Aeolian Research 32 (2018) 102–115

Contents lists available at ScienceDirect

Aeolian Research

journal homepage: www.elsevier.com/locate/aeolia

Chemical composition of windblown dust emitted from agricultural soils amended with biosolids

Huawei Pi[a,b], Brenton Sharratt[c,*], William F. Schillinger[d], Andrew Bary[e], Craig Cogger[e]

[a] State Key Laboratory of Desert and Oasis Ecology, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi, Xinjiang 830011, China
[b] Washington State University, Pullman, WA, USA
[c] USDA-ARS, 215 Johnson Hall, Washington State University, Pullman, WA, USA
[d] Washington State University, Department of Crop and Soil Sciences, Pullman, WA, USA
[e] Washington State University, Department of Crop and Soil Sciences, Puyallup, WA, USA

ARTICLE INFO

Keywords:
Fertilizer
Heavy metals
Sewage sludge
Wind erosion

ABSTRACT

Biosolids are frequently applied to agricultural lands in dry regions, but wind erosion of these lands might transport biosolids particulates offsite and impact environmental quality. Our objective was to measure concentrations of EPA-regulated metals as well as macronutrients and micronutrients in soil and windblown sediment from a biosolids field experiment. A wind tunnel was used to generate windblown sediment from experimental plots subject to traditional (disk) or conservation (undercutter) tillage and application of biosolids or synthetic fertilizer on two measurement dates during the summer fallow phase of a winter wheat-summer fallow (WW-SF) rotation at Lind, WA in 2015 and 2016. Application of biosolids or use of undercutter tillage resulted in higher concentrations of heavy metals in the soil. For example, zinc (Zn) concentration in soil was 14% higher for undercutter than disk tillage and 21% higher for biosolids than synthetic fertilizer on the first measurement date in 2015. Differences in metal concentrations between treatments, however, were not as evident in windblown sediment. Similar results were found for nutrient concentrations in soil, but concentrations in windblown sediment were at least 10% lower for biosolids than synthetic fertilizer and undercutter than disk tillage on at least one measurement date. Little difference was found in loss of heavy metals and nutrients in windblown sediment between biosolids and synthetic fertilizer treatments. Our results suggest similar loss of metals and other elements from agriculture land after application of biosolids and synthetic fertilizer. Biosolids, however, are beneficial for increasing C and N content in soil.

1. Introduction

The treatment of wastewater is an ever-growing environmental concern in maintaining the quality of water resources as the world population rises (Teklehaimanot et al., 2015). The world population is presently 7.6 billion and is growing by 1.1% y^{-1} (United Nations, 2017). Population growth has stressed treatment facilities because of their finite capacity to treat wastewater and store biosolids (Zickefoose, 2013). Therefore, finding more sustainable ways to utilize biosolids could reduce stress on wastewater facilities as communities continue to grow.

Wastewater or sewage sludge can be polluted as a result of harboring enteric bacteria, pathogenic organisms, heavy metals, and particulate matter (Bhat et al., 2013). Since the 1950s, federal legislation in the United States has been strengthened to control water pollution. The treatment of wastewater generates biosolids which are commonly disposed of by incineration or burying in landfills. Application of biosolids to agricultural land to replace synthetic fertilizers and improve quality of degraded agricultural soils represents a relatively safe method to recycle or sustainably use biosolids (Lagae et al., 2009) and is of economic benefit to farmers (Lu et al., 2012).

Sorber et al. (1984) concluded there is little or no risk associated with the land application of liquid biosolids based on the lack of viable pathogens present in air downwind of these lands. Following current US EPA guidelines, there is little risk to human health posed by microbiological entities in properly-treated biosolids based on the rapid degradation of Endocrine compounds (Pepper et al., 2008). Biosolids, however, also contain other harmful ingredients such as heavy metals.

