RESEARCH PROJECT TITLE: Improving Tillage Systems for Minimizing Erosion

INVESTIGATORS: Dr. Erin Brooks, Research Support Scientist II, Dept. of Ag. and Bio. Engr., University of Idaho; Dr. Jan Boll, Assoc. Prof., Dept. of Ag. and Bio. Eng., University of Idaho; Chunmei Yao, Graduate Student, Dept. Bio. Sys. Eng., Washington State University; Dr. Shulin Chen, Prof., Dept. Bio. Sys. Eng., Washington State University.

FINAL REPORT

PROJECT OBJECTIVES:

1.) **Investigate the difference in infiltration and runoff generation mechanisms under different tillage systems. (UI)**
2.) **Study the impact of major field factors on rill/gully formation under different tillage systems. (WSU)**

KEY WORDS: conservation tillage, infiltration, surface runoff, soil erodibility

STATEMENT OF PROBLEM:

Soil erosion and sediment delivery to streams are among the major concerns of producers, government agencies, and environmental communities due to the loss of productive soil and the potential environmental impacts. In the Northwestern Wheat and Range Region producers generally use one of three different types of management techniques: conventional tillage, conservation tillage, or direct seed. The effectiveness of these techniques at minimizing erosion has varied widely. We need better understanding how the effectiveness of these management practices in minimizing erosion varies with the local climate, soil types, and topography. If we understand better the physical processes controlling runoff generation and erodibility, we can develop tools for managers in the selection of optimal management practices that are better suited for the particular climate zone, soil type, and topography.

ZONE OF INTEREST: high precipitation zone

ABSTRACT OF RESEARCH FINDINGS:

After an unusually dry winter in the first year of the study (winter 2004/2005), the second year (winter 2005/2006) of this study was wetter than usual. Collectively, the data sets have provided a better understanding of the impact of climate, soil type, management practice, and topography on runoff generation and soil erosion across different landscapes in the high precipitation zone of the Northwestern Wheat and Range Region. The wetter year led to both saturation excess and Hortonian runoff. Widespread saturation excess runoff occurred in convergent zones of fields having argillic soil layers, regardless of the tillage management practice. Hortonian runoff occurred only at the conservation tillage field site seeded to winter wheat following peas. High surface roughness and residue cover were effective in minimizing erosion and encouraging soil deposition. Like the previous year the soil froze for a short period during the winter even at the direct seed site, however the soil thawed before any measurable runoff occurred. Similar to the drier 2005 winter, subsurface perched water tables developed on somewhat discontinuous buried argillic horizons. At two of the sites shallow restrictive layers on top of "clay knobs" lead to

surface saturation. The direct-seed site did not have a clay knob, but an argillic horizon at the midslope position led to the development of a perched water table. Shallow plow pans have not been a major factor in generating surface runoff and erosion. We see subsurface restrictive layers as a key factor in the generation of runoff especially as land managers use conservation tillage techniques that improve infiltration and increase surface cover. Preliminary comparisons between observed and simulated saturation patterns using the Soil Moisture Routing model are encouraging.

RESULTS AND INTERPRETATION:

This project was divided in two major tasks corresponding to two project objectives listed above. Task 1 investigated infiltration and runoff generating processes in a conventional tilled site, a conservation tillage site, and a direct seed site. Task 2 investigated major factors controlling seasonal changes in soil erodibility at each site. We first describe the location of each site and the climate variability for the second year of study, and then we describe results by task.

- *Research Sites*

Three research sites were used in this investigation, all located in the high precipitation zone of the Northwestern Wheat and Range Region. The conservation tillage site had the highest elevation and received slightly more precipitation than the other two sites. All three sites are characterized by a silt loam topsoil and some argillic soil horizons within 1.5 m of the soil surface. The effect of these horizons on runoff generation is discussed.

- *Climate for the 2005 and 2006 Water Years*

In contrast to the 2005 winter, the climate for the 2006 winter was wetter than the 30 year average for the region. Figure 1 shows minimum and maximum daily temperature, cumulative precipitation, 30 year average cumulative precipitation and snow depth for the 2006 winter recorded at the Moscow weather station. In 2005 the Moscow weather station recorded only 10 mm of precipitation between 1/18/2005 and 3/18/2005. In 2006 the Moscow weather station recorded 175 mm (6.87 inches) of precipitation in January alone which is twice the 30 year average for January (79 mm, 3.12 inches). The coldest weather occurred in December and coincided with a three week period of continuous snow cover. Soil frost developed during this time however snowmelt was slow and did not coincide with any heavy rain storms.

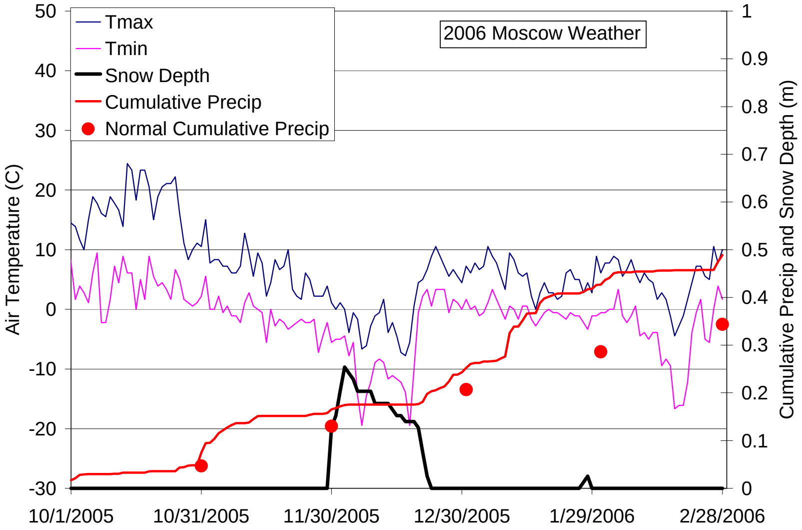


Figure 1. Minimum and maximum daily air temperature, cumulative precipitation, normal cumulative precipitation (30 year average), and snow depth recorded at Moscow, ID for 2006.

