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Sewage sludge as an initial fertility driver for rapid improvement of mudflat salt-soils

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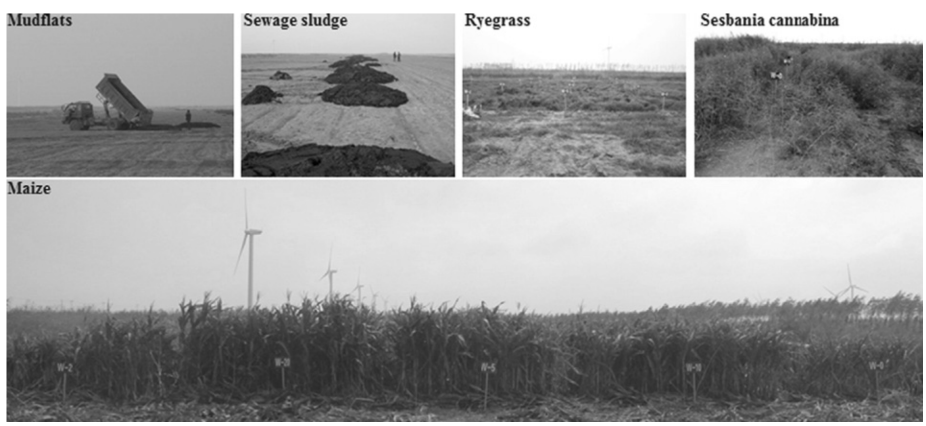
HIGHLIGHTS

- Sewage sludge amendment is an innovative solution for new arable land resources and solid waste disposal.
- Sewage sludge as an initial fertility driver combined with planted and tilled green manures decreased salinity and pH, and increased OC, N and P concentrations in mudflat soil.
- The initial fertility driver increased grain yield of maize
- Heavy metals concentrations in grain of maize did not exceed the safety standard for food.

GRAPHICAL ABSTRACT



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ABSTRACT

Sewage sludge is by-product in the process of centralized wastewater treatment. Land application of sewage sludge is one of the important disposal alternatives. Mudflats in the interaction zone between land and sea can be important alternative sources for arable lands if amended by large amount of organic fertilizers. Rich in organic matter and other nutrients, sewage sludge has been considered as the economic choice for an initial fertility driver. However, sewage sludge amendment has been greatly hampered due to availability of potential toxic metals. Using sewage sludge in compliance with the national standards for agricultural usage could avoid the accumulation of heavy metals. Nevertheless, it is not clear whether massive input of sewage sludge would increase heavy metals concentration in crops. The objective of this study was to investigate impact of sewage sludge amendment (SSA) as an initial fertility driver by one-time input, with the rates of 0, 30, 75, 150, and 300 t ha^{-1}, on biomass of green manures, soil chemical properties, and growth and heavy metals uptake of maize (*Zea mays* L.) grown in mudflat soil. Results showed that one-time sewage sludge amendment promoted an initial fertility for infertile mudflat soil, supported growth of ryegrass as the first season green manure. By tilled ryegrass, it modified the chemical properties of mudflat soil by increasing soil organic carbon, total and available N and P, and decreasing

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soil salinity and pH, which promoted subsequent growth of two green manures for sesbania and ryegrass. The sewage sludge as an initial fertility driver combined with planting and tilling green manures, increased dry matter of the aerial part and grain yield of maize grown in mudflat soil. Cd and Ni concentrations in grain of maize were positively correlated with sewage sludge amendment rates. Importantly, heavy metal concentrations in grain of maize at all SSA rates did not exceed the safety standard for food in China (GB 2762-2012). The study suggests that sewage sludge can be applied as an initial fertility driver for mudflat soil amendment, which provides an innovative solution for arable land resources and solid waste disposal.

1. Introduction

Sewage sludge is a by-product in the process of centralized wastewater treatment. Safe disposal of sewage sludge is a challenge to the world. At present the main methods of sludge disposal and comprehensive utilization include incineration, landfill, ocean dumping, and land application (Fytili and Zabaniotou, 2008). Land application of sewage sludge has a great incentive in view of soil amendment and nutrient recycling and reuse including organic carbon, N, P and other plant nutrients (Herzel et al., 2016; Rigby et al., 2016).

Mudflats (also known as tidal flats) located in the interaction zone between land and sea are valuable land resources and found in many parts of the world (Wang and Wall, 2010), and expected to be important alternative sources for arable lands after being amended by large amount of organic fertilizers. Rich in organic matter and other nutrients, sewage sludge has been considered as the economic choice for mudflat soil amendment (Bai et al., 2013b, 2013c). Due to the concern of heavy metal contamination in soils, however, sewage sludge amendment has been greatly hampered. Using sewage sludge in compliance with the national standards for agricultural use, and controlling total amount of heavy metals from sewage sludge, could avoid the accumulation of heavy metals.

