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Fresh and composted industrial sludge restore soil functions in surface soil of degraded agricultural land

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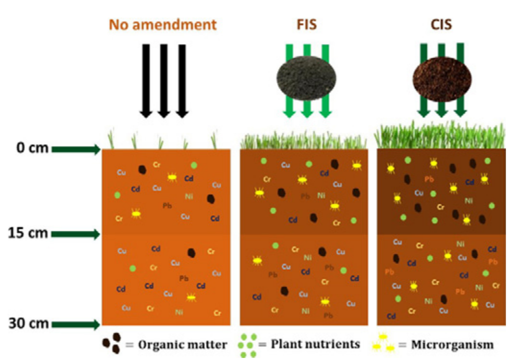
HIGHLIGHTS

- FIS and CIS amended for 5 consecutive years on a degraded agricultural soil.
- Soil quality markedly improved in the surface layer by FIS and CIS amendments.
- FIS and CIS could immobilize heavy metals in surface soil.
- Sludge amendments enhanced agronomic viability of surface soil more than subsurface.
- CIS can be recommended for the restoration of high pH degraded soil.

GRAPHICAL ABSTRACT



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ABSTRACT

A field study was conducted to test the potential of 5-year consecutive application of fresh industrial sludge (FIS) and composted industrial sludge (CIS) to restore soil functions at surface (0–15 cm) and subsurface (15–30 cm) of the degraded agricultural land. Sludge amendments increased soil fertility parameters including total organic carbon (TOC), soil available nitrogen (SAN), soil available phosphorus (SAP) and soil available potassium (SAK) at 0–15 cm depth. Soil enzyme activities i.e. dehydrogenase (DHA), β-glucosidase (BGA) and alkaline phosphatase (ALp) were significantly enhanced by FIS and CIS amendments in surface soil. However, urease activity (UA) and acid phosphatase (ACp) were significantly reduced compared to control soil. The results showed that sludge amendments significantly increased microbial biomass nitrogen (MBN) and microbial biomass phosphorus (MBP) at both soil depth, and soil microbial biomass carbon (MBC) only at 0–15 cm depth. Significant changes were also observed in the population of soil culturable microflora (bacteria, fungi and actinomycetes) with CIS amendment in surface soil suggesting persistence of microbial activity owing to the addition of organic matter source. Sludge amendments significantly reduced soil heavy metal concentrations at 0–15 cm depth, and the effect was more pronounced with CIS compared to unamended control soil. Sludge amendments generally had no

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significant impact on soil heavy metal concentrations in subsoil. Agronomic viability test involving maize was performed to evaluate phytotoxicity of soil solution extract at surface and sub-surface soil. Maize seeds grown in solution extract (0–15 cm) from sludge treated soil showed a significant increase of relative seed germination (RSG), relative root growth (RRG) and germination index (GI). These results suggested that both sludge amendments significantly improved soil properties, however, the CIS amendment was relatively more effective in restoring soil functions and effectively immobilizing wastewater derived heavy metals compared to FIS treatment.

1. Introduction

On global scale, approximately 2 million tons of untreated wastewater is discharged into the earth's waters each day, and utilized to fertigate about 20 million ha of agricultural land (Hussain et al., 2002; Azizullah et al., 2011). Pakistan produces approximately 3643 $\times 10^6$ Mm^3 of untreated wastewater on annual basis (Murtaza and Zia, 2012). At present, only 8% of total wastewater in Pakistan receives primary treatment but only in large urban centres of the country (Pak-SCEA, 2006). Due to limited water resources and extreme climatic variability, the country is started to experience severe water scarcity and now turned into a one of the most water stressed country of the world (Abid et al., 2016). Application of untreated wastewater to agricultural soils could adversely affect their functional capacity (Roohi et al., 2016) thus significantly reducing the ability of soil as a support act medium for plant growth (Fendri et al., 2013; Abegunrin et al., 2016).

Soil degradation can be defined as temporary or persistence loss of productive capacity due to deterioration in soil physical, chemical and biological properties. The extent of this problem is enormous as 25% of global land surface is reduced by degradation, and nearly 1.5 billion people either directly or indirectly affected by this menace (Bai et al., 2008). In terms of processes, soil degradation is mainly triggered by nutrients depletion, pollution, salinization, erosion and/or structural destabilization. Soil degradation is a pervasive problem in the Indo-Gangetic basin of Pakistan, typically characterized by low organic matter content and reduced soil fertility status for agriculture. In addition, lack of good quality water supply could further aggravate the soil productive capacity due to soil compaction, decreasing soil permeability and loss of water holding capacity (D'Odorico et al., 2013).