Objective 1. Investigate the difference in infiltration and runoff generation mechanisms under different tillage systems.

At each research site we identified three slope positions which were instrumented to determine the fundamental process causing surface runoff for different events. The possible runoff producing processes included saturation-excess runoff (i.e., runoff which occurs because the soil can not store any more water) due to a restrictive argillic horizon, saturation-excess runoff due to a restrictive plow pan, runoff which occurs on frozen soil, and runoff which occurs because the rainfall intensity exceeds the infiltration capacity of the soil. Runoff was measured from 3 m x 8 m (9.8 ft x 26.2 ft) plots with tipping bucket flow gages. Both a deep and shallow monitoring well was installed by each plot. The deep well was installed down to an argillic horizon or to approximately 1.5 m (5 ft) if no argillic horizon was found. The shallow well was installed above the plow depth. Each well was instrumented with a pressure sensor to record perched water depth every hour. Two thermocouples were installed beside each plot at 0.1 m and 0.5 m to monitor hourly changes in soil temperature to indicate the presence of a frozen soil layer. Frost tubes were installed at each hillslope location as a secondary measure to monitor soil freezing. In order to better understand the variability in the perched water at each site additional monitoring wells were installed between each of the hillslope positions.

Task 1.1. Tillage system characterization

One of the most interesting aspects of the study was the observed variability in the argillic horizon and its influence on the development of perched water. A map showing the variability of the argillic horizon was already developed for the direct seed site by the USDA-ARS under the direction of David Huggins. Approximately 40 soil cores were extracted using a giddings probe from the conservation tillage site and 200 soil cores extracted from the conventional tillage site following a 30 m gridded sample pattern. Although we noticed general trends between topographic position and soil horizons, there were some exceptional soil features, particularly at the direct seed site, which appear more or less random. Generally, the argillic horizons in the direct seed and conventional tillage sites occur in the Thatuna soils. There seems to be a slight tendency for the shallowest argillic horizons at both these sites to occur at the toe-slopes and the flat bottom-land. The conventional tillage site has a nearly continuous argillic horizon and is described as a Southwick soil type in the Latah County soil survey (Barker, 1981). The conventional tillage site has a shallow clay pan or "clay knob" on the ridge line. The research in this project and recent other projects indicates that the presence of argillic horizons and clay knobs are very important in describing the hydrology of a particular landscape. The distribution of each soil layer will be included in the results section for each site below.

Task 1.2. Measurements of major field parameters for runoff generation

The majority of the runoff and erosion occurred during a two week period in January. The Moscow weather station recorded rain every day from January 6th to January 22nd. The total rain during this period was 143 mm (5.6 inches). Two main events occurred on January 11th and January 18th. Moscow weather station reported that 63 mm (2.5 inches) of rain fell during January 10th and 11th and one week later another 31 mm (1.2 inches) of rain fell on January 17th and 18th. Although the 10th and 11th event had more rainfall, the largest runoff event occurred on January 18th. These events will be discussed below for each site.

Direct Seed Site

The direct seed research site was planted to winter wheat during the fall of 2005 with the exception of the flat bottom land which was planted to alfalfa in May of 2006. Figure 2 shows a cross-sectional profile of the hillslope, the depth of the well, the depth to an argillic horizon, and the maximum water table depth reached at each well location for 2006 water year. Thirteen wells were installed along the hillslope. The top three locations did not have an identifiable argillic horizon, however a distinct argillic horizon was present below the upper and midslope runoff plots. Like the top of the hill, no argillic horizon was present immediately downslope of the lower runoff plot, but it was found again in the four lower well locations. The water table never reached the soil surface except at the lowest well location during the 2005 season. However, in the 2006 season the water table reached the surface multiple times at well 8 (labeled "Down-slope well" in Figure 2) in addition to well 1 at the bottom of the slope. Figure 3 shows the development of the perched water table for the midslope wells (Wells 7-10) for 2006 season. Like the 2005 water year, measurements in 2006 indicate that the perched water depth increased with slope length. Since little water can percolate through an argillic layer the perched water table develops and then drains laterally downslope resulting in a thickening of the perched water layer with distance downslope. The argillic horizon becomes deeper downslope of well 8 and as a result the water table drops below the soil surface, see Figure 3. This effect could be clearly seen on 1/18/2006 when surface saturation could be seen near well 8 at the top of the plot but no runoff occurred at the bottom of the plot near well 7. Although surface saturation was observed in the upper portion of the lower runoff plot, no runoff left either plot during the 2005 or 2006 season. As described by these data, the occurrence of saturation excess surface runoff is controlled almost entirely by the presence and depth of the argillic horizon.

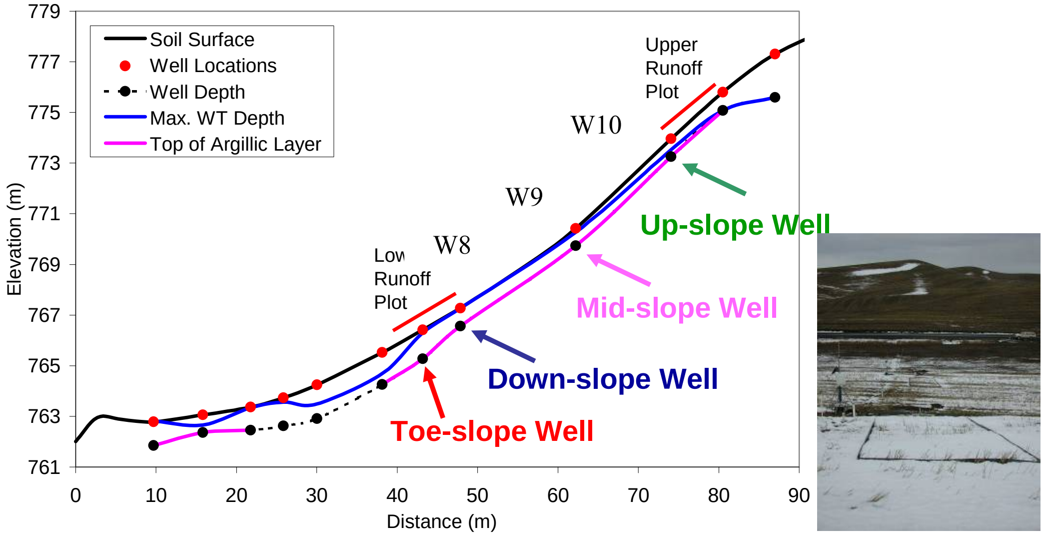


Figure 2. Hillslope profile, with well locations, depth of the well, depth to the top of the argillic horizon, and the maximum water table depth observed during the winter of 2006 at the direct-seed site.

