Soil & Tillage Research 110 (2010) 221–229

Contents lists available at ScienceDirect

Soil & Tillage Research

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

Tillage effects on soil water redistribution and bare soil evaporation throughout a season

R.C. Schwartz *, R.L. Baumhardt, S.R. Evett

USDA-ARS, PO Drawer 10, Bushland, TX 79012, USA

ARTICLE INFO

Article history:
Received 28 January 2010
Received in revised form 10 June 2010
Accepted 29 July 2010

Keywords:
Tillage
Evaporation
Soil water
Infiltration

ABSTRACT

Tillage-induced changes in soil properties are difficult to predict, yet can influence evaporation, infiltration and how water is redistributed within the profile after precipitation. We evaluated the effects of sweep tillage (ST) on near surface soil water dynamics as compared with an untilled (UT) soil during a 7-month period. Plots were established in a fallow field devoid of residue under stubble–mulch tillage management on a clay loam soil. Soil water contents were monitored using time-domain reflectometry at 0.05–0.3 m and using a neutron moisture gage to a depth of 2.3 m. Soil temperature and net radiation was also monitored. During a 114-day period from April through July, tillage with a sweep (0.07–0.1 m) significantly decreased net water storage above 0.3 m soil depth by an average of 12 mm ($P = 0.002$) as compared with UT plots. After tillage, soil water contents at 0.05 and 0.1 m were significantly ($P < 0.05$) lower in ST plots, even following repeated precipitation events. Water contents at soil depths $\geq$0.2 m were not influenced by tillage. Cumulative 3-day evaporation following precipitation events averaged 3.1 mm greater under ST compared with UT ($P < 0.014$). After extended dry periods, evaporation rates were similar among both treatments ($\sim$0.3 mm d^{-1}) despite the greater near-surface water contents of UT plots. Although ST plots exhibited 19 mm greater cumulative evaporation from July through October, this was offset by 26 mm greater infiltration compared with UT. A more advanced surface crust development and greater initial water contents were likely responsible for lower cumulative infiltration of UT compared with ST plots. Immediately after tillage, cumulative daily net radiation averaged 22% greater for ST compared with UT surfaces and these differences diminished with time. Increased evaporation under tillage was likely a result of enhanced vapor flow near the surface and greater absorption of radiation by a tilled surface with reduced albedo.

Published by Elsevier B.V.

1. Introduction

Tillage-induced changes in soil properties are difficult to predict, yet can influence infiltration, redistribution of water within the profile, subsequent evaporation rates, and water availability to crops. The influence of tillage on soil hydraulic properties and infiltration are not always consistent across location and soils. Initially, tillage may have a positive influence on infiltration (Messing and Jarvis, 1993) but this effect is usually transitory and usually leads to a decline in infiltration rates on tilled surfaces as a result of reconsolidation and aggregate disintegration after repeated rainstorms (Moret and Arrúe, 2007). Jones et al. (1994) demonstrated that runoff averaged 56% greater on no tillage (NT) compared with stubble–mulch tillage (ST) watersheds under a winter wheat (*Triticum aestivum* L.)–sorghum (*Sorghum bicolor* (L.) Moench)–fallow rotation. Dryland residue accumulation on the NT surface was insufficient to prevent the formation of a soil crust, primarily during fallow after sorghum, which was destroyed by tillage operations. Maintaining adequate residue is often difficult in semiarid regions with high evaporative demand relative to seasonal precipitation, limited residue production, and rapid decomposition rates (Unger et al., 2006). Under such conditions, residue cover even under NT may decline to less than 30% during fallow (e.g. Lampurlanés and Cantero-Martínez, 2006) resulting in near bare soil conditions.