Cultivation of green manure crops, plays an important role in soil quality and sustainability of agricultural systems, can be an effective way to minimize input of sewage sludge as the source of heavy metals. Green manures have been used to increase the soil fertility, as it adds organic carbon and nutrients to the soil (Fabunmi et al., 2012). Soil fertility is especially affected by soil organic matter, which depends on biomass of green manures input to compensate mineralization (Talgre et al., 2012). Moreover, it is well known that green manures tilled into soil improve soil bulk density, soil porosity, soil structure and water holding capacity (Schulz et al., 1999).

In this study, we aimed to provide a new soil initial fertility driving technology for mudflat soil amendment by sewage sludge and green manures. On the premise of total amount of heavy metals from sewage sludge being controlled in compliance with agricultural standard, we used sewage sludge as an initial fertility driver through one-time application to amend infertile mudflat soils and to support growth of green manure at the first season. Green manure tilled into mudflat soil can be decomposed, and convert into soil organic carbon. By the cycles of planting and tilling green manures, organic carbon in mudflat soils would rapidly increase through self-accumulation. It is a low-input and environmental-safety method for mudflat soil amendment. The past research mainly focused on the application of sewage sludge in farmlands (Pritchard et al., 2010; San Miguel et al., 2012; Sortino et al., 2014; Thomaidi et al., 2016), which showed land application of sewage sludge increased soil organic carbon (Kladivko and Nelson, 1979), plant yield (Kladivko and Nelson, 1979), and heavy metal accumulation in plants (Bozkurt and Yarilgac, 2003). However, the sludge application to mudflats has received little attention (Bai et al., 2013b, 2013c, 2014; Gu et al., 2013). The effects and mechanisms of sewage sludge amendment in mudflat are quite different with those in farmland due to their differences in soil nutrient, soil structure, background level of heavy metal, and microbial flora, etc. (Mallol, 2006; Singh and Kar, 2001; Wang and Wall, 2010).

The objective of this study is, to assess the effects of sewage sludge as an initial fertility driver on mudflat soils combined with planting and tilling green manures, by investigating the change of organic carbon, salinity, pH, and N and P of mudflat soil, as well as the yield, metal uptake and accumulation of maize (*Zea mays* L.) as a test crop. Our hypothesis is that sewage sludge as an initial fertility driver for mudflat soil amendment will increase biomass, nutrient uptake of green manures, and that planting and tilling green manures sustainably improve soil physicochemical properties, and assure environmental safety for heavy metals in crops grown in mudflats.

2. Materials and methods

2.1. Study area

The experiment was conducted at the experimental farm of Senmao Company Ltd. located in Rudong county, Jiangsu Province, China (E121° 23′23″, N 32° 20′03″). This site is a newly reclaimed (4-year old) mudflat located in the north shore of the Yangtze River estuary. The experiment area is flat with an elevation of 3.00 m above the sea level. The region is characterized by subtropic humid monsoon climate with distinct seasons. Precipitation is mainly concentrated from May to August.

2.2. Experimental materials

The experimental mudflat soil was typic halaquepts, which belonged to the halaquepts group of aquepts in inceptisols based on U.S. soil taxonomy. The experimental sewage sludge was collected from Sewage Treatment Plant of Rudong County in September 2011. The chemical properties of mudflat soil and sewage sludge were shown in Table 1. The quality of sewage sludge complied with the standard of disposal of sludge from municipal wastewater treatment plant-control standards for agricultural use in China (GB/T 24600-2009).

2.3. Experimental design

The experiment was carried out in randomized complete block design (RCB) with each plot of 4.0 m length and 4.0 m width. There were five treatments, i.e. 0, 30, 75, 150, and 300 t ha^{-1} sewage sludge amendment (SSA) rates on a dried weight basis, and each treatment had triplicates. With the help of rototiller, the sewage sludge was mixed uniformly with soil up to the depth of 20 cm in October 20, 2011. Ryegrass (*Lolium perenne* L.) was chosen for the first season green manure, and sowed 35 g each plot in October 25, 2011, tilled in May 30, 2012. Sesbania (*Sesbania cannabina*) as the second season green manure was sowed 120 g each plot in June 12, 2012, tilled in September 20, 2012. Ryegrass (*Lolium perenne* L.) as the third season of green manure was sowed in October 30, 2012, tilled in May 25, 2013. Maize (*Zea mays* L.) was chosen as a test crop, and sowed with spacing of 50 cm between hills and 25 cm between rows in July 10, 2013, harvested in September 22, 2013. Soil and plant samples were collected for analysis in May 30 and September 20, 2012, and May 25 and September 22, 2013.