

Impacts of extreme precipitation events on performance of conservation practices

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Introduction

Climate-induced changes in the volume and erosive power of precipitation is the most important effect of global climate change on soil erosion and surface runoff (Nearing, 2001). Greater frequency and intensity of extreme weather events have been observed in the last decades due to the climate change (Milly et al., 2002; SWCS, 2003). One of the direct consequences of those extreme events on agricultural land is the acceleration of topsoil loss, which leads to soil degradation and pollutant transport from the field. A linearly increase of the amount of daily precipitation by 5% or 10% could increase soil erosion by 10.7% and 35.6%, respectively (Savabi et al., 1993). In addition, the risk of gully erosion and stream channel erosion are also increased during the extreme events. Consequently, a more severe and lasting damage to soil and water resources can be caused from these forms of erosion, which require more intensive and costly conservation treatments (SWCS, 2003).

Soil erosion from cropland can be reduced by the implementation of conservation management practices, such as reduced tillage, crop rotation, residue management, vegetative filter strips, terraces, and grassed waterways (Baker et al., 2006). In current practice, the mean annual sediment yield over a long period has often been used to act as a targeted goal for the design and implementation of conservation systems. However, agricultural systems are more vulnerable to the effects of extreme climate events (Philpott, 2008), which usually largely contribute to erosion and sediment transport while the majority of the rainstorms play only a minor role (Coppus and Imeson, 2002). Therefore, conservation practices should be designed and implemented to resist the effects of extreme events of some designated return period, rather than the average annual events (Larson et al., 1997).

With the extreme precipitation events in 2008 there is a need to review and estimate the performance of conservation practices. In this study, we used the Water Erosion Prediction Project (WEPP) model to simulate soil erosion with various tillage systems and conservation practices, and assess their performance in reducing sediment export from the extreme precipitation events.

Material and methods

Site description

Two farms in northeast Iowa were selected to investigate the impact of conservation practices on soil erosion from extreme storm events. One farm (site 1) was located in Winneshiek County, which had a 9% slope. The other farm (site 2) located in Delaware County had a 1.7% slope. The sizes of both farms were about 300 acres. The predominant soils were Downs silt loam and Clyde silty clay loam for sites 1 and 2, respectively.

WEPP model description

The Water Erosion Prediction Project (WEPP) model (version 2006.5) was used to simulate soil erosion and sediment yield (Nearing et al., 1989). The WEPP model is a process-based erosion prediction model for soil loss and sediment deposition for small watersheds and hillslopes. Many processes related to soil erosion are integrated in the WEPP model, including rill and interrill erosion, infiltration, percolation, sediment transport and deposition, surface runoff, residue and canopy effects, tillage effects, and evapotranspiration.

Four main data inputs are required by the WEPP model: climate, topography, soil and management. The climate generator, CLIGEN, was used to create the 50-year climate files for each study site. The historical weather data from the City of Decorah in Winneshiek County was used to create the climate input file for site 1, and the weather data from the City of Oelwein in Fayette County was used to create the climate input file for site 2.

The simulations were performed in the Watershed mode. Each site was subdivided into three sub-areas (hillslopes) using the GeoWEPP, which is a geospatial interface for the WEPP model (Renschler, 2003). The slopes of each hillslope were derived from the 30-m digital elevation data. In the simulations, flow channels were naturally eroded and had the same field management as the rest of the field, unless specified otherwise.

WEPP default values were used for tillage and crop management parameters. Five tillage systems were simulated in this study, including no-tillage (NT), strip-tillage (ST), disk-tillage (DT), chisel-plow (CP), and moldboard plow (MP). NT had no soil or crop residue disturbance except for that occurring during planting. ST prepared narrow rows for seed bed after soybean harvest in the fall while no-till was used after corn harvest. DT included a disking after corn harvest in the fall and field cultivating for both corn and soybean in the spring. CP consisted of chisel operation after corn harvest in the fall and field cultivating for both corn and soybean in the spring before planting. In MP, cornstalks were plowed with a moldboard plow in the spring before planting soybean, and soybean stubble was disked in the spring in preparation for corn planting.

For NT and CP, three additional erosion control structures were simulated: grassed waterways (GW), grass filter strips (FS), and terraces (T). Grassed waterways had a triangular shape with perennial grasses and a width of 3 ft. In FS simulation, a portion of row-cropped field was replaced with perennial grass at the bottom of each hillslope. The length of filter strips was 10% of the slope length. In terrace simulation, parallel narrow-base terraces had a width of 2.7 m and a uniform gradient of 0.5%, with a horizontal spacing of 30 m. The same field management was applied for the terrace as for the rest of the field.

Return period analysis

The return period analysis implemented in the WEPP model was used to estimate the magnitudes of surface runoff and sediment yield during the extreme events (2-year, 5-year, 10-year, 20-year and 25-years events) under different tillage systems and erosion control structures. The return period is the average elapsed time between occurrences of an event (e.g. rainfall, runoff, sediment yield) with a certain magnitude or greater (Haan, 1977). Over a long period of time, for example, a 10-year event has a probability of 10% of being equaled or exceeded in any one year.

Results and discussion

Impact of tillage systems on annual sediment yield

The predicted mean annual sediment yields under various tillage systems were summarized in Table 1 for both study sites. As expected, more tillage produced greater sediment yield because of the less field residue cover. No-tillage and strip-tillage systems had much lower sediment yields than the other three tillage systems.

The steepness of slopes had significant impact on soil erosion. The simulation results showed that the site with greater slope (9%) (site 1) had much higher annual sediment yield than the site with 1.7% slope (site 2) (Table 1). Site 1 also had higher sediment delivery ratios (the ratio of sediment yield to the total sediment eroded) than site 2, regardless of the tillage systems. Due to its steep slope, even the no-tillage system had a higher annual sediment yield (6.8 t/acre) than the commonly-used target value (5 t/acre). Therefore, additional conservation structures may need to be adopted in this site (e.g. filter strips, terraces, etc).

Table 1. Sediment yield and sediment delivery ratio of two study sites in northeast Iowa.