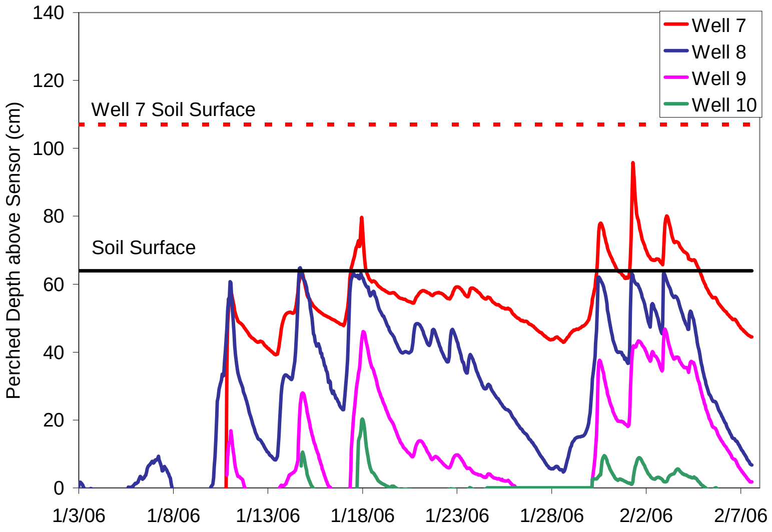


Figure 3. Perched water depth readings at wells 7, 8, 9, and 10 during the 2006 season.

Conventional Tillage Site

At the conventional tillage site three plots were installed on a west facing hillslope during the 2006 winter. The farmed area of the field was in a rough plowed condition following a barley crop and was later seeded to canola in the spring of 2006. A second transect of four wells was installed on another north facing slope in perennial grass, where typically a large snow drift develops, to investigate the influence of snow drifting on runoff and subsurface saturation. As seen in Figure 4, we did not find an argillic horizon below the runoff plots in the 2.88 m soil cores taken with the giddings probe. The depth to the argillic horizon in the north facing transect ranged from 0.3 m at the top of the ridge to 1.2 m throughout the midslope region to greater than 200 cm at the toe slope, see Figures 5 and 6. Despite the unusually wet year, no runoff, erosion, or perched water tables developed at the runoff plot sites during the 2006 year. This is an important finding since it emphasizes the importance of argillic horizons in the development, or in this case the lack of development, of a perched water table. In contrast to the runoff plots, perched water tables and saturation excess runoff occurred on the north facing grassed transect (see Figures 5 and 6). Like the 2005 winter, the shallow upper well recorded multiple periods of saturation excess runoff during the 2006 winter (Figure 6). The perched water table on the midslope locations decreased with distance down slope with the deeper soils.

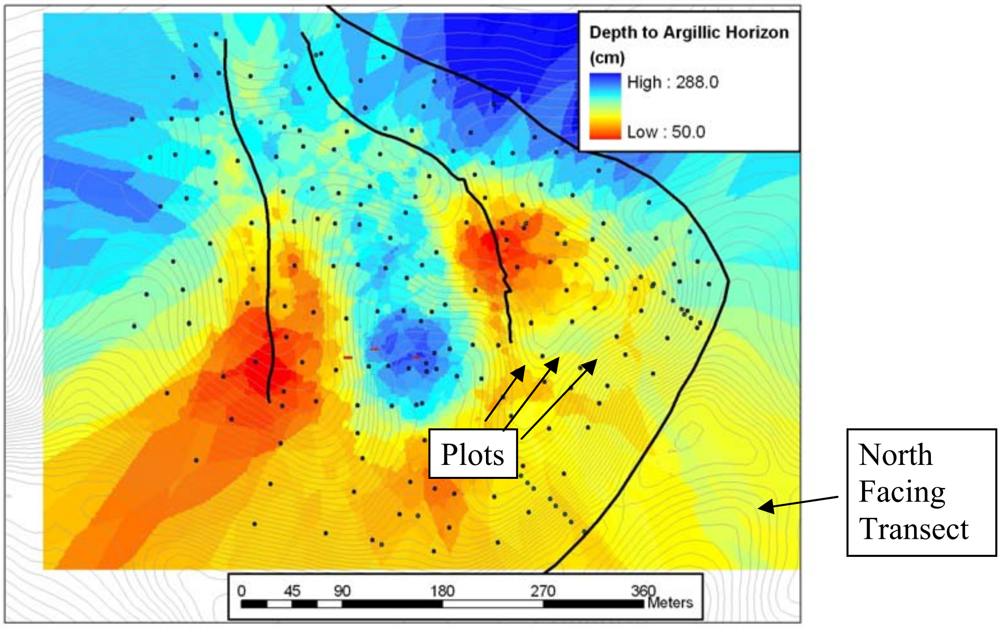


Figure 4. Location of plots and north facing transect in relation to the depth to an argillic horizon. Notice plots installed on a slope where no argillic horizon was detected.

