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Ameliorating some quality properties of an erosion-prone soil using biochar produced from dairy wastewater sludge

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ABSTRACT

Land degradation due to decline in soil quality and wastewater pollution is a major challenge for ecosystems sustainability, worldwide. Hence, utilizing adaptable and multi-objective strategies is essential to address environmental challenges. To this end, we produced a biochar from air-dried dairy wastewater sludge (i.e., Kalleh Dairy Company, Iran) through pyrolysis process at 300–350 °C which led to reduction in initial heavy metals contents. The produced biochar was then used to improve the soil quality of a highly degradable soil. Some important nutrients and heavy metals of dairy wastewater and produced biochar were measured by acid digestion/ICP-MS. We then spread two rates of the biochar (400 and 800 $g\ m^{-2}$) over the surface of the small-scale boxes (0.5 × 0.5 × 0.5-m) filled by an erosion-prone soil collected from the Chalus Watershed, Northern Iran, and left for 30 days. The carbon (C), nitrogen (N) and organic matter (OM) content, and also carbon/nitrogen (C/N) ratio of treated soil were measured to assess effect of the produced biochar on soil quality improvement. The results showed that some contents of the measured heavy metals (i.e., Pb, Ni, Al, Cr, Mn, Fe and Zn) in the produced biochar significantly ($p < 0.01$) reduced compared to those of the raw dairy wastewater. Additionally, application of two dosages of 400 and 800 $g\ m^{-2}$ of biochar to the study soil increased C, N, OM and C/N of the soil at tunes of 2.67–5.5; 2–3 and 2.67–5.5 times, and 22–61%, respectively, in comparison with untreated soils (control). By and large, converting the wastewater as an environmental pollution source to biochar and using it as an eco-friendly soil amendment is a multi-objective and adaptive approach for the ecosystem management.

1. Introduction

Land degradation and soil and environmental pollutions are one of the most serious ecological and economic problems in the world (Rasul, 2014). Soil quality decline particularly from hill-slopes is known as a type of land degradation, which threatens human health and wellbeing (Kheirfam et al., 2017a). Therefore, various techniques have been used to reduce land and soil quality degradation from hill-slopes (e.g., Sadeghi et al., 2015, 2016a; Mamedov et al., 2016; Kheirfam et al., 2017a) striving for environmentally friendly, economically efficient, and practically doable measures. In this regard, many amendments like sawdust and wood ash, municipal wastes, gypsum, lime (Khan and Khan, 2016; Sadeghi et al., 2016a); animal and crop manures, organic composts, crop and food industry remnants (Sadeghi et al., 2015; Gholami et al., 2016; Mamedov et al., 2016) have been applied to conserve and improve soil quality.

Improvement of soil properties using native environmentally based amendments has long been a desired way to improve soil quality. In recent years, biochar has been used for various purposes viz. carbon sequestration with the aim of soil fertility improvement (Glaser et al., 2002; Lehmann and Rondon, 2006; Haider et al., 2017), reduction in greenhouse gas emissions and climate change mitigation (Lehmann and Rondon, 2006; Woolf et al., 2010; Rasul et al., 2016), recapturing excess nutrients from wastewaters (Ghezzehei et al., 2014), controlling runoff and soil loss (Jien and Wang, 2013; Hseu et al., 2014; Hazbavi and Sadeghi, 2016; Sadeghi et al., 2016a), increasing plant growth and yield (Rasul et al., 2017), sorption of heavy metals (Xu et al., 2013; Ghezzehei et al., 2014; Inyang et al., 2015) and even improving soil aggregate characteristics (Li et al., 2017). Although, temperature, residence time, heating rate, and feedstock particle size in pyrolysis

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process potentially affect the quality and quantity characteristics of the produced biochar and thus its interactions with the environment of its application (Yuan et al., 2015).

According to the literature, biochar has been produced from different materials including woodchip (Lai et al., 2013), oak wood (Mukherjee et al., 2014), poultry litter (Brantley et al., 2016), bamboo and rice straw (Liu et al., 2016); vinasse (Sadeghi et al., 2016a), sewage sludge (Yuan et al., 2016), wastewater sludge (Yue et al., 2017a) and cow manure (Yue et al., 2017b) at different conditions. The results showed that biochar application improved soil physical and chemical (Hass et al., 2012; Nelissen et al., 2015) and biological (Mitchell et al., 2015) properties, water holding capacity (Cao et al., 2014), as well as soil fertility, nutrient and plant productivity (Major et al., 2010; Vaughn et al., 2013). Nonetheless, the studies focused on impacts of biochar produced from industry sludge on soil characteristics and particularly pollutants and insanitary absorption are still lacked.

Since dairy industries sludge hugely produced, characterized by high concentrations of heavy metals, nitrogen (N), phosphorous (P), and other elements (Ghezzehei et al., 2014) and resulted in environment pollution (Arvanitoyannis and Giakoundis, 2006; Massah and Mirbagheri, 2012; Mohebi-Fard, 2015), it is fair to apply it in original or modified type for useful goals. Towards the increasing amount of urban wastes, application of different wastes as soil amendments therefore was considered as one of the effective methods in order to manage large amounts of wastes potentially produced worldwide to fulfill human needs (e.g. Hazbavi and Sadeghi, 2016; Sadeghi et al., 2016a). Finding sustainable and economic methods for disposing different wastes and by-products is increasingly becoming a major environmental challenge throughout the globe.

