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Wind erosion potential of a winter wheat–summer fallow rotation after land application of biosolids

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ABSTRACT

Conservation tillage is a viable management strategy to control soil wind erosion, but other strategies such as land application of biosolids that enhance soil quality may also reduce wind erosion. No studies have determined the effects of biosolids on wind erosion. Wind erosion potential of a silt loam was assessed using a portable wind tunnel after applying synthetic and biosolids fertilizer to traditional (disk) and conservation (undercutter) tillage practices during the summer fallow phase of a winter wheat-summer fallow (WW-SF) rotation in 2015 and 2016 in east-central Washington. Soil loss ranged from 12 to 61% lower for undercutter than disk tillage, possibly due to retention of more biomass on the soil surface of the undercutter versus disk tillage treatment. In contrast, soil loss was similar to or lower for biosolids as compared with synthetic fertilizer treatment. Our results suggest that biosolids applications to agricultural lands will have minimal impact on wind erosion.

1. Introduction

Sustainable agriculture involves the production of food, fiber, and/or feed with minimal harm to ecosystems, animals or humans (Seufert et al., 2012). For decades, biosolids generated from wastewater treatment plants have been applied to agricultural fields to replace fertilizer as a sustainable management strategy in the United States (Bhat et al., 2013). With an ever growing world population, the generation of wastewater and biosolids will continue to rise.

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 (Lu et al., 2012). To reduce pollution, wastewater undergoes physical, chemical, and biological treatment at treatment facilities. Effluent resulting from primary treatment of wastewater can be further processed for discharging into surface water systems or the irrigation of crop or public land. Sewage sludge, or the semi-solid slurry collected during primary treatment of wastewater, contain organisms, chemicals, or particulate matter in concentrations that are harmful to humans (Lu et al., 2012). For this reason, sewage sludge undergoes digestion to stabilize organic matter and reduce levels of harmful organisms. The solids that remain after digestion are then referred to as biosolids which are typically dewatered before being transported for application on fields.

Applying biosolids to agricultural land in lieu of synthetic fertilizers is a relatively safe method to recycle or sustainably use biosolids even though biosolids originate from sewage sludge (Lagae et al., 2009). In addition, there is an economic benefit to using biosolids in agroecosystems (Lu et al., 2012). Concerns about the economic, environmental, and social impacts of traditional agricultural practices have led many farmers to seek more sustainable practices (Reganold et al., 1993). With proper application techniques (e.g. rate, depth), biosolids may be a more economical and sustainable practice than use of synthetic fertilizer to meet the nutrient requirements of crops (Lagae et al., 2009; Cogger et al., 2013). Biosolids also contain organic matter which is vital to maintaining soil health (Brady, 1990).

Biosolids are typically applied to agricultural lands in arid and semiarid regions because of the low risk for runoff after precipitation events (Cogger et al., 2001). Wind erosion, however, can be an environmental concern in arid and semiarid regions due to emission of particulates into the atmosphere. Wind erosion could thus potentially transport surface-applied biosolids offsite (Lagae et al., 2009). Liquid or dewatered biosolids are typically spread onto the soil surface and then incorporated into the soil to minimize odors and volatilization of ammonia (Lu et al., 2012). Biosolids may influence soil erodibility as they

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contain relatively high amounts of organic matter and nutrients. Altering the chemical and/or biological composition of the soil may influence soil physical properties and/or plant growth and thus the erodibility of the soil. For example, Garcia-Orenes et al. (2005) found an increase in aggregate stability after applying dewatered biosolids to degraded soils. Wallace et al. (2010) also found an increase in aggregate size and stability after applying dewatered biosolids to a semiarid soil in Canada. Soil particle or aggregate size has a dramatic effect on wind erosion processes as more energy is required to lift and transport larger particles or aggregates (Zobeck, 1991). The increase in aggregate size noted by Wallace et al. (2010) may reduce wind erosion from agricultural land based on the reduction in the soil erodibility factor (Pi et al., 2017).

Previous studies related to wind erosion or windblown particulate emissions from soil amended with biosolids have focused on transport of pollutants during application. Paez-Rubio et al. (2006) found that PM10 (particulate matter $\le 10\,\mu m$ in diameter) emissions were three times lower when disking agricultural soils that had been amended versus non-amended with surface-applied dewatered biosolids. They attributed the reduction in PM10 emissions to higher moisture content of the amended versus non-amended soil. Similarly, Akbar-Khanzadehet al. (2012) reported that application of dewatered biosolids to dry soil resulted in an increase in soil moisture and subsequent reduction in particulate emissions when incorporating biosolids into the soil. Bhat and Kumar (2012) found particulate emissions highest during, rather than before or after, application of liquid biosolids to agricultural soils in Ohio. They suggested that disturbing the soil during injection of biosolids (to a depth of 0.6 m) was one possible reason for the high particulate emissions. Paez-Rubio et al. (2007) measured particulate emissions as dewatered biosolids were applied to agricultural soils using a manure spreader in Arizona. They found 7.6 mg of biosolids were aerosolized for every 1 kg of biosolids that were applied to soils.