	Site 1 (9.0% slope)		Site 2 (1.7% slope)	
	Sediment yield (t/acre/yr)	Sediment delivery ratio	Sediment yield (t/acre/yr)	Sediment delivery ratio
No-till	6.8	0.84	0.19	0.54
Strip-till	8.3	0.79	0.31	0.51
Disk-till	25.1	0.60	0.61	0.54
Chisel plow	31.0	0.59	1.00	0.51
Moldboard plow	45.9	0.68	2.39	0.48

Impact of tillage systems on sediment yield during extreme precipitation events

The simulation results showed that large precipitation events would lead to much greater surface runoff volumes and soil erosion rates regardless of tillage system. For example, the surface runoff of a disk-tillage system was estimated to be about 1.9 inches for a 2-year event and 4.6 inches for a 25-year event. Likewise, the sediment yield of a disk tillage system was estimated to be 12.5 and 46.9 t/acre for a 2-year and 25-year event, respectively (Table 2).

There was only slight difference in surface runoff among different tillage systems for simulated extreme events. However, a reduced tillage system, such as no-tillage or strip-tillage could greatly reduce soil erosion and sediment yield during the extreme events. The effect of reduced tillage systems on sediment reduction was even more evident for the events with longer return period, i.e. larger precipitation events. For example, the sediment yield in the simulated no-tillage system was reduced by about 14 t/acre and 62 t/acre during a 2-year and 25-year event, respectively, compared to the moldboard plow tillage system (Table 2).

Table 2. Return period analysis for different tillage systems at site 1.

	Return period (year)	Daily precipitation (inch)	Surface runoff (inch)	Sediment yield (t/acre)
No-till	2	3.0	1.9	4.5
	5	4.0	3.0	5.9
	10	4.5	4.0	6.5
	20	4.9	4.2	7.2
	25	6.0	4.7	7.7
Strip-till	2	3.0	1.9	5.3
	5	4.0	2.9	6.7
	10	4.5	4.0	7.9
	20	4.9	4.2	8.6
	25	6.0	4.7	8.9
Disk-till	2	3.0	1.9	11.3
	5	4.0	3.0	18.4
	10	4.5	3.8	28.1
	20	4.9	4.2	33.8
	25	6.0	4.6	42.5
Chisel plow	2	3.0	1.9	13.7
	5	4.0	3.0	22.9
	10	4.5	3.8	36.3
	20	4.9	4.2	45.1
	25	6.0	4.6	58.2
Moldboard plow	2	3.0	1.9	18.9
	5	4.0	3.0	31.2
	10	4.5	3.8	47.0
	20	4.9	4.2	54.2
	25	6.0	4.6	69.9

Performance of erosion control structures during extreme precipitation events

For a no-till system, grassed waterways showed relatively small impacts on sediment reduction during extreme events (Figures 1 and 2). This is likely because the high-percentage field residue cover from a no-tillage system has already greatly reduced the sediment load in surface runoff before the water enters into the flow channels. Note that an extreme sediment event of a specific return period with or without grassed waterways implemented, may not necessarily respond to the same precipitation event. That could cause a slightly greater simulated sediment yield under

a no-tillage system with grassed waterways due to the relatively narrow range of sediment yield, for a given return period. For a chisel-plow system, on the other hand, grassed waterways reduced sediment yield to a great extent at both study sites, especially during the 10, 20, and 25 year return periods (Figures 1 and 2).

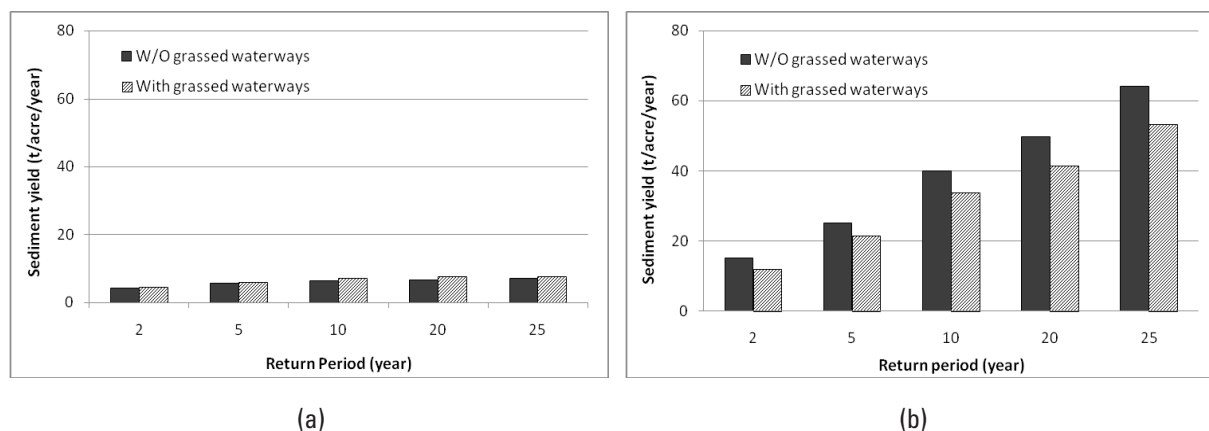


Figure 1. Performance of grassed waterways at site 1 under a corn-soybean rotation with (a) no-till and (b) chisel-plow during the extreme storm events.

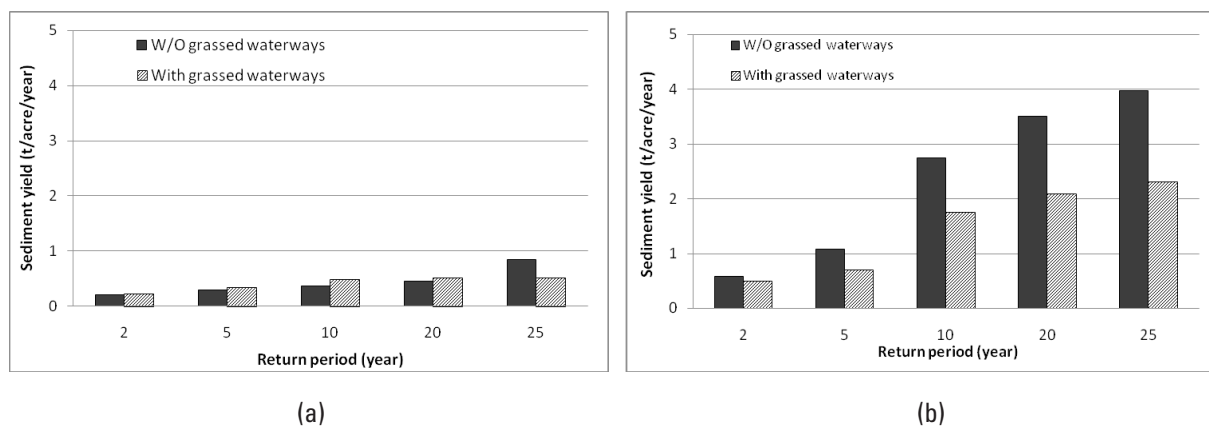


Figure 2. Performance of grassed waterways at site 2 under a corn-soybean rotation with (a) no-till and (b) chisel-plow during the extreme storm events.

