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Nitrogen loss from windblown agricultural soils in the Columbia Plateau

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ABSTRACT

Wind erosion of agricultural soils can degrade both air quality and soil productivity in the Columbia Plateau of the Pacific Northwest United States. Soils in the region contain fine particles that, when suspended, are highly susceptible to long range transport in the atmosphere. Nitrogen (N) associated with off-site transport of windblown particulate matter depletes the parent soil of nutrients important in sustaining the biological activity of soils. The objective of this study was to quantify the loss of N from eroding agricultural fields during high wind events. Soil eroded from fields subject to conventional tillage in winter wheat–summer fallow rotations in eastern Washington was trapped in creep and Big Spring Number Eight (BSNE) samplers installed on the leeward side of fields at heights of 0–1.5 m above the surface. The location of field sites varied over the 8 years of this study, but all sites were characterized by soils with a silt loam texture and annual precipitation of $\leqslant$305 mm. Nitrogen content of the parent soil ranged from 0.063% to 0.090% while N content of sediment trapped by the samplers during high winds ranged from 0.053% to 0.101%. Enrichment ratios (ERs) for N ranged from 0.8 to 1.3, indicating the sediment was not highly enriched in N as compared with the parent soil. Nitrogen loss was estimated to range from 0.1 to 1.9 kg ha^{-1} during a high wind event. Nitrogen loss may be reduced by using conservation practices that have been proven effective in controlling wind erosion.

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1. Introduction

Wind erosion can impact the climate and natural resources of regions throughout the world. Intercontinental transport of windblown sediment from Asia, for example, has been found to influence the climate and air quality in North America (Husar et al., 2001). Wind erosion is a selective process that winnows finer particulates from the parent soil and is largely influenced by climate, human activity, soil type, and vegetation. The finer soil fraction, which is particularly vulnerable to detachment from the surface and transport in the atmosphere during high winds, is generally enriched with nutrients and thus comprises the most fertile part of the soil resource (Zhang et al., 2003; Zobeck and Fryrear, 1986). Nutrients contained in windblown sediment transported offsite represent a loss of a valuable resource important in sustaining the biological activity of soils.

Degradation of air quality caused by wind erosion is of particular concern in the Columbia Plateau region of the Pacific Northwest United States. Windblown dust emitted from agricultural lands has caused vehicular accidents due to poor visibility (Graman, 2009; Hudson and Cary, 1999) and exceedance of the US Environmental Protection Agency ambient air quality standard for PM10 (particulate matter $\leqslant$ 10 μm in aerodynamic diameter) in the region (Sharratt and Lauer, 2006). Exceedance of the air quality standard for PM10 largely occurs during the passage of intense, synoptic, low-pressure systems. High winds generated by these low-pressure systems are effective in eroding dry, unconsolidated, and unprotected soils.

Although annual precipitation varies from about 150 to 700 mm across the Columbia Plateau region, the zone with <300 mm of annual precipitation (low precipitation zone) is very susceptible to wind erosion (Schillinger and Young, 2004). Winter wheat-summer fallow is the principle and most profitable crop rotation employed in the low precipitation zone (Schillinger et al., 2007). During the 13-month fallow phase of the rotation, soils are tilled using sweeps, disks, or cultivators after wheat harvest in late summer and/or the following spring and then rodweeded to control weeds during summer (Schillinger, 2001). Tillage-based summer fallow creates a “soil mulch” that is far superior to no-tillage summer fallow in conserving stored soil water during the dry and hot summer (Wuest and Schillinger, 2011). Winter wheat is sown beneath the soil mulch layer with deep-furrow drills in late August to reach adequate seed-zone

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moisture for germination and emergence (Schillinger et al., 2006). While tillage-based summer fallow is a highly effective land management system for establishing winter wheat in the low precipitation zone, this system creates a surface that is very susceptible to wind erosion. For example, Sharratt et al. (2007) have documented soil losses as high as 2.3 Mg ha^{-1}, but Schillinger and Papendick (2008) have estimated soil losses as high as 180 Mg ha^{-1}from tillage-based summer fallow during singular high wind events in the region.

The amount of nutrients in airborne sediment typically decreases while the enrichment ratio (ER), or the ratio of nutrient concentration in the windblown sediment to that in the parent soil, increases with height above an eroding surface. Zobeck and Fryrear (1986) observed an increase in concentration of extractable cations (Ca, K, Mg, and Na) above an eroding sandy soil in Texas while Van Pelt and Zobeck (2007) found that the ER for total N and NO_3 were respectively 0.8 and 0.4 at 0.2-m height and 1.8 and 0.9 at 1-m height above an eroding agricultural field. Li et al. (2009) and Sterk et al. (1996) also reported an increase in the ER for N with height above respectively an eroding sand in the Chihuahuan Desert and an agricultural soil in the Sahel. This trend in ER with height likely occurs in response to the vertical sorting of particles with finer particles being transported farther from the eroding surface. For example, Van Pelt and Zobeck (2007) noted the ER of many chemical species, including total N and NO_3, in agricultural soils or windblown sediment was greater for the fine-size versus coarse-size fraction. Hagen and Lyles (1985) reported an enrichment ratio of 3.1, 2.25, and 1.67 for respectively N, P and K in the fine-size fraction abraded from large soil aggregates. Sankey et al. (2012) observed enrichment in macronutrient (Ca, K, Mg, and P) and micronutrient (Cu, Fe, and Mn) concentration of windblown sediment soon after a fire consumed a desert shrubland in southeastern Idaho. However, they observed higher nutrient concentrations in the coarser-size fraction of either the parent soil or eroded sediment. Blank et al. (1999) examined the concentration of soluble solutes (NO_3–N, NH_4–N, SO_4, Na, K, B, C_2O_4, S) in windblown dust collected over two years at three locations within and adjacent to a playa in Nevada. They found windblown sediment to be enriched in all solutes, with the enrichment ratio varying from 13.6 to 73.5 for NO_3–N and from 2.7 to 67.1 for NH_4–N across locations.