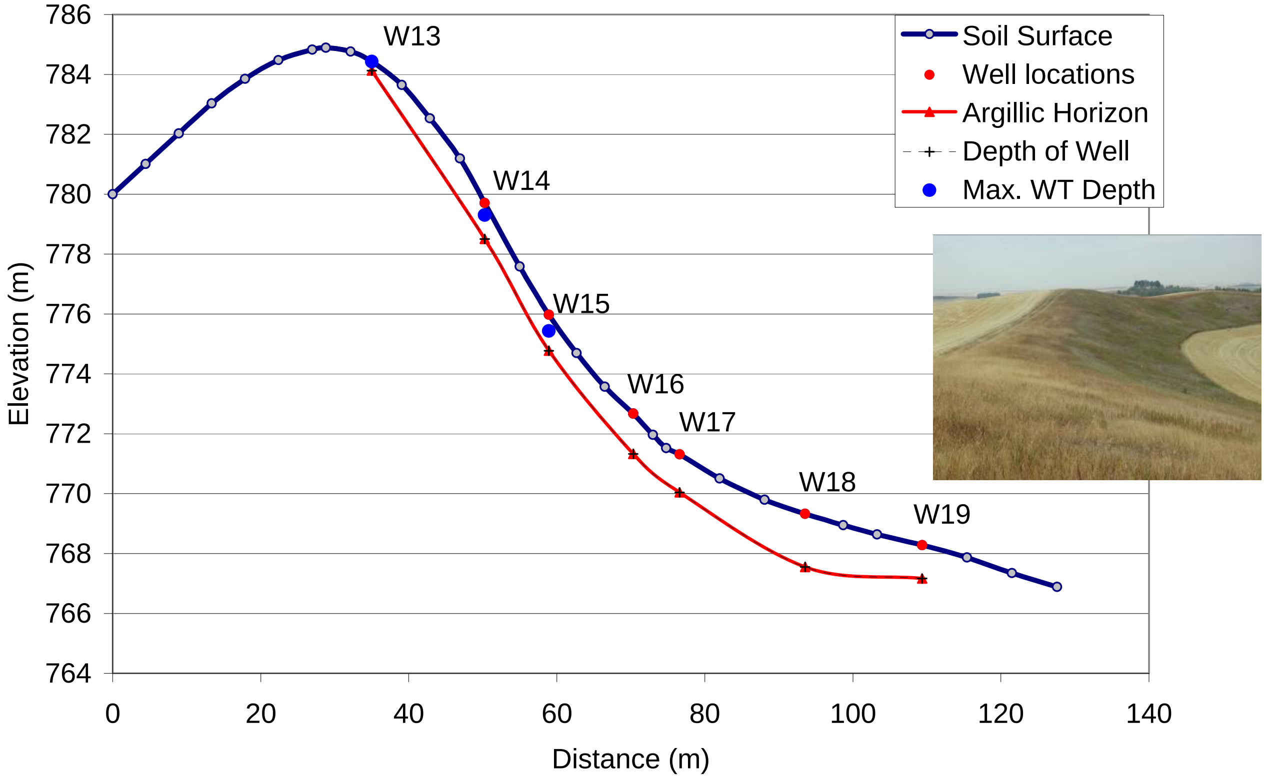


Figure 5. A hillslope profile of the north facing hillslope at the conventional tillage site. W17-W18 were not installed during the 2006 season.

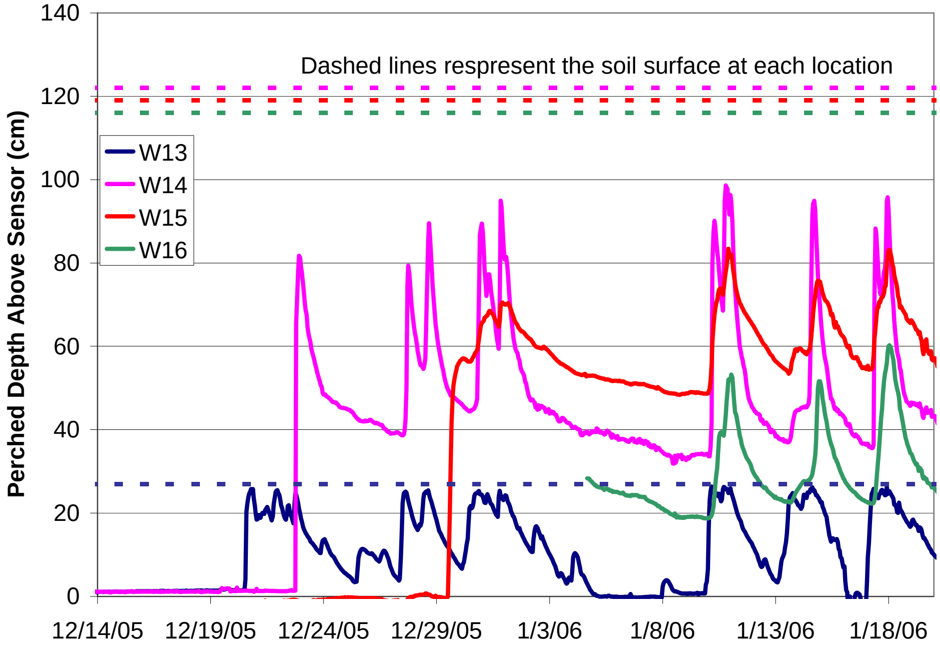


Figure 6. Perched water depth measured at wells 13-16; notice multiple periods of saturation at the shallow upper well 13 location.

Conservation Tillage Site

During the 2006 winter runoff and erosion were most wide-spread at the conservation tillage site, which was seeded to winter wheat following peas on the upper half of the field and winter wheat following spring barley on the lower half of the field. Surface residue was noticeably less on the upper half of the field than on the lower half of the field. The runoff plots and wells were installed in the same locations as during the 2005 winter. The high precipitation on January 10th-11th and January 17th-18th resulted in localized Hortonian runoff in the upper half of the field and saturation-excess runoff in the lower half of the field. Although several rills and a few gullies formed in the field during these events, no rilling or erosion occurred in the plots. As seen in Figures 7 and 8, the lowest toe-slope well saturated to the soil surface during the January 10th event and remained there over the next month. Surface runoff was measured during the January 18th event (see Figure 8) and most likely occurred during the January 10th event but there were problems with the tipping bucket runoff device during this event. Since the perched water table at the mid-slope and upper slope locations remained below the soil surface for these events, these runoff events were caused by a Hortonian runoff processes.

