Bull Environ Contam Toxicol (2007) 79:562–565
DOI 10.1007/s00128-007-9295-3

Principal Physicochemical Properties of Artificial Soil Composed of Fly Ash, Sewage Sludge and Mine Tailing

Hongling Zhang · Lina Sun · Tieheng Sun · Guofeng Ma

Received: 28 March 2007 / Accepted: 2 October 2007 / Published online: 17 October 2007

Exploitation of mineral resources provides energy for economic growth, as well as caused series eco-environment problems, which are displayed in the following aspects: Mining has occupied and damaged lands, triggered secondary geological calamities, polluted the eco-environment, changed the original landscapes and damaged native vegetations, thus leading to land degradation and desertification (Shen et al. 2004; Campbell 1998). Nowadays, mine spoil reclamation is becoming more and more significant, and the major method is by covering it with soil (Hu et al. 2002; Wang and Cai 2006). This method wastes both manpower and material resources, because the mines often locate in areas lacking soil resources.

In China, 1.8×10^8 t fly ash (FA) from the fossil fuel generation of electricity was produced each year (Ben and An 2004). Markets for the large tonnages of FA and other coal combustion by-products are limited and seasonal, with less than 30% of the FA utilized, primarily in the construction industry. Current disposal practices (landfilling, surface impoundment, placement in mines and quarries) can potentially affect air and water quality through fugitive dust, or runoff and leaching of FA constituents to surface and ground water (Abbott et al. 2001; Kriesel et al. 1994). Although benefits associated with the application of FA to soils have been reported, agronomic acceptance of FA is generally low due to low organic, high salinity, and environmental concerns over potentially toxic elements (Carlson and Adriano 1993).

Sewage sludge (SS) is a source of organic matter, a pool of a slow-release essential nutrients (N and P) and microorganisms. Mixing of an organic waster product with FA has been proposed to increase the macronutrient content of the resulting mixture while reducing odor and improving handling properties of the organic waste (Jackson and Miller 2000; Belmonte et al. 2006). Thus, the disposal or use of FA coupled with the utilization of SS could not only solve the shortage of soil resource for mine spoil reclamation, but also result in the high volume use of municipal wastes. In order to analyze the feasibility of SS and FA co-utilization for land reclamation, the principal physical and chemical properties of the artificial soils formed by mixing FA, SS and mine tailing were studied.

Materials and Methods

The mine spoil material (MT) was collected from the Dagushan iron mine in Anshan city, Liaoning province (123°03′36.6″E and 41°03′03″N). Fly ash used in this study was obtained from Anshan Steel Factory Power Plants and SS samples came from the North Waste Water Treatment facility located in Haicheng city, China.

To study the water-holding capacity of artificial soils composed of fly ash, sewage sludge and mine tailing, experiments were designed to simulate rainfall and natural

H. Zhang · T. Sun
Institute of Applied Ecology, Chinese Academy of Sciences, 110016 Shenyang, People's Republic of China

H. Zhang (✉)
Graduate School of Chinese Academy of Sciences, 100039 Beijing, People's Republic of China
e-mail: gfma@imr.ac.cn; zhl19792002@163.com

H. Zhang · L. Sun
Key Laboratory for Environmental Engineering of Shenyang University, 110041 Shenyang, People's Republic of China

G. Ma
Institute of Metal Research, Chinese Academy of Sciences, 110016 Shenyang, People's Republic of China

evaporation. The artificial soils were air-dried, sieved (<5 mm) and mixed well. Treatments of artificial soil with the ratio of FA to sewage sludge were listed in Table 1. Treatments consisted of: A, B, C, D, E, SS, FA, MT and the meadow brown soil as control. Nine samples (40 g each) of dry soil were placed into hard plastic cups with some pores at the bottom. A layer of plastic gauze was put on the surface of soil and then a filter paper (avoiding the soil paste in the filter paper). Water dropped on the paper and filtered in the artificial soil equably till soil was water saturation and the soil solution exuded from the pores in the bottom of cups. Stop dropping water and weigh the samples, then put the treatments in the room and let them evaporate naturally.

In order to analyze the chemical properties of artificial soil solution, we carried another experiment: Eight samples (1,000 g each) of dry soil were placed into plastic buckets. The resulting artificial soil was wet to 17% (w/w) moisture content with deionized water and re-wet to this moisture content throughout the incubation study a day prior to soil solution sampling. The treatments were open to the atmosphere but not allowed to leach, excepting the minor amount ($\approx$5%) of soil solution withdrawn from the system during sampling. In order to reproduce the loading rates utilized for the mixed waste treatments in the field trial, we sub-sampled three times from one treatment rather than employing three replicates. By using this approach we minimized the effect of soil loss during sampling and thus were better able to keep each treatment at an equivalent moisture content for the duration of the study.