Similar to grassed waterways, grass filter strips greatly reduced sediment yield with a chisel-plow tillage system, but had relatively small impacts on sediment yield with a no-tillage system from the extreme events (Figures 3 and 4). Comparing to the results from site 2, the effect of filter strips on trapping sediment at site 1 during the extreme events was greater because of the higher sediment loading in surface runoff at steep site 1.

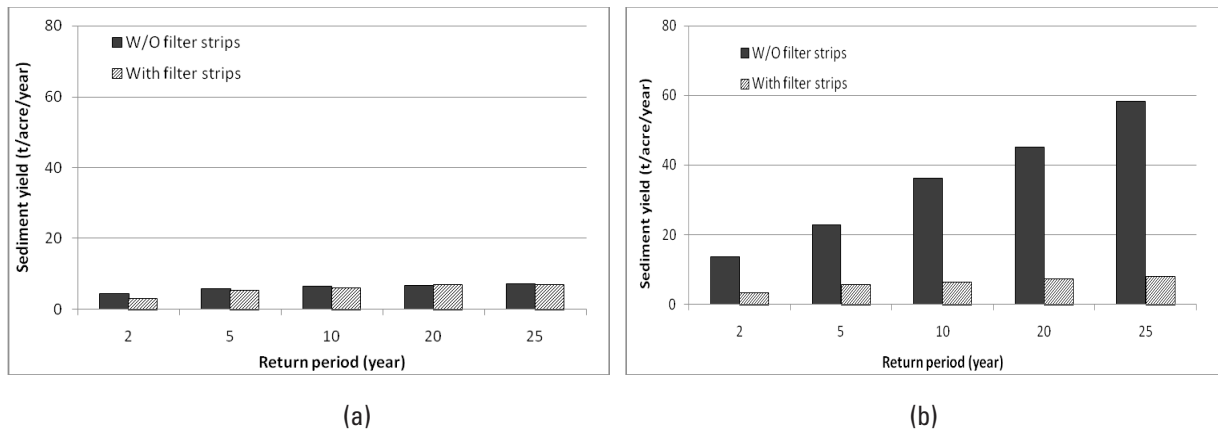


Figure 3. Performance of grass filter strips at site 1 under a corn-soybean rotation with (a) no-till and (b) chisel-plow during the extreme storm events.

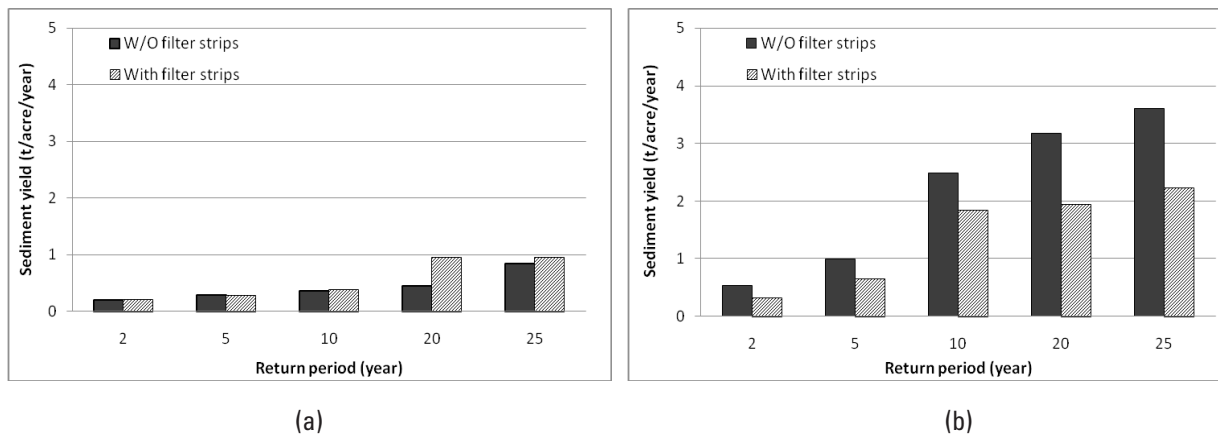


Figure 4. Performance of filter strips at site 2 under a corn-soybean rotation with (a) no-till and (b) chisel-plow during the extreme storm events.

Terraces were effective in sediment reduction at the steeper site 1 with both the no-tillage and chisel-plow systems (Figure 5). The increases of sediment yield during some extreme events with a no-tillage system at site 2 might be because the inter-rill flow and erosion are more critical than rill erosion for a no-tillage system (Figure 6). As a result, the WEPP model did not do a good job in simulating the impact of terraces by reducing slope length for a no-tillage system, especially for flat areas, but overall there were relatively low levels of simulated soil erosion at site 2.

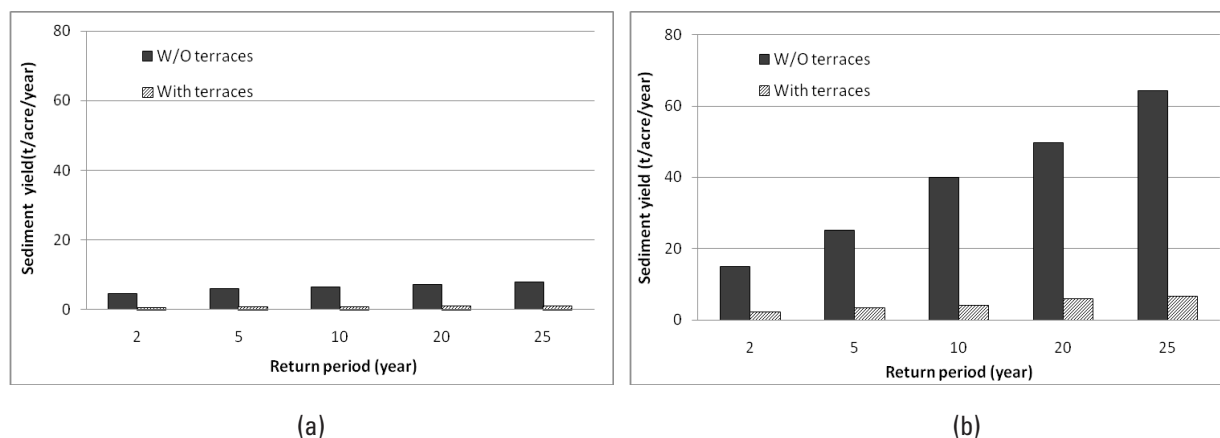


Figure 5. Performance of terraces at site 1 under a corn-soybean rotation with (a) no-till and (b) chisel-plow during the extreme storm events.

