Current water erosion studies at Pullman, WA, USA

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1. Abstract

Long-term studies on extensively instrumented experimental plots at the USDA-ARS Palouse Conservation Field Station near Pullman, WA, USA are targeted toward obtaining a better understanding of water movement into and through the soil under freeze/thaw conditions, with the objective of improving winter process modeling. Two treatments, continuous tilled fallow and long-term no-till winter wheat after spring barley, provide a wide contrast in management and in runoff and erosion results as well. Instrumentation includes soil water probes and temperature sensors installed incrementally to a depth of 1 m. Weather data include temperature, precipitation, wind speed and direction, solar radiation, and relative humidity. Runoff and soil loss are measured throughout runoff events. These data are currently being used to validate an energy-budget-based winter process module recently implemented in the USDA's Water Erosion Prediction Project (WEPP) model. Data and results from the first four years of the study are presented, along with results of the application of the new winter process module in WEPP to these data.

2. Introduction

The dry-farmed areas of the Northwestern Wheat and Range Region (NWRR) frequently experience high rates of erosion throughout the winter season. The excessive soil loss is a result of a combination of winter precipitation, intermittent freezing and thawing of soil, steep slopes, and aggressive tillage practices (Papendick et al., 1983; McCool et al., 1987). Soil strength is typically decreased by the cyclic freeze and thaw, particularly during the period of thawing. This study was aimed at improving the knowledge of winter hydrology and erosion in the NWRR through combined field experimentation and mathematical modeling.

WEPP, a computer-implemented, physically-based water erosion prediction model, was initially developed in the late 1980's and has been continually improved (Laflen et al., 1997; Dun et al., 2008). WEPP is based on the fundamentals of hydrology, erosion mechanics, plant growth, and open channel hydraulics. On an hourly basis, WEPP winter routines partition snow and rain, calculate new snow accumulation and density, track snow depth and density, and account for snow drift and snowmelt. WEPP estimates timing and depths of soil frost and thaw, and tracks soil water and infiltration capacity. (Flanagan et al., 1995). WEPP frost simulation approach is based on 1-*d* heat transfer theory. Over a 24-hr period, heat flow from above and below the frozen front is balanced. While most important heat transfer processes are included in WEPP, a number of assumptions are used, and numerous parameters are required. WEPP allows the use of daily climate input for continuous simulation, or break-point climate input for event-based simulation and can be used with a GIS interface, making it a promising research and management tool. Detailed description of the WEPP model and summary of important model components and functions can be found in the *WEPP User Summary* (Flanagan and Livingston, 1995) and *WEPP Technical Documentation* (Flanagan and Nearing, 1995).

WEPP has hillslope and watershed capabilities. For our modeling activities, the hillslope version was appropriate. A WEPP hillslope may comprise one or more overland flow elements (OFE), with each OFE representing a region of unique soil, plant, and cultural practice conditions. An OFE can be further discretized in the vertical direction into multiple soil layers of distinct properties.

Previous experience with application of WEPP (v2006.5) to winter conditions in the eastern Washington and in west-central Minnesota indicated problems in estimating frost depth and duration. In general, depth of frost was underestimated and the soil remained frozen longer than observed (Greer et al., 2006). This indicated inadequacy in either the theory or coding of the model. The objectives of this project then became to develop an alternative winter process module for estimating soil freezing and interaction with snow accumulation and melt that would make USDA's WEPP model a more robust tool suitable for estimating runoff and erosion in the PNW and other areas where winter hydrology is important in runoff and erosion.

3. Methods

In the process of seeking another snow-frost modeling strategy to support soil erosion models, a simpler approach that required less data input and follows general physical principles was preferred. In general, a model can easily encounter error-compounding problems because of the sub-modeling activities. Especially for soil freezing modeling that involves many physical factors from the surrounding environment, such as climate, soil characteristics and soil surface conditions, site-specific problems with models' performance may occur. A simpler approach was preferred not only to avoid error-compounding problems but also to avoid increasing the complexity of the soil erosion model into which the new snow-frost model was to be inserted. In spite of simplicity, this new winter hydrology model was still required to provide reasonable predictability and to be universally applicable.

Another principle of developing the new approach is that modeling of snow and modeling of soil frost should be linked, regarded as a whole system because of their interactive effects, and developed under the same framework. As the energy-driven approach has been applied to snow management (Gray and Male, 1981; Kustas and Rango, 1994) and used to predict the occurrence of soil frost formation (Cary et al., 1978), it could be further developed to simulate snow and frost depths simultaneously. An energy-budget approach was then developed and tested (Lin and McCool, 2006) and later incorporated into WEPP.

The concept of the energy budget approach is to predict changes in snow as well as soil frost depth by the daily amount of energy flux across the air-earth interface. In fact, this energy flux can be seen as the result of the energy balancing process, or the net sum of all energy sources and sinks occurring at the soil or snow surface.