Soil solution was periodically extracted (days 1, 5, 7, 15 and 22) from the incubated treatments by centrifugation. About 100 g moist soil was loaded into a plastic bottle and 10 mL deionized water was added (in order to extract a sufficient volume for analysis of soil solution). The soil centrifuged at 3,000 rpm for 25 min. After centrifugation, the bottle was took out and the soil solution filtered (0.22 μm). The solid cake collected on the filter paper was returned to the appropriate bucket, broken up by hand, and remixed with the remaining soil. Three replicate soil samples were centrifuged from each treatment on each sampling occasion.

Table 1 Artificial soils (A–E) of sewage sludge mixed with mine tailing and fly ash in weight proportions

Composition	Treatments				
	A	B	C	D	E
Fly ash	3	2	1	1	2
Sewage sludge	1	1	1	2	1
Mine tailing	0	0	0	0	1

Aliquots of the filtered soil solution were taken for measurement of organic carbon by TOC (liquid TOC 35.10-0000, Germany). The anions Cl, NO_3, NO_2, SO_4, and F concentrations in the leachates were determined by ion chromatography (IC 1010). Measurements of pH and Eh were made on a slurried (1:1 soil/H_2O) sub-sample of the incubated soil. Fe, Mn, Cu, Zn, Ni, Cd, Pb contents in artificial soils were analysis by means of atomic absorption spectrophotometry. Data obtained were subjected to statistical analysis of variance (ANOVA) in the SPSS statistical package.

Results and Discussion

Water-holding capacity is an important physical property of soil, which affects plants survival and growth directly, especially in the mine spoil areas. According to Fig. 1, SS treatment had the longest water-holding time (23 days), possibly due to the high organic content of sewage sludge (36.69%), which exhibited as colloidal and had a strong water storage capacity helping to restrain water evaporate from the soil (García-Agustín et al. 2004; Menti et al. 2006). FA had a shorter water-holding time (22 days) than SS, and MT had the worst water-holding capacity in all the treatments. At the third day, the water evaporation percentage of MT was up to 95.03%. When fly ash was mixed with sewage sludge at different ratio, the water-holding capacity of artificial soils ranged from 14 to 22 days. As compared to the control (meadow brown soil), B, C and E treatments had a longer water-holding time, A and D had a shorter water-holding time. This indicated that with the percentage of sewage sludge increasing, water-holding capacity of artificial soil was not becoming better all the while. Su and Zhang (1997) reported that appropriate ratio of fly ash to sewage sludge could enhance the water-saturation coefficient and water transport ability. In this research, we found B, C and E treatments had a fine water-holding capacity.

One of the potential beneficial attributes of alkaline FA mixed with organic waste as an artificial soil is that the

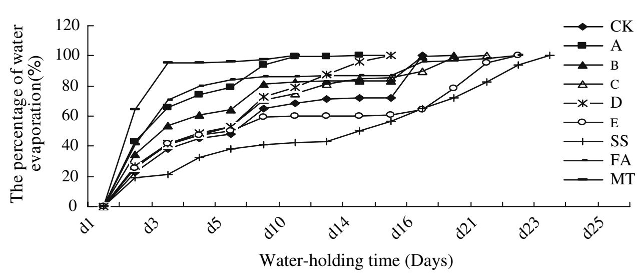

Fig. 1 Water-holding capacity of artificial soils (*CK* control, *SS* municipal sewage sludge, *FA* fly ash, *MT* mine tailing)

liming effect of the FA can offset decreases in soil pH arising from decomposition of the organic waste (Jackson and Miller 2000). Figure 2 shows that soil solution pH of the SS treatment initially increased to pH 7.4 by Day 7 of the incubation due to a production of alkalinity as a result of hydrolysis of urea (Sumner 1991). Soil pH then fell to 6.3 by the end of the incubation study, consistent with the liberation of protons during nitrification (Sumner 1991; Du et al. 2005). The pH of the FA treatment increased from 7.8 to 8.7 and keeping higher than all treatments during incubation, possibly due to low sulfur content of coal and presence of hydroxides and carbonates of calcium and magnesium (Abbott et al. 2001). Soil solution pH of iron mine tailing was near to neutral (7.1–7.3). The ameliorating effect of FA on the soil-acidifying nature of the organic wastes was observed that the pH of all the artificial soils were significantly higher than SS by the end of the incubation. With the percentage of FA increasing, pH value of the artificial soils increased. In all mixtures, pH of the C treatment (FA:SS = 1:1) was constant and approached to neutral throughout the duration of the incubation.

The soluble salt content of artificial soils were measured by an assessment of electrical conductivity (EC). Figure 2 shows that soil solution EC of the SS treatment was the highest, while that of the MT and FA treatments were not significantly different from each other but were significantly lower than the other treatments. When sewage sludge mixed with fly ash and iron mine tailing, the ECs of the five artificial soils were higher than FA and MT, but lower than SS, moreover, the more SS in artificial soil, the higher EC of the soil solution. After 22 days wetting incubation study, the ECs of all the artificial soils decreased and achieved a stable level, except the D treatment increased in a smooth and gradual fashion. The results of our study together with other researchers have shown that the municipal sewage sludge had a high salinity that would have impacted detrimentally on the plants (Degenhardt et al. 2000), and with adding fly ash could decrease the salinity and improved the chemical property of the amended soil.

