, Mg²⁺ (e–h) and SAR in the soil columns by different treatments (j) (a: cumulative cations of CK in the leachate; b: cumulative cations of T1 in the leachate; c: cumulative cations of T2 in the leachate; d: cumulative cations of T3 in the leachate; e: comparison of Na⁺ by different treatments between before and after leaching in soil columns; f comparison of Ca²⁺ by different treatments between before and after leaching in soil columns; comparison of K⁺ by different treatments between before and after leaching in soil columns; comparison of Ka²⁺ by different treatments between before and after leaching in soil columns; i: variation of SAR in the leachate by different treatments; j: comparison of SAR in the soil

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columns by different treatments). Note: CK was the control; T1 was the treatment of 10 g/kg leonardite dosage; T2 was the treatment of 30 g/kg leonardite dosage; T3 was the treatment of 50 g/kg leonardite dosage. Different lower case letters indicated significant differences among different treatments at p < 0.05. The cations in the soil columns were determined through the extract obtained at soil-water ratio of 1:5.

13.48 mmol/column at the end of leaching, accounting for 50.33%/56.97%/65.13%/69.31% of the total cation (Na⁺, Ca²⁺, Mg²⁺, and K⁺). The cumulative mass of Ca²⁺ and Mg²⁺ increased moderately after 200 ml leaching volume. The final leached-out mass of Ca²⁺ was 2.81/2.87/ 3.19/3.53 mmol/column while that of Mg²⁺ was 2.32/2.28/2.14/2.11 mmol/column for CK/ T1/T2/T3. The loss of Mg²⁺ decreased with the application dose of leonardite to demonstrate the possible bond with humic substances (Wang et al., 2016). Generally, excessive Na⁺ could lead to soil colloid swelling and structure deterioration to cause low soil nutrients (Ferretti et al., 2018). Therefore, soil salinity damage would be alleviated when more Na⁺ was washed out with the leonardite addition.

Soil salinity is characterized by high amounts of soluble cations like Na⁺, Mg²⁺, Ca²⁺. For CK and all applied amendment columns, the content of all cations shown in Figure 2 (e–h) decreased significantly by the end of leaching relative to that of before leaching. At the end of leaching, the content of Na⁺ in CK and T1-3 was reduced by 75.1%, 79.7%, 72.6%, and 71.5%. It was reported that excessive Na⁺ could cause colloidal dispersion and structural deterioration in salt-affected soils (Fay & Shi, 2012). Therefore, once soluble and exchangeable Na⁺ were leached out of soil, the damages caused by Na⁺ could be probably alleviated. There was no significant difference among CK and treatments on the content of Ca²⁺ in the soil column after leaching (p < 0.05). K⁺ increased with the application dosage, the content of K⁺ in T3 was nearly three times higher than that of CK, which could provide more nutrients for plants. The amount of Mg²⁺ in T2 and T3 was lower than CK and T1, which was corresponding to the accumulative loss.

SAR, the relative amount of divalent Ca^{2+} and Mg^{2+} as well as monovalent Na^+ (Bourrie, 2014), reflects the composition of soil solution and the soil exchangeable sodium percentage (ESP). SAR index has been widely identified as a valuable indicator of Na^+ risk in soils and irrigation. In the process of leaching, SAR reached the highest at the fifth leaching event and then decreased (Figure 2(i)). The SAR value in the leachate increased with the leonardite dosage, demonstrating the role of leonardite in accelerating Na^+ release. The SAR peak for CK/T1/T2/T3 was 6.39/8.76/12.36/17.36. SAR of soil column for CK/T1/T2/T3 reached 0.61/0.60/1.29/1.84 at the end, decreasing by 61.1%/ 68.1%/50.0%/44.9% compared with the initial (Figure 2(j)). The declined Na^+ content contributed to the most of reduced final SAR (Figure 2(e)).

Variation of organic matters in the leachate and soil

Leonardite is rich in organic materials like humic substances. DOM such as humic substances might be released with salts or be resorted in soil solution during leaching to improve the plant growth (García et al., 2016; Olaetxea et al., 2018). TOC was used as an indicator representing DOM in this study. Contents of TOC content decreased firstly, increased from the second leaching event until the fifth event, and finally decreased again (Figure 3(a)). Higher TOC content occurred with a larger leonardite application dosage.



Figure 3. Variation of E_2/E_3 , E_4/E_6 and TOC content in the leachate, comparison of SOM between before and after leaching in the soil columns. (a: variation of TOC content in the leachate by different treatments; b: comparison of SOM between before and after leaching in the soil columns; c: variation of E_2/E_3 in the leachate by different treatments; d: variation of E_4/E_6 in the leachate by different treatments). Note: CK was the control; T1 was the treatment of 10 g/kg leonardite dosage; T2 was the treatment of 30 g/kg leonardite dosage; T3 was the treatment of 50 g/kg leonardite dosage. Different lower case letters indicated significant differences among different treatments at p < 0.05.

The highest content of TOC in CK/T1/T2/T3 reached 59.78/100.65/175.39/281.58 mg/l with pH rapidly increasing (Figure 1(b)), indicating the possible relationship between pH and TOC loss.