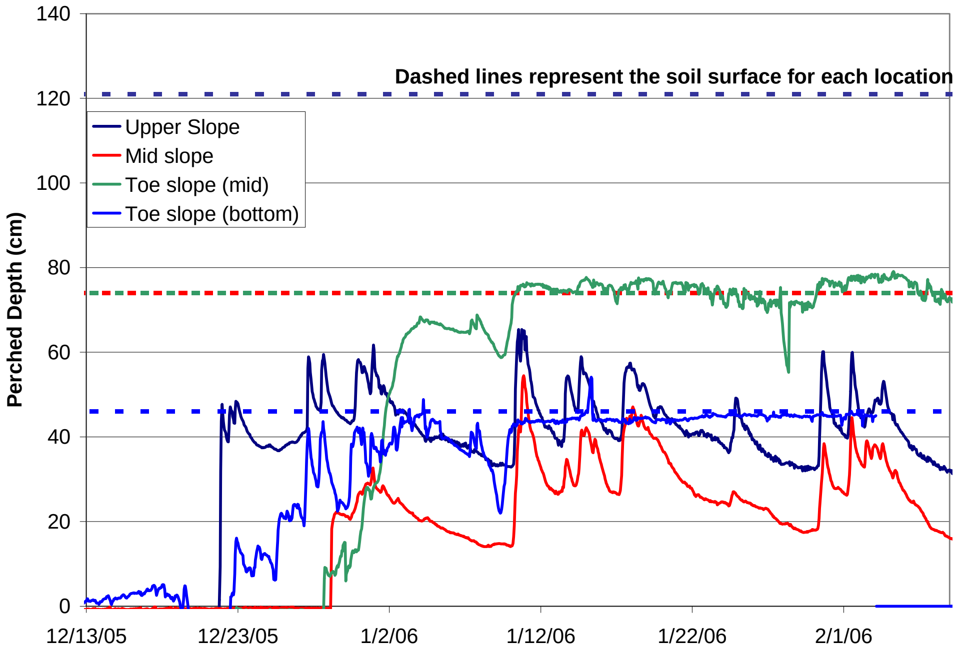


Figure 7. Perched water depth measured in deep wells at the conservation tillage site.

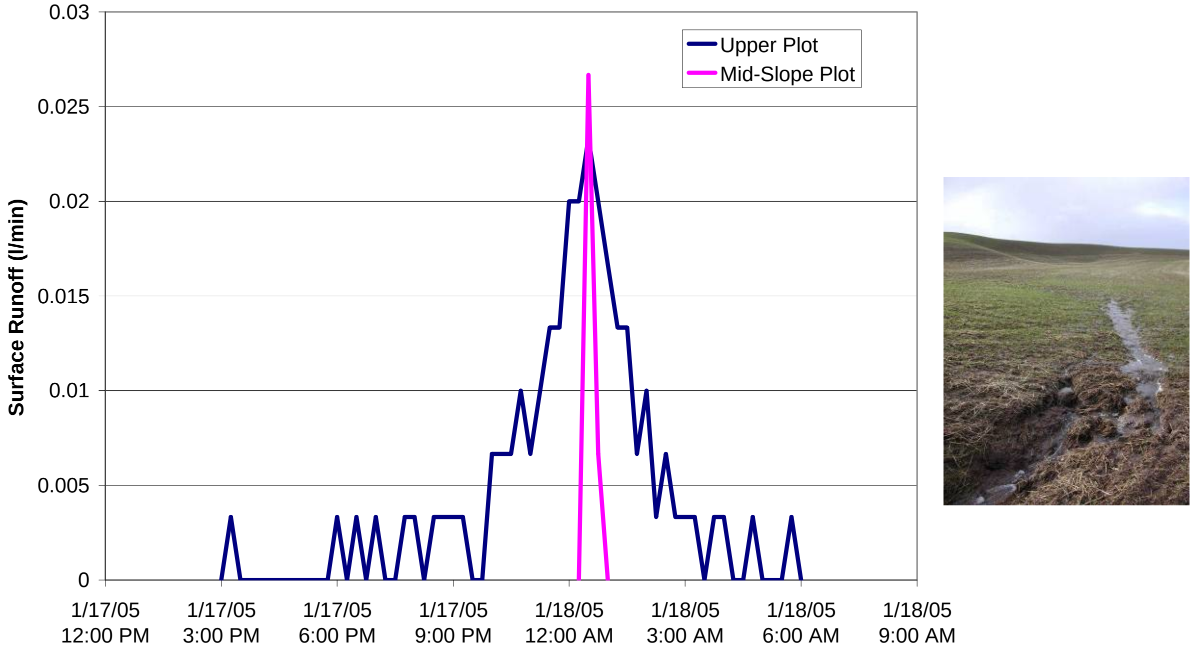


Figure 8. Surface runoff from the upper and mid-slope plots during the January 18th event at the conservation tillage site.

Task 1.3. Watershed scale runoff generation

To improve our understanding of surface runoff generation at the watershed scale we mapped runoff generation areas and rills with a GPS unit on selected days during the year. Figures 9 and 10 identify saturated areas measured at the direct-seed, conventional tillage, and conservation tillage sites during the 2006 winter. These maps were used to assess the accuracy of our distributed Soil Moisture Routing model. Measured and modeled spatial runoff patterns are quite similar (see Figure 10).

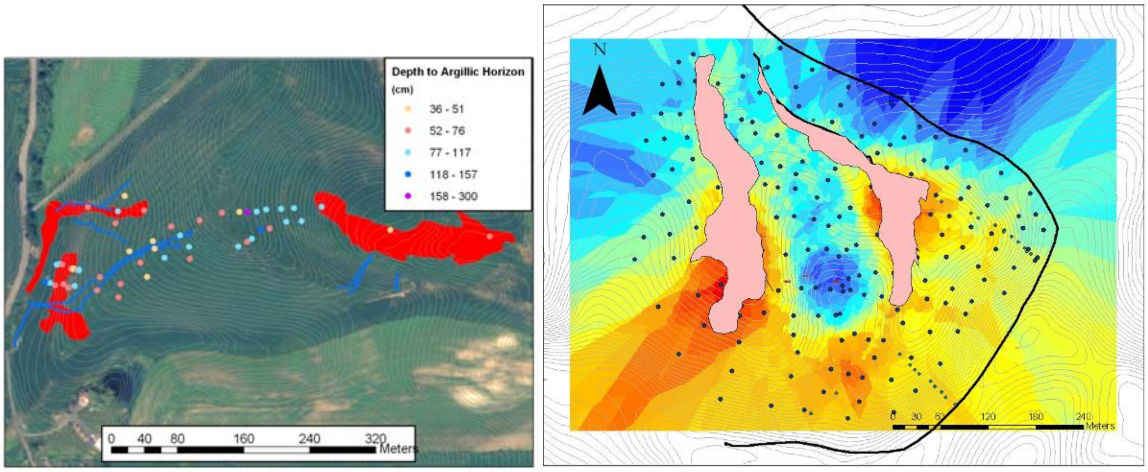


Figure 9. Mapped saturated areas and rills on 2/6/2006 at the conservation tillage site (left). Mapped saturated areas on 4/7/2006 at the conventional tillage site (right).