Soil amended with biosolids could be especially valuable in the WW-SF region of the Inland Pacific Northwest (PNW) where conservation-tillage and no-tillage management practices have failed to significantly bolster soil organic matter due to relatively low stable carbon content of wheat residue and modest production levels (Gollany et al., 2013). There is, however, potential risk associated with biosolid particulates being emitted from the soil surface into the atmosphere and adversely affecting air quality. Sullivan et al. (2007) suggested that enhancements in soil physical properties (e.g. aggregation, water retention, infiltration) resulting from applications of biosolids can reduce soil erosion, thus minimizing the risk of off-site transport of biosolid particulates.

Wind erosion is of paramount importance in the low-precipitation zone (< 300 mm of annual precipitation) of the PNW where 1.5 million ha are managed in a WW-SF rotation (Schillinger et al., 2006). Emission of soil particulates from land managed in conventional tillage-based WW-SF has caused road closures and exceedance of National Ambient Air Quality Standards for PM10 during high wind events (Sharratt and Lauer, 2006). For this reason, Sharratt and Feng (2009) and Sharratt et al. (2010) focused attention on conservation or reduced tillage practices in WW-SF to control wind erosion in the region. While undercutter tillage has been proven to reduce wind erosion by up to 65% as compared with conventional tillage in WW-SF (Sharratt and Feng, 2009), other methods are yet sought to control wind erosion. We are not aware of published reports that document the influence of biosolids application on wind erosion of agricultural lands which, if successful, will improve air quality in the region. Thus, the focus of this study was to determine the wind erosion potential associated with application of biosolids to land in a WW-SF rotation.

2. Materials and methods

2.1. Field site description

Field experiments were conducted in 2015 and 2016 at the Washington State University Dryland Research Station located near Lind, Washington (47°00′N, 118°34′W). Lind is located in the low precipitation zone of east-central Washington and receives 242 mm of average annual precipitation. Winter wheat-summer fallow is the dominate rotation practiced throughout the region. The experiment was conducted on a Ritzville silt loam (coarse-silty, mixed, superactive, mesic Calcidic Haploxerolls) in 2015 and a Shano silt loam in 2016. Although sets of experimental plots were located 0.7 km apart and subject to the same climatic conditions, Ritzville silt loam had a geometric mean particle diameter of 24 μm, 13% clay, 61% silt, 26% sand, and 0.7% organic matter while Shano silt loam had a geometric mean particle diameter of 31 μm, 9% clay, 56% silt, 35% sand, and 0.7% organic matter. Soils in the WW-SF region of the PNW are highly susceptible to wind erosion due to meager precipitation, low 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 during the fallow phase of the rotation in spring and the subsequent sowing of winter wheat in late summer (Papendick, 2004).

Our experiment was configured as a split-block design with four replications. Main plot treatments were tillage and subplot treatments were fertilizer. Tillage treatments were traditional tillage using a tandem disk implement and conservation tillage using an undercutter implement. Size of individual main plots were 76×8 m and subplots were 38×8 m. Fertilizer treatments were either synthetic or biosolids fertilizer.

Wind erosion assessments were made after primary tillage and sowing winter wheat in 2015 and 2016, although on different sets of experimental plots. The plots were harvest the preceding July and were not disturbed until Glyphosate herbicide [N-(phosphonomethyl) glycine] was applied at rate of 0.43 kg acid equivalent ha^{-1} to control weeds in mid-April 2015 and 2016. Class B biosolids, obtained from the King County Wastewater Treatment Division, Seattle, Washington, were then applied using a manure spreader to one set of experimental plots on 4 May 2015 and to the other set of experimental plots on 19 April 2016. Biosolids were applied at a rate to meet the nutrient requirements for two crop years. 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. The dewatered biosolids were applied at a rate of 6508 kg ha^{-1} to traditional and conservation tillage (hereafter referred to as respectively disk and undercutter tillage) main plots during the fallow phase of the rotation. Synthetic fertilizer (56 kg N ha^{-1} plus 11 kg S ha^{-1}) was broadcast on the surface of plots prior to disk tillage or injected into the soil during undercutter tillage. Immediately (within 2 h) after surface-applying biosolids or synthetic fertilizer (4 May 2015 and 19 April 2016), the plots were tilled to a depth of 0.13 m in both the disk and undercutter tillage treatments (note that synthetic fertilizer was injected below the soil surface with the undercutter during tillage). The undercutter implement has 0.8-m wide sweeps that slice beneath the soil with minimal disturbance of surface crop residue. In 2015, plots were rodweeded to a depth of 0.1 m on 15 June and sown to winter wheat on 8 September using a deep furrow grain drill. In 2016, plots were rodweeded on 3 June and 10 July and sown to winter wheat on 2 September.

2.2. Measurement of wind erosion potential

Horizontal sediment flux representative of a high wind event in the PNW was assessed soon after rodweeding and sowing operations using a portable wind tunnel. Sediment flux of treatments was measured on 18 June and 10 September 2015 and on 6 June and 7 September 2016.