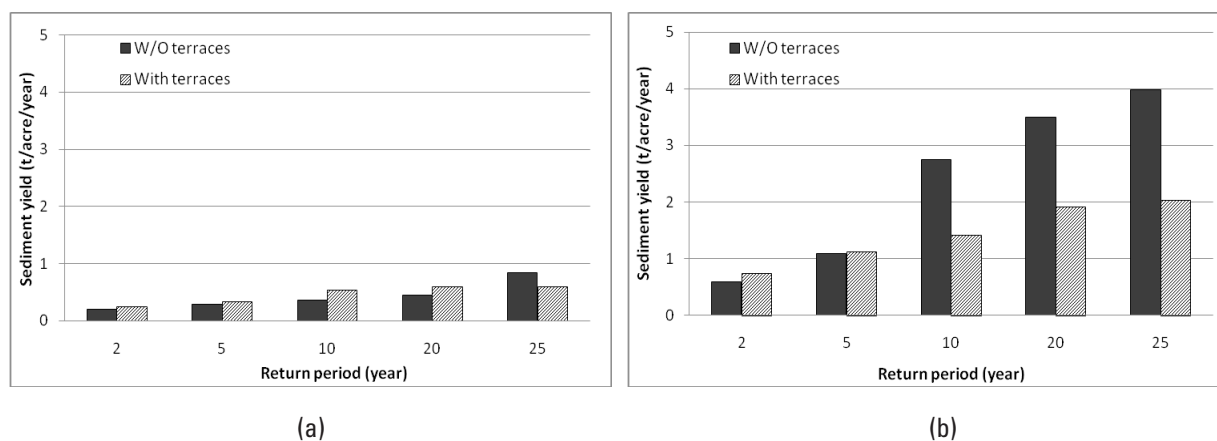


Figure 6. Performance of terraces at site 2 under a corn-soybean rotation with (a) no-till and (b) chisel-plow during the extreme storm events.

Conclusions

The performance of conservation practices during extreme precipitation events is very critical to assessing their effectiveness on soil erosion control. The return period analysis from the WEPP model simulation showed that reduced tillage systems can greatly reduce soil erosion and sediment yield by increasing field residue cover during extreme events. Additional erosion control structures (grassed waterways, filter strips and terraces) were very effective in reducing sediment yield from extreme events for croplands with a high soil loss potential, such as steep slopes, intense tillage, or highly erodible soils.

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Effect of cover crops in reducing nitrate-nitrogen leaching in Iowa

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Introduction

Nitrate-nitrogen ($\text{NO}_3\text{-N}$) has been deemed a main source of pollutant for both shallow groundwater and surface water bodies. The main source of $\text{NO}_3\text{-N}$ in the Mississippi River Basin (MRB) is linked to tile drainage (Lowrance, 1992; David et al., 1997). Approximately 25% of agricultural land is artificially drained in Iowa (Baker et al., 2004) and subsurface drainage is the main source of $\text{NO}_3\text{-N}$ loss. Schilling and Zhang (2004) reported that while Iowa accounts for 5% of the area of the MRB it contributes approximately 25% of $\text{NO}_3\text{-N}$ load (23 lb-N acre⁻¹) over a 28-year period from 1972 to 2000. Plot scale experiments measured $\text{NO}_3\text{-N}$ loss of 23 to 49 lb-N acre⁻¹ year⁻¹ in northeast Iowa (Weed and Kanwar, 1996), 24 to 27 lb-N acre⁻¹ in central Iowa (Baker et al., 1975; Baker and Johanson, 1981; Kanwar et al., 1983) and 6 to 56 lb-N acre⁻¹ year⁻¹ in northwest Iowa (Lawlor, et al., 2008).

The mass of $\text{NO}_3\text{-N}$ loss is closely related to subsurface drainage volume (Baker et al, 1975; Cambardella et al., 1999). April, May and June were found to be the main subsurface drainage period. In these 3 months, nearly 70% of the drainage occurred in north-central Iowa (Helmers et al., 2005), and 71% of the annual drainage and 75% of $\text{NO}_3\text{-N}$ loss were observed in Minnesota during this period (Randall and Vetsch, 2005).

Annual cover crop, perennial living mulch and perennial grassland have the potential to reduce $\text{NO}_3\text{-N}$ leaching in the Midwest. Annual winter cover crops, which have historically been added into corn-soybean rotation to achieve soil and water conservation benefits in the Midwest (Kaspar et al., 2001; Unger and Vigil, 1998), were studied to assess their potential in reducing subsurface drainage volume and $\text{NO}_3\text{-N}$ concentration in the drain flow thereby decreasing the $\text{NO}_3\text{-N}$ loss from the soil. Strock et al. (2004) found that using rye as a winter cover crop in Minnesota reduced drainage water by 11% and $\text{NO}_3\text{-N}$ leaching by 13%. In a 4-year field experiment conducted in Iowa, Kaspar et al. (2007) reported that average annual $\text{NO}_3\text{-N}$ loss from winter rye cover treatment was 17.7 lb-N acre⁻¹ which was 61% lower than the control treatment, and that N uptake by rye was as high as 43 lb-N acre⁻¹ with a fertilizer rate of 210 lb-N acre⁻¹ and 220 lb-N acre⁻¹ to corn in a corn-soybean rotation. Italian ryegrass, alfalfa, and kura clover are examples of living mulches. Perennial grassland serves as an effective nitrogen loss reduction approach because no fertilization is necessary and it has a longer growing period than winter cover crop, however at present there is little economic market for the product. Baker and Melvin (1994) documented that the $\text{NO}_3\text{-N}$ concentration in the drain tile under alfalfa was much lower than that under corn or soybean.