Biochar technical intervention has increased potential for adaptation in areas where large agricultural and urban wastes are available (Sadeghi et al., 2016a; Haider et al., 2017). But, the possibility of biochar production from dairy wastewaters as a major source of environmental pollution threatening the water and soil resources has not been considered or documented yet.

The present study was therefore planned to (1) produce biochar from air-dried dairy wastewaters of the Kalleh Company, Amol City, Mazandaran Province, Iran, (2) measure and assess the content of heavy metals in raw material and produced biochar in comparison with the standards given by the United States Environmental Protection Agency (U.S. EPA), and (3) appraise the effect of produced biochar on improving the nutrient contents of a highly degradable soil under laboratorial circumstances.

2. Materials and method

2.1. Biochar production

To produce biochar, 20 kg of fresh dairy wastewater was provided through sampling from 50 points of the waste tanks of the Kalleh Dairy Company, Amol City, Mazandaran Province, Iran. The wastewater samples were air-dried for three days under natural condition at the Rainfall and Soil Erosion Simulation Laboratory, International Campus of Tarbiat Modares University, Noor, Iran. The air-dried samples were thoroughly mixed together and then pyrolyzed in a vertical kiln (Sadeghi et al., 2016a) at 300–350 °C for 3 h residence time. The produced biochar samples were allowed to cool down up to the laboratory temperature (Sadeghi et al., 2016a; Zornoza et al., 2016). The produced biochar was ultimately crushed and subsequently passed through a 2-mm sieve (Butnan et al., 2015), and hence, it was thoroughly mixed to obtain a fine granular product allowing better uniform mixing (Butnan et al., 2015). The obtained biochar was directly used in subsequent experiments. All different steps of biochar production have been depicted in Fig. 1.

2.2. Heavy metals and nutrient analyses

In order to assess the potential of pyrolysis process in changeability of heavy metals and nutrient contents compared to dairy wastewaters, 11 heavy metals viz. lead (Pb), nickel (Ni), aluminum (Al), cobalt (Co), cadmium (Cd), arsenic (As), chromium (Cr), copper (Cu), manganese (Mn), iron (Fe) and zinc (Zn) with higher concentrations than other metals, as well as content of carbon (C), nitrogen (N), phosphorus (P), potassium (K) and C/N ratio were measured in both raw dairy wastewater and produced biochar samples. To this end, we used the acid digestion method (Uras et al., 2012). Afterwards, the Whatman No. 2 paper was used to filter solutions. Finally, the inductively coupled plasma optical emission spectrophotometry (ICP/OES) was used to detect element concentrations.

Summary of the backgrounds and standards for determining the measured heavy metals and other elements have been given in Table 1. The international standards given in “Code of Federal 40CFR Regulations” protocols (U.S. EPA, 1977, 1979, 1992) were used as basis for the comparative analyses.

2.3. Experimental setup

A Silty-Loam-Clay (40% clay, 44% silt and 16% of sand) soil from the Chalus Watershed, Mazandaran Province, Northern Iran was used for the study. Soil bulk density, pH, electrical conductivity (EC), organic matter and total nitrogen were 1.16 g cm^{-3}, 7.55, 0.21 dS m^{-1}, 0.57% and 0.09%, respectively. The study soil was air-dried and sized using a 4-mm sieve (Sadeghi et al., 2014, 2016a, 2016b, 2017; Kheirfam et al., 2017a, 2017b).

Three layers of mineral pumice grains with different sizes and a total thickness of 28 cm were used as a filter layer and placed at the bottom of the boxes to simulate natural conditions and decreasing boxes weights (Sadeghi et al., 2014, 2016a and b; Kheirfam et al., 2017a). An approximately 0.075 m^3 of soil was packed in the 0.5 × 0.5 × 0.5-m boxes for each experiment. Unlike conditions governing agricultural lands, no tillage was applied to the experimental plots because of necessity of imitating governing conditions on soil origin. To overcome the disturbance made in soil conditions through collecting and transferring process from study area into the experiment boxes, the soil surface was levelled and compacted manually by a hand roller until natural conditions of hill-slopes of the soil origin was achieved in viewpoint of bulk density. The experimental boxes consisted of control and treated with 400 and 800 g m^{-2} of biochar were set in three replications (Fig. 2). The produced biochar with the help of a small sieve was evenly spread over the surface of the study boxes (Hazbavi and Sadeghi, 2016; Sadeghi et al., 2016a, 2016b). However, in sloping soils, biochar may be lost through wind (Peng et al., 2016). To resolve this, before treating, we moisten the soil surface to increase the adhesion of biochar and soil particles together. To simulate natural condition, the boxes were placed at the outside of the lab on 25% slope (according to the study area slope) for a 30-days period for complete settlement of the soil. The period was arbitrarily selected based on apparent features of the soil conditions which it was supposed to be similar to real conditions and pointed by Galvez et al. (2012), Chintala et al. (2014) and Berihun et al. (2017) as a suitable period for effective influence of biochar on soil properties.

2.4. Some soil quality properties analyses

The soil carbon (C), nitrogen (N), organic matter (OM), and C/N ratio were also considered as accessible soil quality indicators (Kheirfam et al., 2017a; Valle and Carrasco, 2018).

2.5. Statistical analyses

The Shapiroe-Wilk and the Levine's tests were used to test normality