The US EPA analyzed the risk of biosolids to humans, plants, animals, and soil organisms and has set limits on concentrations of 10 elements found in biosolids (USEPA, 1995; National Research Council, 2002). These 10 elements are arsenic (As), cadmium (Cd), chromium

* Corresponding author.
E-mail address: Brenton.sharratt@ars.usda.gov (B. Sharratt).

https://doi.org/10.1016/j.aeolia.2018.02.001
Received 18 October 2017; Received in revised form 1 February 2018; Accepted 6 February 2018
1875-9637/ Published by Elsevier B.V.

(Cr), copper (Cu), lead (Pb), mercury (Hg), molybdenum (Mo), nickel (Ni), selenium (Se), and Zn. The US EPA guidelines did not consider off-site exposure to bioaerosols which can affect human health (National Research Council, 2002; Paez-Rubio et al., 2007). The concentration of certain metals in aerosols emitted during the application of biosolids to agricultural lands in Arizona was observed by Paez-Rubio et al. (2006). They found an order of magnitude higher concentration in regulated metals during the spreading of dewatered biosolids to land. Bhat et al. (2013) reported that Cr, Pb, phosphorus (P), Cd, and manganese (Mn) were present only in bioaerosols collected during application of biosolids and not before or after the application of biosolids to land in Ohio. Baertsch et al. (2007) found the presence of biosolids in 56% of aerosol samples collected downwind of treated agricultural fields during high-wind events in Arizona. They found the biosolids concentration in downwind aerosols was high and varied from 0.1 to 2 g m^{-3}. Yang et al. (2007) confirmed the presence of biosolids in aerosols emitted during tillage of lands amended with biosolids in Arizona.

There is risk for windblown sediment to be enriched or contain high concentrations of metals or other elements if soils amended with biosolids have elevated concentrations of these elements. Macronutrients tend to increase in soil following land application of biosolids. Pepper et al. (2008), for example, indicated that total and available soil phosphate significantly increased in the soil, particularly near the surface, after land application of biosolids in Arizona. A similar increase in soil phosphate was reported by Mantovi et al. (2005) in the Po Valley of Italy and Brendecke et al. (1993) in Arizona. Mantovi et al. (2005) found organic matter (OM) and total nitrogen (N) increased in the soil after the application of biosolids. An increase in soil organic carbon (C) after land application of biosolids was reported by Gibbs et al. (2006) and Mantovi et al. (2005). In western Washington, biosolids were observed to increase soil organic C by 2–5 g kg^{-1} and P by 300–600 mg kg^{-1} (Cogger et al., 2001). Enrichment of the soil in metals or other elements caused by biosolid applications can also be affected by tillage management. Mallmann et al. (2014), for example, found Cu concentrations at threshold values in the topsoil after 86 years of applying pig slurry, but only when using no-tillage versus more intensive tillage practices. Metal concentrations attained threshold values in the topsoil under no-tillage due to non-inversion of the topsoil suppressing movement of metals to deeper layers. Lavado et al. (2001) found tillage (no tillage versus conventional tillage) affected the vertical distribution of metals, but not nutrients, in the soil profile of soybean, wheat and maize cropping systems in Argentina. They reported tillage practices affected root absorption of metals and thus their distribution in the soil profile.

In the Columbia Plateau region of the Pacific Northwest United States, wind erosion threatens sustainable agriculture and environmental quality as a result of removing topsoil and emitting fine particulate matter into the atmosphere. Wind erosion is most evident in the low precipitation zone ($<$ 300 mm annual precipitation) where 1.5 million ha are managed in a WW-SF rotation. Scant precipitation, low biomass production, fragile soils, and tillage-based summer fallow contribute to the erodibility of agricultural land in this zone. Fine particulate matter is emitted from soils into the atmosphere primarily during the fallow phase of the rotation and has negatively impacted air quality since the US EPA began regulating atmospheric fine particulate (particles $\leq$ 10 µm in aerodynamic diameter or PM10) concentrations in 1987 (Sharratt and Lauer, 2006; Sharratt and Edgar, 2011). Wind erosion not only removes fine particulate matter from the surface, but could potentially transport surface-applied biosolids offsite without proper application and management (Pi et al., 2018).