In Iowa previous research on $\text{NO}_3\text{-N}$ loss with rye as a winter cover crop were conducted with relative high N rates (Kaspar et al., 2007). Reports on perennial living mulch as an approach of water quality protection is very limited. To get a better understanding on the effects of land

covers on $\text{NO}_3\text{-N}$ loss, a field experiment was conducted in northwest Iowa with winter rye cover crop in corn-soybean rotation, kura clover as a living mulch for corn and a pasture land cover. The objectives of this study were: 1) to evaluate the impact of a different land covers on $\text{NO}_3\text{-N}$ loss in subsurface drainage under a recommended crop fertilization; 2) to investigate the $\text{NO}_3\text{-N}$ concentrations in the soil water under different land covers and 3) to quantify the N uptake by different cover crops in the spring.

Materials and methods

Site description

The field study was conducted from 2006 to 2008 on the Agricultural Drainage Water Quality - Research and Demonstration Site (ADWQ-RDS, former Agricultural Drainage Well Site) near Gilmore City in Pocahontas County which has been described in greater detail by Helmers et al. (2005), Singh et al. (2006) and Lawlor et al. (2008). An automatic meteorological station was installed at the site. The size of each plot was 125 feet in length and 50 feet in width. The plots were established after the installation of corrugated plastic drain tiles through the center and both boundaries parallel to the long dimension (25 foot spacing) at a depth of 3.5 feet. All subsurface drainage lines extended to one of the two sumps where water was collected and pumped into a nearby wetland. Drainage water from each center line is collected in an aluminum culvert with automatic pumping, volume monitoring and water sampling systems.

A six-treatment experiment was established in a completely randomized block design. The six land cover treatments in 2006, 2007, and 2008 were (Table 1): 1) corn-soybean rotation initiated with corn in 2006 with fallow in spring (fallow-Corn-fallow-Soybean-fallow-Corn, fCfSfC); 2) corn-soybean rotation initiated with soybean in 2006 with fallow in spring (fallow-Soybean-fallow-Corn-fallow-Soybean, fSfCfS); 3) corn-soybean rotation initiated with corn in 2006 with rye cover crop (rye-Corn-rye-Soybean-rye-Corn, rCrSrC); 4) corn-soybean rotation initiated with soybean in 2006 with rye cover crop (rye-Soybean-rye-Corn-rye-Soybean, rSrCrS); 5) Corn with established kura clover as a living mulch (kura-Kura-kura-Corn-kura-Corn, kKkCkC); and 6) Pasture as a perennial grass treatment (PP). The plots were blocked by drainage characteristics, resulting in 4 blocks as high drainage, medium high, medium low and low blocks based on the long-term drainage performance. One plot in each block was randomly assigned to each treatment (6 treatments \times 4 blocks \times 1 replication) in this study. This experiment was initiated in 2005 but data presented in this paper started in April 2006 since 2005 was considered a transition year due to previous plot treatments.

Agronomic management

Agronomic field activities were completed in a timely manner prior to and during the crop season beginning in October 2004 with plot tillage and rye seeding. Tillage for seedbed preparation for perennial crops was completed in the spring just prior to planting on April 18, 2005. 'Endura' kura clover (*Trifolium ambiguum*) was hand seeded at a rate of 11.6 lb acre⁻¹, the perennial pasture plots were hand seeded with 'Duration' red (*Trifolium pratense*), and 'Pinnacle' ladino (*Trifolium repens*) clovers with 'Extend' orchardgrass (*Dactylis glomerata*) at 8.0, 0.5, and 4.0 lb acre⁻¹, respectively. 'Rymin' rye (*Secale cereale*) was drill seeded at a rate of 89.2 lb acre⁻¹ in 7.5 inches rows with a skip row every 30 inches for subsequent corn or soybean planting in the spring. Commercial-grade 28% aqueous ammonia-nitrogen (N) was applied at 125 lb-N acre⁻¹

in spring closely following corn emergence to corn plots only. See Table 2 for agronomic timing details.

Drainage volume monitoring, sampling and analysis

Drainage flow volume was measured by a magnetic flow meter, connected to an electronic data logger. Meter readings were also recorded manually. Samples were collected after every 0.5 inch of subsurface drainage flow, and thereafter were stored in a cooler at 39°F until analyzed. NO₃-N concentration was analyzed in the Wetland Research Laboratory, Iowa State University through the second-derivative spectroscopy technique.

Soil water solution and biomass sampling

Soil water solution was sampled using two suction lysimeters (3 feet apart) installed along the median line between the center and boundary lines at the depths of 1 and 2 feet in each of the medium high, medium low and low flow block plots. A vacuum of -10.8 psi was applied to the suction lysimeters every week and any available soil water solution sample was collected every three to four days. Soil solution samples were processed and analyzed in the Agricultural and Biosystems Engineering Water Quality Laboratory, Iowa State University using a Quickchem 2000 Automated Ion Analyzer flow injection system (Lachat Instruments, Milwaukee, Wisc.). Rye shoots were sampled weekly from early spring until chemically desiccated by roundup. Weekly kura clover and pasture shoots sampling coincided with rye and continued until late June. From July, corn, soybean, kura clover and pasture were sampled once every three weeks until early October. Rye, corn and soybean were sampled along a 1-foot long section at four randomly selected locations; Kura and pasture were sampled in a 1×1 foot² area randomly selected at three locations in each plot. Samples were dried at 140 F for a week in ovens at the Agricultural Engineering Farm of Iowa State University. Dry matter weight was recorded. Total nitrogen (TN) content was analyzed for all samples obtained from rye plots, two occasions for Kura clover and pasture, and two occasions for corn soybean plots. Total nitrogen analysis was conducted in Soil Plant Analysis Laboratory at Iowa State University by the combustion method. TN for the plant shoots of 2008, which is still in process, is not available.

Statistical analysis

Subsurface drainage volume, flow-weighted NO₃-N concentration in the subsurface drainage, NO₃-N loss and NO₃-N concentration in the suction lysimeter were analyzed as a completely randomized block design using PROC GLIMMIX procedure in SAS software which can test the significance of difference for unbalanced data. Means were grouped using a least significant difference test at p=0.05 (LSD_{0.05}).