Nitrogen in the environment is important from the standpoint of air, soil, and water quality; climate change; and plant nutrition. For example, degradation of water quality has been linked to deposition of N-rich windblown sediment onto riparian areas or surface waters in Australia (Leys and McTainsh, 1999). Emission of nitrous oxide, a greenhouse gas, from soils can accelerate warming of the atmosphere. Nitrogen is a primary macronutrient essential for plant growth and is the most common nutrient applied by farmers to bolster crop and animal production. Thus, loss of N from soil to the environment by erosion, leaching, or volatilization represents the loss of a resource that has major economic value to farmers. Despite the importance of minimizing the loss of N to the environment, previous field studies have focused specifically on nutrient concentrations in windblown sediment (Blank et al., 1999; Van Pelt and Zobeck, 2007). Wang et al. (2006) estimated an annual N loss of 6 to 768 kg ha^{-1} from windblown soils across northern China, but their estimates were based upon measured soil loss and an approximation of N content of the parent soil. Similarly, Hasselquist et al. (2011) measured an annual N loss of 123 kg ha^{-1} from newly burned desert shrubland in southern Idaho while Sterk et al. (1996) measured N loss of 5 to 13 kg ha^{-1} from sand cropped to pearl millet during singular high wind events in the Sahel. We are not aware of other studies documenting measured losses of N from agricultural lands by wind erosion.

Limited information exists regarding nutrient concentration in windblown sediment across a diversity of climates, land management systems, and soils. We are not aware of information available that documents N concentration or loss in sediment eroded from loess soils managed for agricultural production. The objective of our study was therefore to quantify N concentration and loss in sediment eroded from loess soils in summer fallow during high wind events in the Columbia Plateau.

2. Materials and methods

This study assessed N loss associated with sediment discharge from eroding agricultural fields in the Columbia Plateau of eastern Washington. Sediment transported by creep, saltation, and suspension was collected at field sites managed and owned by farmers during high wind events that occurred in 1999–2001, 2003–2006, and 2012. All sites were located in the low precipitation zone (annual precipitation < 300 mm) of the Columbia Plateau (Fig. 1). This precipitation zone encompasses 1.5 million hectares of dryland crops. Soils at the field sites were silt loam and contained 1.5% organic matter.

2.1. Field sites

Sediment discharge was assessed at field sites that were in the summer fallow phase of a winter wheat-summer fallow rotation. The tillage-based summer fallow phase of the rotation begins after wheat harvest in July and ends at the time of sowing the subsequent wheat crop the following late August or early September. Multiple tillage operations during summer fallow create a partially-denuded and fine-grained soil surface highly susceptible to wind erosion. The field sites in 1999, 2000, 2001 and 2004 were tilled with chisels or sweeps after wheat harvest the previous autumn and also with sweeps or disks in spring and then rodweeded (using a square bar that rotates counterclockwise to the direction of travel to uproot weeds) two to three times prior to sowing winter wheat. The field site in 2003 was cropped to wheat in 2001 and then in summer fallow in 2002 and 2003. In 2003, the site was disked in spring and then rodweeded five times during summer and early autumn. The field sites in 2005, 2006 and 2012 were undercut with a conservation tillage implement having wide v-shaped sweeps during the spring following wheat harvest and then rodweeded two to three times prior to sowing winter wheat. Winter wheat was sown on 6 Sep 1999, 5 Sep 2000, 28 Aug 2001, 27 Aug 2004, 31 Aug 2005, 27 Aug 2006, and 29 Aug 2012. Wheat was not sown in 2003. Fertilizer (aqua or anhydrous ammonia) was injected 0.1–0.15 m into the soil at a rate of 40–50 kg N ha^{-1} during or immediately after spring tillage in preparation for sowing wheat later that summer. Little loss of N from denitrification or leaching occurs from the time of application to sowing wheat due to the lack of precipitation and presence of a dry soil mulch layer above the depth of fertilizer injection.

2.2. Sediment loss

Sediment discharge at the field sites was assessed at the end of the summer fallow phase of the rotation and near the time of seeding of winter wheat. The soil is most exposed to the forces of wind at this time in the rotation. Sediment discharge was assessed by monitoring horizontal sediment flux at both the windward and leeward positions in the field. High winds typically occur in late summer and early autumn with winds predominately from the SW. Fields were either square or rectangular with a minimum and maximum fetch of respectively 150 m (2012) and 1 km (2001) during high wind events. The windward (south and west)