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Wind erosion and PM10 emission affected by tillage systems in the world's driest rainfed wheat region

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ABSTRACT

The Horse Heaven Hills of south-central Washington is the driest rainfed wheat growing region in the world. Low precipitation, high winds, poorly aggregated soils, sparse residue cover, and a tillage-based winter wheat (*Triticum aestivum* L.) – summer fallow (WW-SF) cropping system often combine to create soil surfaces which are susceptible to wind erosion. No-tillage summer fallow (NTF) and conservation tillage fallow (CTF) with an undercutter sweep implement were examined as alternative practices to traditional tillage fallow (TTF) with a tandem disk implement for reducing wind erosion and PM10 (particulate matter ≤10 μm in aerodynamic diameter) emissions during the fallow phase of the WW-SF rotation. Wind erosion and PM10 emissions were assessed with a wind tunnel after primary spring tillage in mid-to-late April and after sowing winter wheat in August. Sediment loss and PM10 vertical flux and loss were generally less for NTF than with TTF, likely due to retention of surface residue and maintaining a soil crust in NTF. Sediment and PM10 loss increased after sowing wheat in both the TTF and CTF treatments. Although NTF abated the loss of sediment and PM0 compared with TTF, NTF is not yet an economical option for most growers in the region. Conservation tillage fallow using the undercutter sweep is an economically viable alternative to TTF for reducing windblown sediment and PM10 loss from agricultural soils in the Horse Heaven Hills.

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1. Introduction

High winds, poorly aggregated soils, low biomass production, tillage-based summer fallow, and extended time periods without precipitation promote wind erosion of agricultural lands in the Columbia Plateau region of the US Pacific Northwest. Wind erosion impacts air quality in this region due to the emission of fine sediment or dust into the atmosphere during high winds. The sediment-laden air sometimes forces road closures due to zero visibility and is enriched in PM10 (particulate matter ≤10 μm in aerodynamic diameter), an air pollutant that adversely affects human health (Dockery and Pope, 1994; Paden, 2001). Based on the linkage between high PM10 concentration and respiratory ailments, air quality standards have been set for PM10 (USEPA, 2006). PM10 represents the chemically active portion of soil and has the potential to transport heavy metals, pesticides, and microbes (Garrison et al., 2003; Whicker et al., 2006). In addition, PM10 can also transport nutrients and organic matter that will affect soil productivity (Van Pelt and Zobeck, 2007). Zhang et al. (2003) suggested that fine particulates represent the most fertile part of the soil resource.

Wind erosion has long been a problem in the western United States. In the drier (<300 mm annual precipitation) zone of the Inland Pacific Northwest, where rainfed winter wheat is produced every other year on land managed in a WW-SF rotation, controlling wind erosion to maintain air quality is a major challenge for growers (Saxton et al., 2000). Wind erosion, mainly occurring from March through October, is a major cause of soil loss and also significantly degrades air quality.

Low precipitation, with the majority of precipitation occurring in winter, necessitates the use of summer fallow to store a portion of over-winter precipitation in the soil for successful establishment and profitable production of winter wheat. Average annual precipitation in the Horse Heaven Hills of south-central Washington, where 120,000 hectares is devoted to WW-SF production, ranges from a high of 200 mm in the east to a low of 150 mm in the west (Fig. 1). The western portion of the Horse Heaven Hills is considered the driest rainfed wheat producing region in the world (Schillinger and Young, 2004).

Summer fallow is necessary for profitable wheat production compared to alternate management practices such as no-tillage annual cropping in the low precipitation zone of the Inland Pacific

Abbreviations: CTF, conservation tillage fallow; NTF, no-tillage fallow; TTF, traditional tillage fallow; WW-SF, winter wheat-summer fallow.

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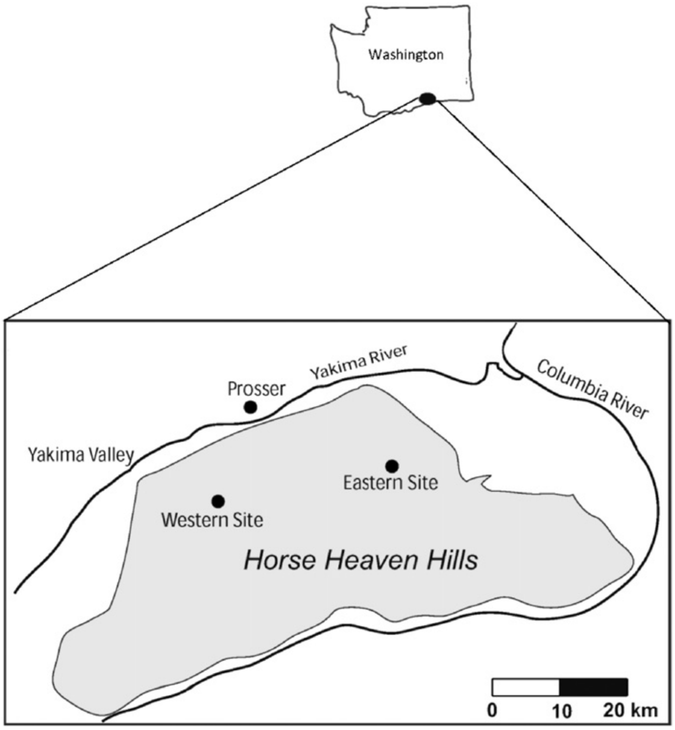

Fig. 1. Location of the Eastern and Western field sites in the Horse Heaven Hills of Washington.