Results and discussion

Precipitation and temperature

Daily precipitation and temperature for the study period are presented in Fig 1. The annual precipitation in 2006 and 2007 was 21.6 and 33.7 inches respectively, with 21.0 and 33.1 inches in the drainage season from March to November. The total precipitation in 2008 until July was 24.0 inches. The long term average rainfall in the drainage season for Pocahontas, Iowa, was 28.4 inches (Lawlor et al., 2008). The long-term monthly average temperatures during the rye growing season in March, April, and May are 33.8°, 47.5° and 60.0°F. The temperatures during

these three months in 2006 were 34.3°, 53.1° and 60.4°F which were higher than the long term average. However, in 2007, the average temperatures in March and May were 38.8° and 64.6°F which were higher than the average, but in April the average temperature was 45.3°F, lower than the long-term average in April. The average temperatures in March, April, and May for 2008 were 29.5°, 43.9° and 56.5°F, which were lower than the long-term averages.

Drainage and NO₃-N leaching

The annual discharge for the 24 plots varied from 1.2 to 9.4 inches in 2006, 4.1 to 39.8 inches in 2007, and 3.5 to 35.7 inches in 2008 (Table 3, 4, and 5). The average annual drainage of all land cover treatments was 13.4 inches during the three years observation, which represented 51.4% of the rainfall during the drainage season. The total average drainage in April, May and June was 8.7 inches which accounted for 65.0% of the annual drainage while 81.5% of the total rainfall occurred in these three months. There was no significant difference in monthly or annual drainage volume due to land cover treatments except that the drainage of kKkCkC in May 2007 was significantly lower than fSfCfS, fCfSfC, and rSrCrS treatments.

NO₃-N concentration in the tile drainage water samples varied from 3.5 to 21.9 mg N L⁻¹ during 2006, 1.0 to 25.3 mg N L⁻¹ in 2007, and 1.0 to 18.3 mg N L⁻¹ in 2008. The average annual flow-weighted NO₃-N concentration of fSfCfS and fCfSfC treatments was 13.7 mg N L⁻¹, and the value for rSrCrS and rCrSrC treatments was 12.2 mg N L⁻¹. In the corn-soybean rotation plots no matter with or without winter rye as a land cover, monthly flow-weighted NO₃-N concentration in April, May and June consistently exceeded the 10 mg N L⁻¹ maximum contaminant limit set by the USEPA for drinking water. Treatments with rye followed by soybean in 2006 and 2007 showed the lowest annual flow-weighted NO₃-N concentration for the corn-soybean rotation with a NO₃-N concentration 21.7% lower than the treatments with fallow-soybean. Although significant annual NO₃-N concentration reduction by rye was only observed in rSrCrS for 2006, the reduction of monthly NO₃-N concentration was found in most cases during April, May and June of 2006 and 2007 (Table 3 and 4).

The average annual flow-weighted NO₃-N concentrations from the drain tile of the kKkCkC were 6.7, 7.2, and 6.4 mg N L⁻¹ for 2006, 2007, and 2008, respectively, and were 8.2, 4.8, and 3.4 mg N L⁻¹ for PP treatment, below the 10 mg N L⁻¹ of USEPA limit for drinking water. The annual flow-weighted NO₃-N concentrations of kKkCkC treatments, even with fertilizer application on June 5, 2007 and June 20, 2008, was found to be significantly lower than the fSfCfS and fCfSfC treatments (p<0.05). NO₃-N concentration in PP treatment decreased from 2006 to 2008 and was significantly lower than all treatments with corn-soybean rotation in 2007 and 2008 (p<0.05). The lowest annual flow-weighted concentration of 3.4 mg N L⁻¹ was observed in PP treatment for 2008.

The annual NO₃-N loss of the 24 plots varied from 7.2 to 56.6 lb-N acre⁻¹ for 2006 and from 6.5 to 96.2 lb-N acre⁻¹ for 2007, and 6.5 to 77.3 lb-N acre⁻¹ for 2008. The annual NO₃-N loss was 36.3 lb-N acre⁻¹ for fSfCfS and fCfSfC treatments, and 35.8 lb-N acre⁻¹ for rSrCrS and rCrSrC treatments on average over the three years. The average total NO₃-N loss during April, May, and June was 25.0 lb-N acre⁻¹ for fSfCfS and fCfSfC, 59.6% of the annual NO₃-N leaching. Rye followed by soybean grew around 20 days longer than that followed by corn due to the later planting date for soybean. While not significantly different there was some slight reduction in NO₃-N loss during April, May and June for the winter rye cover crop treatment. In these three

months, the average $\text{NO}_3\text{-N}$ loss for fSfCfS and fCfSfC was $25.0 \text{ lb-N acre}^{-1}$ and $22.7 \text{ lb-N acre}^{-1}$ for rSrCrS and rCrSrC.

The average drainage volume was not significantly different over the three years (Table 6). The three-year flow weighted $\text{NO}_3\text{-N}$ concentration of kKkCkC and PP treatments were significantly lower than other treatments (Table 6). Average annual $\text{NO}_3\text{-N}$ losses from fSfCfS and fCfSfC were 40.0 and $32.7 \text{ lb-N acre}^{-1}$, comparable to the values of $\text{NO}_3\text{-N}$ loss from rSrCrS and rCrSrC which were 34.5 and $37.0 \text{ lb-N acre}^{-1}$. The average annual $\text{NO}_3\text{-N}$ loss of kKkCkC and PP treatments were $21.5 \text{ lb-N acre}^{-1}$ and $13.9 \text{ lb-N acre}^{-1}$, which were 48.9% and 66.9% lower than the annual $\text{NO}_3\text{-N}$ loss from fSfCfS and fCfSfC treatments. The average annual $\text{NO}_3\text{-N}$ loss of PP treatment was significantly lower than all corn-soybean treatments ($p < 0.05$).

Suction lysimeter $\text{NO}_3\text{-N}$ concentration

Nitrate-nitrogen concentration in soil solution ranged from 0.1 to 33.4 mg N L^{-1} for fSfCfS, 0.4 to 38.1 mg N L^{-1} for fCfSfC, no detection ($\leq 0.01 \text{ mg N L}^{-1}$) to 26.6 mg N L^{-1} for rSrCrS, no detection to 22.1 for rCrSrC, no detection to 77.6 for kKkCkC, and no detection to 15.0 mg N L^{-1} for PP.