Organic matter plays a large role in increasing land fertility, nurturing crops, regulating soil quality, improving the soil physical properties, etc. (García-Agustín et al. 2004). Moreover, humus of the organic matter can also complex with heavy metals found in an artificial soil, effectively reducing heavy metal pollution (Belmonte et al. 2006).

Figure 3 demonstrates the change of organic matter content in artificial soil solution during a incubation study. Initially the dissolved C concentrations rapidly increased for the treatments except for the MT and FA in the first 7-days, and initial concentration of dissolved C for SS treatment was obviously higher than all the other treatments, which indicates that the main source of organic matter in the artificial soil in this study was the municipal sewage sludge (Jackson and Miller 2000). However, in the period of 7-days to 15-days the concentrations of organic C for artificial soil and SS treatments rapidly declined and achieved stable level by the end of the study. This was presumably due to continuous decay of organic matter from sewage sludge, and some dissolved C from the sewage sludge was sorbed on the FA solid phase in the artificial soil treatments.

The high concentration of heavy metals for fly ash and sewage sludge was one of the limiting factors that restricted the wastes using in land application (Kriesel et al. 1994). In this experiment, it was observed that five heavy metals (Cd, Pb, Cu, Zn, Ni) found in FA only Nickel was close to the critical limit of the control standard for harmful substances in fly ash (GB8173–87) (Table 2). The concentration of five metals in sewage sludge (collected from Anshan, China) was significantly below the toxicity threshold limit proposed by several researchers for spoil materials (Kabata-Pendias and Pendias 1992).

Using wastes such as fly ash, poultry, mine tailing and municipal sewage sludge mixtures without nature soil for ecological remediation in mining areas to solve the shortage of soil resource would be a trend in the future. These

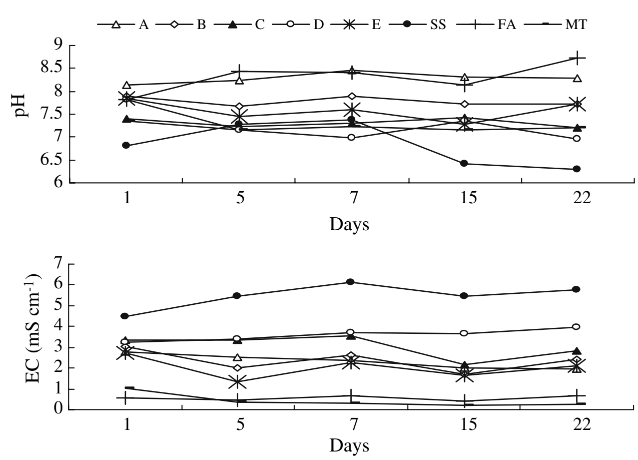

Fig. 2 Soil solution pH and electrical conductivity (EC) (*SS* municipal sewage sludge, *FA* fly ash, *MT* mine tailing)

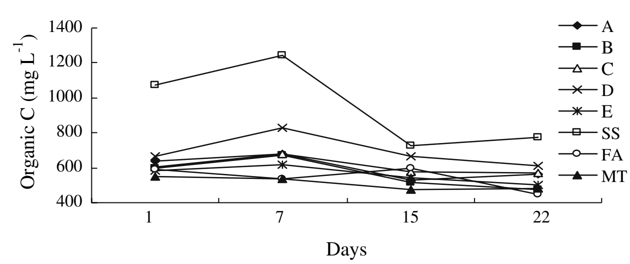

Fig. 3 The organic C content of artificial soils solution (*SS* municipal sewage sludge, *FA* fly ash, *MT* mine tailing)

Table 2 Contents of heavy metals in fly ash and sewage sludge and their standards for land application (GB4284–84 and GB8173–87) (mg kg^{-1})

Item	Cd	Pb	Cu	Zn	Ni
Content for SS	2.92–3.38	354.2–373.6	191.5–195.3	154.3–162.5	42.3–48.9
Control standard (pH ≥ 6.5)	20	1,000	500	1,000	200
Content for FA	0.6–0.75	38.0–70.4	74–81.4	3.5–7.3	240.8–322.5
Control standard (pH ≥ 6.5)	10	500	500	–	300

artificial soils also promoted the environmentally sound reuse of waste materials. From the study, it was found that when the ratio of fly ash to sewage sludge (0.60 kg kg^{-1} water content) was 1:1 and 2:1, the artificial soil C and B had a great physical and chemical property. Soil solution pH and electrical conductivity (EC) were constant over the experimental period, and the contents of five heavy metals (Cd, Pb, Cu, Zn, Ni) were below the toxicity threshold limit. However, other heavy metals not tested here would necessitate further studies on their bioavailability before these artificial soils could be used in the environment.

Acknowledgments This research was financially supported by the National Basic Research Project of China (No. 2004CB418503), the National Natural Science Foundation of China (No.30370972) and Liaoning Natural Science Foundation (No.20062002).

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