Northwest (Schillinger and Young, 2004). During the summer fallow phase of the rotation, growers do not typically disturb the standing wheat stubble that remains after grain harvest in July until April or May when primary spring tillage is conducted with a tandem disk, duck-foot cultivators, or undercutter sweeps. The tandem disk and cultivator partially invert the soil and bury considerable wheat residue whereas the undercutter sweep slices below the surface and lifts the soil with minimal residue burial. The purpose of primary spring tillage is to break soil capillary continuity by creating a loose, dry surface layer to retard evaporation of stored soil water during the dry summer months (Papendick et al., 1973; Lindstrom et al., 1974; Hammel et al., 1981). Weeds are controlled during late spring and summer with a rodweeder which consists of a square bar that rotates under the soil surface in the opposite direction of travel to uproot weeds. If adequate seed-zone water is available, growers sow winter wheat into moist sub-soil with deep-furrow drills in mid-to-late August. Timely winter wheat emergence through the loose, dry surface layer (generally >10 cm thick) is extremely important because grain yield is reduced by 30% or more when sowing is delayed until the onset of rains in mid October or November (Donaldson et al., 2001). No-tillage summer fallow is not widely practiced in the Horse Heaven Hills because soil drying occurs to a deeper depth compared with tilled fallow (Singh et al., 2011; Hammel et al., 1981) which does not allow sowing winter wheat into sub-surface soil moisture.

Despite the advantage of using tillage to conserve soil water, multiple tillage operations degrade soil aggregates and expose the soil to high winds. Tillage not only degrades the soil, but also reduces residue cover (Wagner and Nelson, 1995) and surface roughness (Römkens and Wang, 1986; Zobeck and Onstad, 1987). Residue cover and surface roughness affect the wind speed at the surface; an increase in cover or roughness reduces wind erosion (Fryrear, 1984, 1985; Horning et al., 1998). Alternate tillage practices are therefore sought that will enhance residue cover as well as surface roughness of soils during summer fallow in the Columbia Plateau. No-tillage summer fallow and CTF using the undercutter sweep method are two alternate practices that may enhance residue cover and surface roughness and reduce wind erosion. With NTF, herbicides are used to control weeds and thus retain residue and soil structure throughout the fallow period. Conservation tillage minimizes soil inversion by using wide-blade sweeps to undercut the soil. Sharratt and Feng (2009) found that CTF with the undercutter reduces wind erosion and PM10 emissions by as much as 70% as compared with TTF in eastern Washington where annual precipitation is >200 mm.

The objective of this study was to determine the effectiveness of alternative tillage practices in reducing wind erosion and dust emissions from soils during the summer fallow phase of a WW-SF rotation in the Horse Heaven Hills of south-central Washington. Of particular interest was comparing erosion and PM10 emissions from NTF, CTF, and TTF practices.

2. Materials and methods

The potential for wind erosion and PM10 emissions was assessed in 2007 on land owned and operated by two wheat growers located in the eastern and western portions of the Horse Heaven Hills (Fig. 1). The crop rotation practiced by both growers was WW-SF. The fallow phase of the rotation began after wheat harvest in July 2006 and continued until sowing winter wheat in August 2007.

The distance between the two sites was 30 km. The sites were characterized by a slope of <2% and soil depth of >1.5 m. Average annual precipitation is about 200 mm at the Eastern site and 165 mm at the Western site. The soil at the Eastern site (46°08′N, 119°28′W and elevation of 440 m) is a Ritzville silt loam (coarse-silty, mixed, superactive, mesic Calcidic Haploxeroll) consisting of 33, 54, 13% sand, silt, and clay and at the Western site (45°59′N, 119°51′W and elevation of 240 m) a Warden silt loam (coarse-silty mixed, superactive, mesic Xeric Haplocambid) (Rasmussen, 1971) consisting of 36, 50, 14% sand, silt, and clay.

2.1. Tillage treatments

Traditional tillage fallow, CTF, and NTF treatments were established in 2007 at both the Eastern and Western sites. The design of the experiment was a randomized complete block with four replications. Individual plot size was 61 m × 18 m. For the TTF treatment, glyphosate [*N*-(phosphonomethyl) glycine] herbicide was applied in early April. The soil was disked to a depth of 13 cm on 18 April at the Eastern site and 9 April at the Western site. Liquid aqua NH_3–N fertilizer was injected with shanks spaced 30 cm apart in June. The soil was subsequently rodweeded at a depth 10 cm in June and July at the Eastern site and June and early August at the Western site. For the CTF treatment, glyphosate herbicide was applied in April. The plots were undercut and fertilized with aqua NH_3–N to a depth of 13 cm in one pass with overlapping 0.7-m-wide V-blades on 18 April at the Eastern site and 9 April at the Western site. The soil was rodweeded to a depth of 10 cm in June and July at the Eastern site and June and early August at the Western site. In the NTF treatment, the soil remained undisturbed throughout the 13-month fallow period. Weeds in NTF were controlled with application of glyphosate herbicide in April and June at the Eastern site and April and July at the Western site.

One-half of the TTF and CTF plots were sown to winter wheat on 11 August and 23 August at the Eastern and Western sites, respectively. The purpose of sowing one-half of the plots was to simulate two scenarios that typically occur when sowing winter wheat in the Horse Heaven Hills. In years with adequate seed-zone water, growers sow winter wheat in mid-to-late August to maximize grain yield. In years with insufficient seed-zone water,