Exposure of moist soil to the atmosphere by tillage can initially accelerate evaporative losses during the initial few days after tillage (Unger and Cassel, 1991). Good and Smika (1976) demonstrated that sweep tillage operation reduced soil water contents by 2.3 mm after the first day and a total of 3.6 mm by the fourth day after tillage. Hatfield et al. (2001) measured soil water evaporative fluxes of 10–12 mm in central Iowa following cultivation whereas evaporative fluxes from no-tillage fields totaled <2 mm for the same 3-d period. Long-term evaporation

* Corresponding author. Tel.: +1 806 356 5762; fax: +1 806 356 5750.
E-mail address: robert.schwartz@ars.usda.gov (R.C. Schwartz).

0167-1987/$ – see front matter. Published by Elsevier B.V.
doi:10.1016/j.still.2010.07.015

measurements usually show a persistence of greater average soil water contents near the surface for NT as compared with recently tilled soils (Smika, 1976; Zhai et al., 1990). In Eastern Washington state, USA, evaporative water loss under NT during dry summer months has been shown to result in lower soil water contents deeper in the profile (0.2–0.3 m) compared with tillage (Lindstrom et al., 1974; Hammel et al., 1981; Schillinger and Bolton, 1993). However, spring tillage was shown to affect only the near surface soil water content profile and not cumulative soil water depletion during the summer fallow period (Lindstrom et al., 1974). Undoubtedly, differences in the precipitation pattern, potential evapotranspiration, and soils influence the mechanisms governing infiltration, redistribution and evaporation and, consequently, the overall effects of tillage on soil water storage. Because previous studies have typically been confounded by the presence of different residue amounts, differences in evaporation among tillage treatments do not necessarily reflect differences in physical properties and related hydraulic properties.

In arid and semiarid environments, most evaporation occurs as a second stage process whereby water fluxes are limited by a soil surface resistance (Brutsaert and Chen, 1995; Suleiman and Ritchie, 2003). This resistance manifests itself as an evaporation front where both vapor and liquid transport contribute to total water flux and the phase change from liquid to vapor occurs below the soil surface (Saravanapavan and Salvucci, 2000; Grifoll et al., 2005). Under these conditions vapor transport can play a key role in mass and energy flows, and can account for half of the energy (Wescot and Wierenga, 1974; Cahill and Parlange, 1998) and water (Rose, 1968a,b; Jackson, 1973) flux near the soil surface. Experimental evidence of Rose (1968a,b) and Jackson (1973) demonstrated that the direction of vapor flux oscillates in response to the diurnal temperature gradient, moving downward during the daytime and upward at night. This is manifested in sinusoidal variations in soil water content very near (e.g. < 50 mm) the soil surface.

Early on it was recognized that estimation of near surface soil water contents at high temporal resolution using time domain reflectometry (TDR) could be used to monitor changes in soil water content and aid in the understanding of infiltration and evaporation processes (Zhai et al., 1990; Evett et al., 1993; Plauborg, 1995; Cahill and Parlange, 1998). Evett et al. (1993) showed that vertical arrays (0.0–0.4 m) of horizontally installed TDR probes in conjunction with neutron scattering at deeper depths could be used to estimate daily change in soil water storage to within 0.7 mm. A limitation with electromagnetic measurements such as TDR is that the apparent permittivity of soil can be strongly temperature dependent, especially in fine-textured soils (Or and Wraith, 1999; Schwartz et al., 2009a). Consequently, temperature corrections are required to properly determine the actual diurnal changes in soil water content under field conditions.

We monitored near-surface soil water and temperature dynamics during fallow on untilled (UT) and periodically sweep-tilled (ST) field plots to examine tillage effects on infiltration and evaporation in the absence of residue. *In situ* monitoring of soil water has the advantage of integrating the precipitation and evaporation history and gradual changes in hydraulic properties on the aggregate response of the system which is manifested as soil water storage.