On average over two depths, $\text{NO}_3\text{-N}$ concentration in the soil solution in 2007 for the rCrSrC treatment was found to be significantly lower than fCfSfC by 56.4% ($p < 0.05$) (Table 7). Although not significant, $\text{NO}_3\text{-N}$ concentration in rSrCrS treatment was 21.5% lower than that in fSfCfS treatment. PP treatment significantly ($p < 0.05$) reduced the $\text{NO}_3\text{-N}$ content in soil solution compared with any other treatments.

$\text{NO}_3\text{-N}$ -nitrogen concentrations at 1-foot were not significantly different than those at 2-foot depth, indicating that $\text{NO}_3\text{-N}$ concentration was not stratified at these two depths. However, in the PP plots, the average $\text{NO}_3\text{-N}$ concentration in the soil solution at 1- and 2-foot was 1.2 mg N L^{-1} , 72.9% lower than the flow-weighted $\text{NO}_3\text{-N}$ concentration in the tile line (3.5 feet deep). For the corn-soybean rotation treatments, no matter with or without rye as a winter cover, the $\text{NO}_3\text{-N}$ concentrations at 1- and 2-foot were generally higher than that in the tile flow in spring and early summer but lower in August and September. Moreover, in the corn-soybean and pasture treatment plots, the $\text{NO}_3\text{-N}$ concentration in the soil solution in April, May and June were lower than those in August and September. An inverse pattern was observed in kKkCkC treatment, which reflected the fertilizer application in June, 2007 and little uptake of N fertilizer due to poor corn growth.

Biomass and N uptake of spring land covers

Biomass and nitrogen uptake of spring land covers was lower in 2007 than in 2006 (Table 8 and Table 9). Winter rye cover crop growing in the rye-soybean treatment was chemically desiccated in the middle to late May and the rye in the rye-corn treatment was killed in the late April with a difference around 20 days. At killing, the average rye biomass was $1320 \text{ lb acre}^{-1}$. The average biomass of rye followed by soybean was $2086 \text{ lb acre}^{-1}$, while biomass of rye followed by corn was 553 lb acre^{-1} . Within the 20 days after the rye followed by corn was killed, rye followed by soybean accumulated 79.8% of the biomass in 2006 and 77.9% of the biomass in 2007. In the early June, observed biomass was $3500 \text{ lb acre}^{-1}$ for Kura clover and $2706 \text{ lb acre}^{-1}$ for pasture.

With the accumulation of above ground biomass, nitrogen content in the grass and legume shoot decreased during the sampling period from late March to early June. Nitrogen content declined

from 5.7% on March 29 to 1.9% on May 25 for the rye followed by soybean in 2007. At killing, the average nitrogen uptake by rye was 29.7 lb-N acre⁻¹. In early June, the cumulative nitrogen uptake was 53.4 lb-N acre⁻¹ for kura clover and 29.6 lb-N acre⁻¹ for pasture.

Conclusion

This study evaluated the impacts of various land covers in NO₃-N concentration and leaching in Iowa. In total, 51.4% of the annual rainfall exited through the subsurface drainage system. April, May and June were the main drainage months with 65.0% of the annual drainage. From the six different land cover treatments over two years, there were no significant differences among annual drainage volume.

The average annual flow-weighted NO₃-N concentration in the fallow corn or soybean treatments was 13.7 mg N L⁻¹. NO₃-N concentration in the drainage flow from the corn-soybean treatments during April, May and June consistently exceeded the 10 mg N L⁻¹ limit set by USEPA for drinking water. Rye followed by soybean was found to significantly reduce annual flow-weighted NO₃-N concentration for 2006. Reduction of monthly flow-weighted NO₃-N concentration in April, May and June was observed in some months of 2006 and 2007. The average annual flow-weighted NO₃-N concentrations from the drain tile of the kKkCkC and PP treatments were 6.9 and 5.4 mg N L⁻¹ respectively, and were significantly lower than other treatments. Compared with corn-soybean without spring land cover treatments, kura clover as a living mulch and perennial pasture treatments resulted in a 48.9% and 66.9% reduction in annual NO₃-N leaching, respectively.

Rye followed by soybean reduced the NO₃-N concentration in the soil water solution significantly (56.4%) at the 1- and 2-foot depths. Pasture treatment showed significantly lower NO₃-N concentrations in the soil solutions at these depths than all other treatments. At killing, the average nitrogen uptake by rye was 29.7 lb-N acre⁻¹. In early June, the cumulative nitrogen uptake was 53.4 lb-N acre⁻¹ for kura clover and 29.6 lb-N acre⁻¹ for pasture.

Overall, this study indicates that winter rye cover crop, kura clover as a living mulch and perennial pasture land covers had positive effects on NO₃-N concentration under the weather conditions presented during these three years in Iowa.

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Table 1. Land cover treatments.

Treatment	2006		2007		2008	
Notation	Spring	Summer	Spring	Summer	Spring	Summer
fSfCfS	fallow	Soybean	fallow	Corn	fallow	Soybean
fCfSfC	fallow	Corn	fallow	Soybean	fallow	Corn
rSrCrS	rye	Soybean	rye	Corn	rye	Soybean
rCrSrC	rye	Corn	rye	Soybean	rye	Corn
kKkCkC	kura clover	Kura clover	kura clover	kura clover+Corn	kura clover	kura clover+Corn
PP	pasture	Pasture	pasture	Pasture	pasture	Pasture

Table 2. Agronomic field activity timing.

Year	Management	fSfCfS	fCfSfC	rSrCrS	rCrSrC	kKkCkC	PP
2005	rye seeding	-	-	11-Oct	11-Oct	-	-
2006	rye termination	-	-	16-May	24-Apr	-	-
	corn planting	-	4-May	-	4-May	-	-
	soybean Planting	10-May	-	10-May	-	-	-
	fertilizer application	-	18-May	-	18-May	-	-
	rye seeding	-	-	12-Oct	12-Oct	-	-
2007	rye termination	-	-	30-Apr	23-May	-	-
	corn planting	14-May	-	14-May	-	14-May	-
	soybean Planting	-	17-May	-	17-May	-	-
	fertilizer application	5-Jun	-	5-Jun	-	5-Jun	-
	rye seeding	-	-	25-Oct	25-Oct	-	-
2008	rye termination	-	-	26-May	6-May	-	-
	corn planting	-	15-May	-	15-May	15-May	-
	soybean Planting	23-May	-	23-May	-	-	-
	fertilizer application	-	20-Jun	-	20-Jun	20-Jun	-

Table 3. Average drainage volume, flow-weighted NO₃-N concentration and NO₃-N loss in 2006.