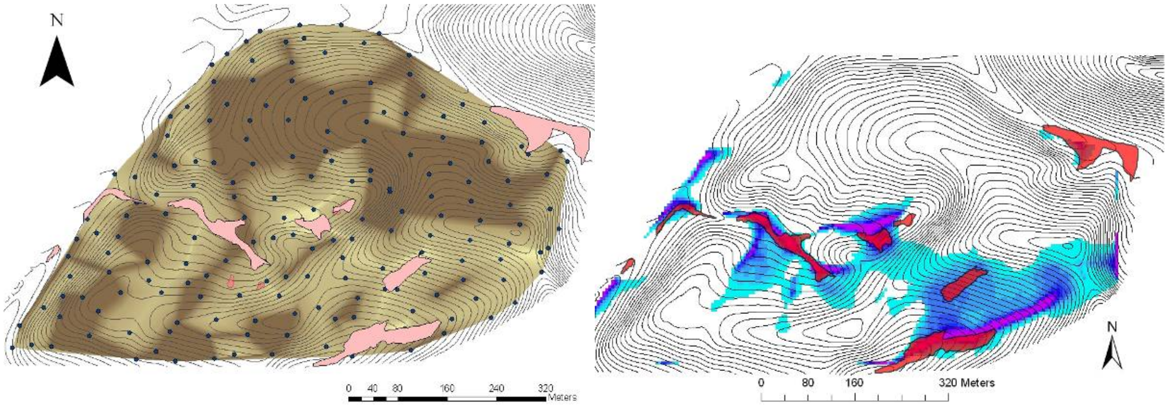


Figure 10. Mapped saturated areas at the direct seed site on 2/7/2006 (left). Measured saturated areas (red polygons) mapped over simulated saturated areas (blue and pink pixels) throughout the direct seed site (right).

Objective 2. Study the impact of major field factors on rill/gully formation under different tillage systems.

We conducted a two-season field study with matching funds from other sources. The results are summarized below.

Task 2.1 Measurements of major field parameters for rill erosion

Main research activities under this task included installing runoff and erosion experimental plots, field data collection and observations in both winter seasons (2005 and 2006). During the 2006 season, seven 3 m x 8 m plots were installed (Figures 11-14); two were installed at the direct seed site, three at the convention tillage site, and two at the conservation tillage site. Additionally, a sampler and a flow meter were also installed at the outlet of the Conventional tillage site (Figure 14). Additional data collection at the Palouse Conservation Field Station (PCFS) was conducted for comparing the plot results.

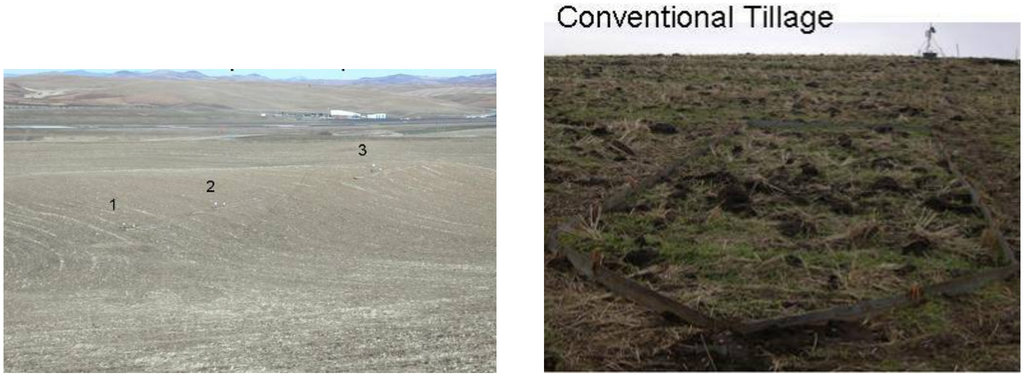


Fig.11 Conventional tillage site, rough till over wheat, 3 plots.

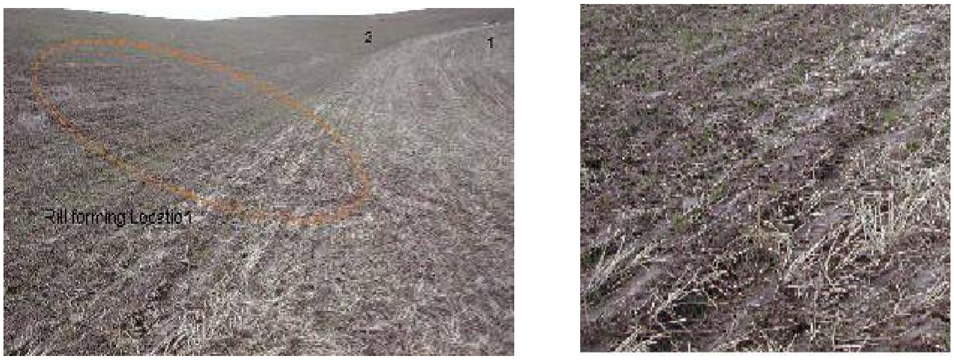


Fig. 12 Conservation tillage site, upslope winter wheat seeded after peas, down-slope winter wheat seeded after barley, 2 plots.

Fig. 13 Direct seed sites, 2 plots.