2. Materials and methods

The study was established in a fallow field on a Pullman clay loam (Fine, mixed, superactive, thermic Torrertic Paleustolls) that was previously under stubble–mulch tillage management. The Bt horizon (0.15–0.75 m) in this field was homogeneous with respect to bulk density (1.41 Mg m^{-3}) and clay content (50.7%) (Schwartz et al., 2008). The field was kept weed free and devoid of residue throughout the study period. Intensive tillage operations were necessary to break-up a plow pan and permit installation of time domain reflectometry (TDR) probes. In September 2004, the entire field was tilled using a para-plow (Tye Co., Lockney, TX)[1] to a depth of 0.25–0.30 m followed by a chisel chopper (BJM Co., Hereford, TX), rotary hoe, and 0.3-m sweeps. During the following month, three plots with TDR and thermocouple instrumentation were established in each of the four parallel strips with alternating tillage treatments imposed the following year. Type-T thermocouples and 200-mm trifilar TDR probes were installed horizontally in the 12 plots at soil depths of 0.05, 0.1, 0.15, 0.2, and 0.3 m accessed through small ($0.25 \text{ m} \times 0.35 \text{ m} \times 0.35 \text{ m}$) excavated pits. Waveforms were acquired using a metallic cable tester (Tektronix, Inc., Beaverton, OR, model 1502C) and processed by a computer running the TACQ software (Evett, 2000a,b). Interconnects between the cable tester and TDR probes consisted of 12 m of RG8/U (Belden 9913), two 16-port coaxial multiplexers (Dynamax, Inc., Houston, TX, model TR-200; Evett, 1998) and 4 m of RG 58A/U (Alpha 9058AC) 50-Ohm coaxial. Waveforms from each of the probes were acquired at half-hourly or hourly intervals and soil temperatures were recorded at 5-min intervals.

On 7 April, 20 May, and 21 July, 2005, (ST) tillage plots were tilled to a depth of 0.07–0.1 m using a plow with two 0.9-m sweeps. Only a single strip was tilled for the 7 April tillage operation. The other two plots were untilled (UT) throughout the remainder of the year. Prior to tillage, TDR probes and thermocouples at 0.05 and 0.1 m depth were excavated and removed. Probes and thermocouples were reinstalled in the same location a few hours after tillage. Soil bulk densities of the surface 0.0–0.05 and 0.05–0.1-m depth increments were determined using extracted soil cores before and after tillage and periodically throughout the study. Measurements were centered between wheel traffic/tracks. Soil water contents were also monitored using a neutron moisture gage (Campbell Pacific Nuclear International, model 503DR, Martinez, CA) at three locations in each of the four plots from 0.1 to 2.3 m depth in 0.2 m increments at weekly intervals. The gage was previously calibrated *in situ* on the Pullman soil at Bushland, TX. Ambient air temperature, relative humidity, wind velocity, and global radiation (LICOR Biosciences, model LI-200SA pyranometer, Lincoln, NE) sensors were deployed at 2 m in the field interior during the study. Net radiation (REBS model Q7.1, Bellevue, WA) was measured at 1 m above one tilled and one untilled strip and corrected for wind velocity effects. Precipitation depth was recorded every 0.25 h with a tipping bucket rain gage (Texas Electronics, model TR-525M, Dallas, TX). Reference evapotranspiration (ET_0) was determined with the ASCE equations (Allen et al., 2005) for a short grass reference crop using meteorological data collected at the site.

The complex permittivity model of Schwartz et al. (2009a,b) was used to estimate water content from measurements of apparent permittivity and soil temperature. Bulk electrical conductivity was estimated with a power law model (Schwartz et al., 2009a) using the fitted parameters for the Pullman soil (Schwartz et al., 2009b). Water contents at 0.3 m estimated using the neutron probe can be compared with TDR measurements by integrating TDR water contents with depth across a sphere of influence with a radius of 0.15 m. This radius corresponds to a sphere that contains approximately 80% of the response for a water content of 0.35 m^3 m^{-3} (Kristensen, 1973; Ølgaard, 1965). With these assumptions, treatment averaged TDR water contents for this radius differed by only -0.001 to 0.021 m^3 m^{-3} with neutron

[1] The mention of trade names of commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.