Incorporating of organic matter from organic waste is one of the convenient and cost-effective options to revitalize degraded soil (Pascual et al., 1998). Soil application of sludge amendment, either fresh or composted, has been proposed as a viable alternative to recycle essential nutrients from organic waste, and to improve soil fertility at lower cost (Benzarti et al., 2007). Sludge amendment improves soil organic matter content and soil fertility (Cellier et al., 2014), as well as, it also promotes soil microbial activity and reduced soil contamination (Petersen et al., 2003).

Textile sludge, a major by-product of textile industry, comprises of processed solid fraction of the industry and contains high concentrations of organic matter and plant nutrients (Balan and Monteiro, 2001). Textile sludge, however, also commonly contains high contaminants load including heavy metals (Islam et al., 2017), dyes (Sonai et al., 2016) and pathogenic microorganisms (Karthik and Rathinamoorthy, 2015). Nonetheless, industrial sludge can be beneficial as a soil amendment on agricultural land as well as in remediation and revegetation projects (Liu et al., 2017).

Most previous studies involving sludge as a soil amendment were mainly focused on sewage derived sludge (Monera et al., 2002; Latare et al., 2014; Alvarenga et al., 2016; Yue et al., 2017). Little information is available about the industrial sludge, in particular, textile sludge application effects on soil properties. A few previous studies have demonstrated the benefits of applying both fresh and composted textile sludge on soil properties (Araújo and Monteiro, 2006; Araújo et al., 2007; Rosa et al., 2007a, 2007b). However, most of these studies related to sludge application on soil are either performed for short-term scale (e.g., days to months) or under controlled laboratory (e.g., pot/microcosm/column) conditions. In this context, a field experiment was carried out to determine the suitability of fresh industrial sludge and its derived compost as amendments for the restoration of degraded alkaline soil which received untreated textile wastewater for 15 years by ascertaining: the effects of 5 year consecutive application of fresh industrial sludge (FIS) and composted industrial sludge (CIS) on (i) physico-chemical, (ii) biochemical, (iii) microbiological, (iv) phytotoxic properties at surface (0–15 cm) and subsurface (15–30 cm). It was hypothesized that the fresh industrial sludge could be phytotoxic and negatively affect the soil properties, but these effects could be reduced by composting sludge for beneficial effects on soil physico-chemical, biochemical and microbiological properties.

2. Materials and methods

2.1. Collection of textile sludge, composting and characterization

In each year, the fresh industrial sludge was collected in November from a local textile unit of Khurrianwala-Faisalabad, Pakistan (31° 29′ N, 73° 16′ E). The sludge was dewatered and anaerobically digested for stability and hygienisation. The sludge was air dried and grinded uniformly to obtain a homogenous mass for an organic amendment. The composted sludge was prepared from same sludge by mixing the compost feedstock (industrial sludge, saw dust and fruiting peels) in an approximate proportion of 4:3:1 (v/v), respectively. This ratio was identified considering both co-compost agents (saw dust and fruiting peels), and to obtain a compost mixture with optimal water content and C/N ratio during composting. These conditions were also essential to improve the porosity, regulate moisture content and provide suitable niche for microbes during the composting process. The compost was prepared in a locally fabricated tin sheets reactor (40 cm × 30 cm × 30 cm, H × L × W). The compost matrices with effective flow rate of 30 L min^{-1} were passively aerated for 15 min after every hour. This passive air flow rate was sufficient to ensure adequate oxygen supply, maximum biological activity and temperature regulation during composting process. Moreover, humidity of the compost mixture was adjusted to 55% by periodic sprinkling of water during first week of composting. The composting process lasted for 60 days, including mesophilic phase (30–40 °C for the first 5–7 days) and thermophilic phase (40–60 °C, 7–35 days) with highest temperature recorded on day 32. At the end of the thermophilic phase, the material was placed in an open container without forced air, and curing phase was concluded at room temperature 25 °C in 18–25 days. Mature compost was used for each year amendment and sub-samples were taken for its physico-chemical analysis. Chemical characteristics of FIS and CIS presented in Table 1 were determined in triplicate as follows: electrical conductivity (EC) and pH were measured in a 1:10 sludge/compost: water extract ratio. Moisture content was determined after drying at 105 °C in an oven for 24 h. Total organic carbon content was determined according to Walkley and Black method. Total nitrogen content was determined by Kjeldahl method. The contents of Na, P, K, Cu, Ni, Cr, Pb and Cd in FIS and CIS were determined as previously described by in Proietti et al. (2015).