Fig. 14 Instrumentation

As documented in previous studies in the Palouse, two of the most important factors for minimizing erosion are surface roughness and surface residue cover. The conventional tillage site was in a rough plowed condition following a spring barley crop with a very rough surface and relatively high amounts of surface residue, see Figure 11. In contrast the conservation tillage site, which was seeded to winter wheat, had relatively less surface roughness and surface residue cover. Within the conservation tillage site the surface roughness and surface residue cover of the upslope half of the field, seeded to winter wheat following spring peas, was less than the downslope half of the field, seeded to winter wheat following spring barley, see Figure 12. The direct seed site, which was seeded to winter wheat, had the highest amounts of residue, see Figure 13.

As described in the hydrologic section, despite the wet January, the only surface runoff from the plots occurred during the January 18th event from the conservation tillage sites. These runoff rates were low and did not transport any measurable sediment. The upper part of the lower direct seed runoff plot site had some surface saturation but this water was retained in the surface residue and, as described in the previous section, this water re-infiltrated before reaching the plot outlet. Rill erosion did occur in several locations outside the runoff plots at the conservation tillage sites and these are further discussed in section 2.3.

Task 2.2 Determination of soil erodibility

To study the practical soil erodibility in the field, undrained shear strength was measured using both the automatic vane shear (AVS) and a pocket penetrometer (Figure 15). The shear stress value can be used to determine the ability of soil particles to resist detachment. The results of the measurements made at the end of the 2006 season are presented in Table 1. These data showed difference in the measured values between the test sites; however, a direct relationship between the shear stress data and rill formation cannot be established. It needs to be pointed out that the spatial variability was very significant. The variability was probably related to soil surface moisture distribution and other soil character variations.

Although we expect the largest erosion events to occur on frozen and thawing soils, no frozen soil erosion events occurred during the two years of this study. Due to funding limitations, frozen soil erodibility test in flume was not conducted.

Table 1 Penetrometer and shear stress observation in seven plots

Plot name	Item	Data									
Conv. Till. Plot 1	Penetrometer(kg/cm^2)	2.0	1.8	2.5	3.8	1.8	3.8	3.0	3.8	4.0	
	Shear stress(kg/cm^2)	2.5	3.5	2.5	2.7	3.5	3.3	3.0	5.5	8.5	
Conv. Till. Plot 2	Penetrometer	3.0	4.4	4.0	3.5	3.8	3.0	4.0	4.2	3.0	5.0
	Shear stress	5.8	3.7	5.5	8.0	6.4	3.1	5.5	3.2	3.3	7.3
Conv. Till. Plot 3	Penetrometer	1.5	1.5	3.0	4.8	4.5	3.2	1.9	3.7	3.6	
	Shear stress	3.6	3.6	3.9	8.5	5.0	3.0	3.8	5.8	4.0	
	Penetrometer	5.5	3.0	2.0	2.2	3.3	3.5	4.3	2.6	3.5	
	Shear stress	3.4	6.3	1.9	2.2	4.5	9.0	4.8	4.5	3.8	
Direct Seed Plot 1	Penetrometer	3.0	4.4	3.3	4.4	1.8	3.2				
	Shear stress	3.0	4.4	6.5	10.7	2.8	8.0				
Direct Seed Plot 2	Penetrometer	3.5	3.8	3.0	3.0	3.8	4.0	3.6	2.5	3.0	
	Shear stress	3.5	4.2	3.3	2.7	3.8	2.8	3.5	2.5	5.0	
	Penetrometer	4.0	4.0								
	Shear stress	5.5	7.0								
Cons. Till. Plot 1	Penetrometer	2.0	2.0	1.5	3.0	3.0	3.25	3.25			
	Shear stress	10	10	10	10	10	10	11			
Cons. Till. Plot 2	Penetrometer	3.5	2.5	2.5	3.25	3.0	3.0	2.0	2.5	8.0	
	Shear stress	10	10	10	7.0	10	8.0	8.5	8.0	2.5	

Figure 15. Penetrometer and shear strength meter

Task 2.3. Watershed scale rill/gully formation

Despite the minimal runoff and erosion that occurred in the plots at the conservational tillage site, rill erosion did occur outside the plots in several locations across the field which provided valuable insight into the effects of surface roughness, surface residue cover, and direction of tillage on rill erosion. Each of these factors will be discussed below.

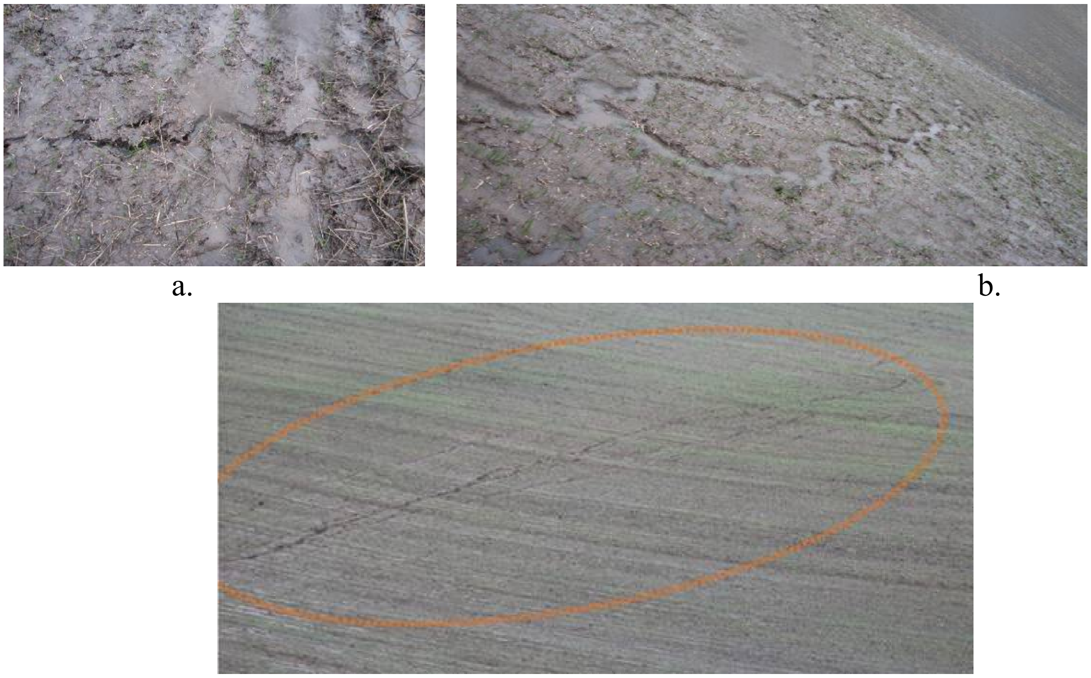
Fig.16 Rills comparing the different direction of tillage (left). Soil surface storage ponds (right).