SOM, a critical component of soil and an important parameter for sustaining soil productivity plays an essential role in a series of ecological and environmental processes including plant growth, the sorption, and distribution of plant nutrients (Petrov et al., 2017; Senesi & Loffredo, 2018). The reclamation of salt-affected soil by leonardite in this study promoted the content of SOM significantly (Figure 3(b)). SOM in T1/T2/T3 increased by

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110.9%/295.2%/466.9% compared with that of CK. The final content of SOM after leaching in CK/T1/T2/T3 was 9.74/17.20/31.41/42.88 g/kg and lower than that before leaching with SOM content of 11.01/23.22/43.51/62.42 for CK/T1/T2/T3. The result indicated the losses of soluble organic matter to some extent during the leaching process.

UV-Vis spectroscopy was utilized as a simple and informative method in order to describe the molecular properties of the organic materials (Shirshova et al., 2006). The E_2/E_3 absorbance ratio measured at 250/365 nm was inverse to the molecular size and aromaticity (Peuravuori & Pihlaja, 1997). The value of E_2/E_3 in leachate fluctuated at the beginning of leaching with 6.59/7.13/7.12/6.50 for CK/T1/T2/T3, then decreased from the third to the fifth leaching event, and finally kept stable or slightly rose at the end of the leaching (Figure 3(c)). The final E_2/E_3 ratio of leachate for CK/T1/T2/T3 was 5.64/3.69/2.12/1.46, indicating that the lower E_2/E_3 ratio was accompanied by higher leonardite dosage. The variation trend of E_2/E_3 implied that dissolved organic matter with small molecular weight was firstly washed down and molecular weight in the leachate became larger due to variation of the salt and pH of soil during the leaching proceeding (Figure 1(b)). After the third leaching event, pH rapidly increased to promote the release of humic acids (HAs) contained in leonardite (Klučáková & Kolajová, 2014). The dissolved HAs had the capacity of exchanging or complexing with cations such as Na⁺ or Ca²⁺, reducing the strength of ions, thereby alleviating the damage to salt (Cheng et al., 2016; Maghsoodloo et al., 2011; Olaetxea et al., 2018).

It is reported that the E_4/E_6 absorbance ratio determined at 465 nm and 665 nm is proportional to the degree of humification (Zalba et al., 2016) and to the molecular weight of humic substances. High E_4/E_6 absorbance ratio reflected the relative high aromaticity degree and large molecular mass (Chen et al., 1977; Deng et al., 2019; Li & Hur, 2017). The ratio of E_4/E_6 generally increased with the leonardite dosage, contrary to that of E_2/E_3 (Figure 3(d)). The final value of E_4/E_6 in leachate was 18.00/29.81/31.01/48.14 for CK/T1/ T2/T3 and higher than the initial value, indicating that the aromaticity degree increased with the application dosage of leonardite and number of leaching events.

Fulvic acids are lower in molecular mass and more complex than humic acids of the same origin (Vieyra et al., 2009). Fulvic acids could disperse in solution at any pH (Canellas et al., 2015). Moreover, the solubility of humic substances had a close relationship with pH. Fulvic acids were probably discharged at the initial stage of leaching, and humic acids were released with the rising pH as the undergoing leaching process. Therefore, controlling the pH in the process of leaching could benefit for reducing loss of organic matters.

After leaching, the air-dried soil was examined by FTIR in the spectral range of 400–4000 cm⁻¹ of the wavenumber. The spectral signals of CK/T1/T2/T3 were similar in shape according to the FTIR analysis (Figure 4). The fingerprint peaks for SOM were limited due to the relatively low concentration and technical challenge for analyzing whole soil particles with FTIR (Calderon et al., 2011; Simonetti et al., 2012). Generally speaking, wavenumbers in the range of 500–1200 cm⁻¹ indicate the specific absorptions of soil minerals such as clay, quartz, or iron oxides (Xing et al., 2016; Zhao et al., 2016). The spectra in the range of 1600–1750 cm⁻¹ normally contain fingerprint peaks for functional groups of amides, carboxylates, and aromatics (Wang et al., 2017; Xing et al., 2016). A small peak at 1650 cm⁻¹ was detected for soils in this study. The small peaks near 2894 and 2985 cm⁻¹ were assigned to characteristic for the presence of aliphatic carbon and the peaks became significant as the leonardite dosage increased, which corresponded to the result of E_4/E_6 .



Figure 4. FTIR analysis of soils after leaching in CK and T1-3 columns. Note: CK was the control; T1 was the treatment of 10 g/kg leonardite dosage; T2 was the treatment of 30 g/kg leonardite dosage; T3 was the treatment of 50 g/kg leonardite dosage.

Conclusions

The amelioration of salt-affected soil in the Yellow River Delta could not only promote the yield but also increase the income of farmers. This study showed a positive effect on amending the salt-affected soil by leonardite to provide some guidance in the field application. The results demonstrated that the simulated rainfall process of leaching could effectively reduce salts in the soil. Cation composition changed during the leaching process and Na⁺ content that caused the most of the damage could be reduced to a low degree. The SAR of the soil thereby declined consequently. The content of SOM was promoted significantly as leonardite once applied. The leonardite dosage of 1% in the field application was recommended by considering the lower cost and relatively better effect on salt leaching. In addition, the increase of soil pH caused by desalination should be paid more attention since humic substances that were sensitive to pH. Therefore, the adjustment of pH would be useful to prevent the organic matters from leaching.

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