The energy flux is usually not accessible from observation but can be derived from other energy components, net radiation, latent heat of vaporization, sensible heat flux, and other sources, such as heat of soil at greater depths.

Two types of radiation, long-wave and short-wave radiation, contribute to the amount of net radiation. Daily total short-wave radiation data as observed records are accessible from weather stations. For estimating long-wave radiation, the Stephan-Boltzmann equation that uses surface temperature of emitting objects as the calculation basis is adopted. Latent heat of land surface vaporization is calculated by surface resistance/conductance method. Latent heat flux value is equal to the product of the difference in vapor concentration between the air and the land surface multiplied by the latent heat of vaporization and the vapor transfer conductance. Similar to the calculation for vaporization heat, the temperature difference between soil surface, or snow surface, and the upper air drives the sensible heat flux. In addition to the four major energy components above, another heat source is the soil at greater depths. If frost exists, it is assumed that this ground energy component only affects the frost layer. If there is snow but no frost, this energy source should contribute to snow melting. An empirical model also used in Cary's model (Cary et al., 1978) is applied to calculate this adjustment. After the daily value of energy flux is derived, the heat storage change and latent heat utilized by snow melting are estimated next and subtracted from the net energy flux. Frost and thaw depths are estimated by dividing the net energy flux into the soil by soil water or ice content and latent heat of fusion. Tests with this model were promising and it was implemented in the WEPP model for further tests.

A well-instrumented set of runoff plots was used to collect data for testing. Surface runoff and sediment were collected on a daily or event basis from three paired field plots under continuous tilled fallow (CT) and long-term no-till (NT) winter wheat after spring barley treatments. Transient soil water and temperature at various depths were continuously monitored for two selected plots. Weather data included temperature, precipitation, wind speed and direction, net radiation, and relative humidity. Frost depth data was collected from all plots. These plots were on Palouse silt loam (fine silty, mixed Mesic-Pachic, Ultic, Haploxeroll) on south-facing slopes of 17 (Plots 5 and 6), 23 (Plots 1 and 2), and 24% (Plots 3 and 4), respectively. The plots were V-shaped on both ends to provide resistance to border failure at the top and to ensure a collection gradient at the bottom and were 3.7 m wide and 25.0 m long at centerline. Additionally, the plots were bordered with a 200-mm galvanized sheet metal forced approximately 100 mm into soil. The six plots were divided into three paired plots with treatments of NT (Plots 2, 4, and 5) and CT (Plots 1, 3, and 6). The adjacent distance between pairs of the CT and NT plots was approximately 80 m. The average plot area was 86.3 m^2. Data for testing and validation were collected from the winter erosion seasons of water years 2004 through 2007.

4. Results

Field observations revealed that both runoff and erosion from the no-till plots were negligible, whereas erosion from the continuous tilled fallow plots greatly exceeded the tolerable rates (5 to 11.3 t/ha) recommended by the US Department of Agriculture Natural Resources Conservation Service (Table 1). Several complicated mechanisms causing runoff and erosion were observed in the field. Runoff and erosion may result from rainfall and/or snowmelt. The soil may be unfrozen, frozen to the surface, or thawing from the surface at the time of the rainfall or snowmelt. Soil frozen to the surface may initially be quite resistant to high rates of runoff, but as it eventually thaws from the surface, will exhibit very low erosion resistance and erosion may be excessive if the snowmelt or rainfall continues. Rain on a thawed bare soil overlaying a solid frozen layer, may erode at high rates with very little rainfall because the water content of thawed soil is quite high, erosion resistance is low, and the frozen layer impedes infiltration. Finally, soil has been observed to erode, without rainfall or snowmelt, at first thaw on a sunny morning because the water content of the thawing surface layer is above saturation. Such events may not happen frequently but are highly dynamic and can generate considerable amounts of sediment from uncovered surfaces. The WEPP model, with the recently implemented energy-budget winter routine, could reasonably reproduce major winter processes (e.g., snow and thaw depths, runoff and erosion). Yet it is not able to represent all the complicated winter phenomena observed in the field. Continued efforts are needed to further improve WEPP's ability to properly account for soil freeze and thaw and thus the transient soil hydraulic properties and hydrologic and erosion processes.

5. References

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6. Tables

Table 1 Observed and predicted runoff and sediment

	Year	Continuous Tilled Fallow		No-Till
		Observed	Predicted	
Runoff, mm	2004	66	93	Both observed and predicted runoff and sediment yield from treatment were negligible
	2005	22	20	
	2006	151	60	
	2007	97	92	
Sediment yield, t/ha	2004	78	178	
	2005	3	17	
	2006	163	135	
	2007	317	252	