Surface roughness reduces erosion by providing temporary surface storage (Figure 16). In a rough tilled field, as found in the conventional tillage site, the high degree of roughness allows water to be stored on the soil surface giving the water more time to infiltrate. Surface and subsurface residue binds the soil together, decreases the erodibility of the soil, and reduces the risk of rill formation. Interestingly, a smooth field right next to the conventional tillage site which did not have any surface residue developed deep rills during the winter of 2006, (see Figure 17).

At the conservation tillage site rill erosion occurred at several locations in the upper half of the field which had the least surface roughness and residue cover, see Figures 16 and 18. The major rills were mapped using a GPS, see the blue lines in Figure 9. The surface roughness in the upper half of the field was caused primarily by the furrows left while seeding in the field. We observed surface runoff ponding and draining down these furrows until a point where the runoff depth exceeded the furrow depth. At this point the runoff would erode the furrow and a rill would be generated following the dominant hillslope direction of the field, see Figure 16. An interesting observation was that residue in the lower half of the conservation tillage site had enough residue, in most cases, to stop the rill and cause deposition, (see Figure 19, left). Rills formed in the field right next to the conservation tillage field which did not have the lower strip of high residue continued to erode down to the bottom of the field (see Figure 19, right).

Fig. 17. Bare field next to the conventional tillage site (no residue, low roughness).

As described in the hydrology section of the report, the lower part of the conservation tillage site remained saturated and ponded for several weeks in a row. However this part of the field had the greater amount of surface residue cover and the only erosion which occurred in this area took place at the outlet of the field where the surface runoff concentrated into a small channel, (see photograph in Figure 8). Without this surface residue cover the erosion in this region would likely have been much more.



a.

b.

c.

Fig. 18. Rills in concave hillslope (outside of plot)

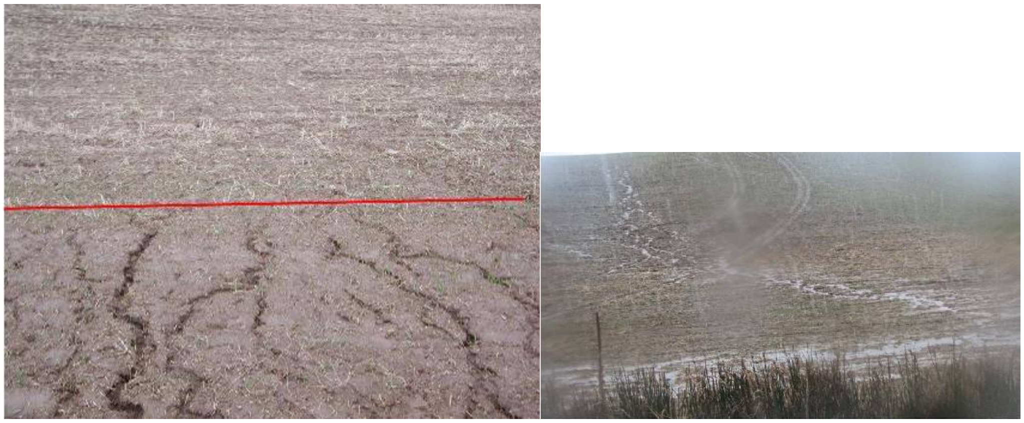


Fig. 19 Down-slope view from winter wheat with low residue to winter wheat with high residue at the conservation tillage site (left). Higher down-slope residues essentially stopped the further development of rills and led to soil deposition. Rill developed in a field adjacent to the conservation tillage site having minimal surface residue (right).

Impact of the research

This research has several key short term and long term impacts. In terms of hydrology we found that argillic soil horizons largely control the surbsurface flow of water and generation of saturation excess runoff. Wide-spread surface saturation and runoff was observed in topographic convergent zones in soils having argillic horizons regardless of the management practice. However even small scale discontinuities in these argillic layers can quickly drain these perched layers. In terms of erosion, increased surface roughness and surface residue cover can greatly minimize erosion. Operators in the region should continue to farm on the contour as completely as possible since the furrows generated from seeding increases the surface detention. Plowing up and down the slope greatly increases the risk of rill erosion. Hortonian runoff (i.e. infiltration excess runoff) can be greatly minimized with increased residue and surface roughness. In the short term land operators need to be aware of the impact of these restrictive argillic horizons on both surface runoff and in terms of water quality. Fields having these argillic soil horizons should be maintained in high residue cover especially in topographic convergent zones. In the long term there needs to be further emphasis on how these landscapes having argillic horizons can be better managed to minimize not only erosion but also the transport and export of nutrients. The Soil Moisture Routing (SMR) model appears to have the potential for being a useful management tool for predicting subsurface flow above these argillic layers and for delineating portions of fields that are most susceptible to saturation excess runoff.

Interactions with other scientists

The research team interacted with Dr. Joan Wu and Dr. Don McCool in their research conducted at PCFS, and with David Huggins, USDA-ARS and Dr. Kent Keller's research group on similar studies conducted on the Cook Agronomy Farm.

Publication and presentations

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Chunmei Yao , Shulin Chen. "Critical conditions of rill incision on hillslope".2006. Presentation given at the 2006 ASABE Annual International Meeting in Portland, Oregon, July 9-12, ASABE, 2950 Niles Road, St. Joseph, MI.

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WSU publications are in preparation to incorporate the results from this study to on-going laboratorial experiments conducted on the same soil and plot size.