We are not aware of published reports documenting emissions of metals or nutrients in windblown sediment after applying biosolids to agricultural lands. The purpose of this study was to determine the concentrations of metals and nutrients in windblown dust associated with biosolids applications to a field maintained in a WW-SF rotation. Our primary focus was on elements that are of environmental concern when applying biosolids to land.

2. Materials and methods

2.1. Field site description

This field experiment was conducted in 2015 and 2016 at the Washington State University Dryland Research Station located near Lind, Washington (47°00′N, 118°34′W). The Station is located in the low-precipitation zone of the Columbia Plateau and receives 242 mm y^{-1} of precipitation. Agriculture is the main industry and WW-SF is the dominant crop rotation throughout this precipitation zone.

Two sets of plots were established at the Lind Station so that both the wheat and fallow phases of the WW-SF rotation were present every year. The 2015 set of plots was established on a Ritzville silt loam (13% clay, 60% silt, 27% sand and 0.7% organic matter) which has a mean particle diameter of 24 µm. The 2016 set of plots was established on a Shano silt loam (10% clay, 55% silt, 34% sand and 1.0% organic matter) which has a mean particle diameter of 36 µm. Both soil types are highly susceptible to wind erosion which is exacerbated by little precipitation, low crop biomass production, and multiple tillage operations during the fallow phase of the rotation. High winds typically occur in March-April and September-October and coincide with primary tillage in spring and sowing winter wheat in late summer.

Tillage and fertilizer treatments were applied during the fallow phase of the rotation. The fallow phase of the rotation began after wheat harvest in July and ended 13 months later with sowing winter wheat in early September. Plots remained undisturbed after harvest until primary tillage the following spring. Treatments were applied in a split-block experimental design with four replications. Tillage was the main plot factor and fertilizer was the subplot factor. Primary tillage treatments were traditional tillage (hereafter referred to as disk tillage) using a tandem disk implement and conservation tillage (hereafter referred to as undercutter tillage) using an undercutter implement with 0.8 m wide sweeps. The disk and undercutter implement respectively mix and cut parallel to the surface without inverting the soil to a depth of 0.1 m. A rodweeder, which was set to a depth of 0.1 m, was used to control weeds between primary spring tillage and sowing winter wheat. Fertilizer treatments were applied at the time of primary spring tillage and included the use of synthetic or biosolids fertilizer. Size of individual main plots was 76 × 8 m and subplots 38 × 8 m.

Class B biosolids, obtained from the King County Wastewater Treatment Division (Seattle, Washington), were applied at a rate of 6508 kg ha^{-1} (dry weight) to both the disk and undercut treatments during the fallow phase of the rotation. Biosolids were applied using a manure spreader to the 2015 set of experimental plots on 4 May 2015 and to the 2016 set of experimental plots on 19 April 2016. Biosolids were spread on the plots at a rate to meet the nutrient requirements for two winter wheat crops. Thus, experimental plots used in 2015 received their first application of biosolids in 2011 and experimental plots used in 2016 received their first application of biosolids in 2012. Biosolids were incorporated into the soil to a depth of 0.1 m using disk or undercutter tillage.

Synthetic fertilizer was applied as liquid aqua NH_3-N plus thiosol S at a rate of 56 kg N plus 11 kg S ha^{-1} to both the disk and undercut treatments to meet the nutrient requirements of one winter wheat crop. Thus, experimental plots received an application of synthetic fertilizer every other year. Synthetic fertilizer was injected into the soil at a depth of 0.1 m during primary spring tillage with the undercutter implement. In the disk treatment, synthetic fertilizer was applied to the soil surface and then incorporated into the soil to a depth of 0.1 m. Fertilizer treatments were applied to plots on 4 May 2015 and 19 April 2016. In 2015, experimental plots were rodweeded to a depth of 0.1 m on 15 June and sown to wheat on 8 September using a deep furrow grain drill. In 2016, plots were rodweeded on 3 June and 10 July and sown to wheat on 2 September.