Month	Land cover treatments					
	fSfCfS	fCfSfC	rSrCrS	rCrSrC	kKkCkC	PP
----- Drainage inch -----						
April	2.6 a	2.8 a	2.8 a	1.8 a	2.6 a	3.2 a
May	1.8 a	1.6 a	1.4 a	1.2 a	0.8 a	0.9 a
July	0.5 a	0.3 a	0.4 a	0.8 a	0.2 a	0.1 a
Annual	4.9 a	4.7 a	4.5 a	3.9 a	3.6 a	4.3 a
----- Flow weighted NO ₃ -N concentration mg L ⁻¹ -----						
April	14.4 a	11.9 a	13.0 ab	13.2 ab	7.0 c	8.4 bc
May	16.3 ab	16.2 a	12.4 bc	13.4 ab	5.3 d	8.1 cd
July	14.6 ab	10.2 a	9.6 b	21.1 ab	8.3 b	6.0 b
Annual flow-weighted average	15.1 a	13.2 ab	12.6 b	14.8 a	6.7 c	8.2 bc
----- NO ₃ -N loss lb-N acre ⁻¹ -----						
April	8.5 a	7.5 a	8.2 a	5.5 a	4.1 a	6.1 a
May	6.5 a	5.7 ab	4.0 abc	3.8 abc	1.0 c	1.7 c
July	1.6 a	0.7 a	0.8 a	3.7 a	0.3 a	0.2 a
Annual	16.6 a	14.0 ab	12.9 ab	12.9 ab	5.4 b	7.9 ab

Means within a row followed by the same letter are not significantly different at p=0.05.

Table 4. Average drainage volume, flow-weighted NO₃-N concentration and NO₃-N loss in 2007.

Month	Land cover treatments					
	fSfCfS	fCfSfC	rSrCrS	rCrSrC	kKkCkC	PP
----- Drainage inch -----						
March	0.3 a	0.2 a	0.2 a	0.5 a	0.6 a	0.4 a
April	4.6 a	3.7 a	5.2 a	4.4 a	5.6 a	4.4 a
May	1.5 ab	1.5 ab	1.7 a	0.7 bc	0.4 c	1.2 abc
June	0.4 a	0.1 a	0.2 a	0.1 a	0.1 a	0.2 a
August	7.2 a	4.7 a	7.2 a	10.2 a	9.4 a	6.9 a
September	0.2 a	0.2 a	0.2 a	0.0 a	0.1 a	0.3 a
October	5.1 a	4.7 a	6.8 a	6.9 a	4.9 a	3.9 a
Annual	19.2 a	15.1 a	21.5 a	22.7 a	21.2 a	17.2 a
----- Flow weighted NO ₃ -N concentration mg L ⁻¹ -----						
March	13.0 a	12.7 a	11.2 a	9.3 a	3.0 a	6.4 a
April	14.3 a	13.2 ab	11.7 b	10.6 b	2.9 c	5.0 c
May	16.1 a	16.0 a	13.1 b	12.7 b	3.1 c	4.6 c
June	16.3 a	13.5 abc	13.1 ab	11.8 ab	3.9 c	4.9 bc
August	12.3 a	12.9 a	9.6 a	8.9 a	11.1 a	5.2 b
September	11.4 a	10.5 a	7.5 a	5.8 a	5.8 a	3.3 a
October	13.5 a	12.0 ab	12.9 a	9.2 b	5.8 c	3.9 c
Annual flow-weighted average	13.5 a	12.9 ab	11.5 ab	9.5 bc	7.2 cd	4.8 d
----- NO ₃ -N loss lb-N acre ⁻¹ -----						
March	0.8 a	0.6 a	0.6 a	1.0 a	0.4 a	0.5 a
April	15.1 a	11.1 ab	13.8 a	10.6 abc	3.7 c	4.9 bc
May	5.4 a	5.5 a	5.1 a	1.9 b	0.3 b	1.2 b
June	1.4 a	0.4 b	0.5 ab	0.2 b	0.1 b	0.2 b
August	20.1 a	13.7 a	15.6 a	20.7 a	23.6 a	8.1 a
September	0.5 a	0.4 a	0.3 a	0.0 a	0.1 a	0.2 a
October	15.5 ab	12.7 abc	19.8 a	14.3 ab	6.5 bc	3.5 c
Annual total	58.7 a	44.3 ab	55.7 a	48.7 ab	34.8 ab	18.7 b

Table 5. Drainage volume, flow-weighted nitrate concentration and nitrate loss in 2008

Month	Land cover treatments					
	fSfCfS	fCfSfC	rSrCrS	rCrSrC	kKkCkC	PP
----- Drainage inch -----						
April	3.8 a	3.3 a	3.8 a	5.1 a	4.8 a	5.5 a
May	4.2 a	2.8 a	2.6 a	4.2 a	2.9 a	4.1 a
June	9.0 a	7.0 a	6.8 a	10.1 a	9.3 a	8.7 a
July	0.4 a	0.3 a	0.1 a	0.1 a	0.0 a	0.5 a
Annual	17.3 a	13.4 a	13.3 a	19.5 a	17.0 a	18.8 a
----- Flow weighted NO ₃ -N concentration mg L ⁻¹ -----						
April	13.2 a	13.8 a	13.1 a	11.5 a	7.7 b	4.9 b
May	12.2 a	12.7 a	11.6 a	11.4 a	6.6 b	3.7 b
June	11.5 a	12.6 a	12.1 a	11.4 a	5.8 b	2.5 c
July	9.8 ab	12.4 a	11.3 a	10.8 a	6.8 b	2.5 c
Annual flow-weighted	12.0 a	13.1 a	12.2 a	11.4 a	6.4 b	3.4 c
----- NO ₃ -N loss lb-N acre ⁻¹ -----						
April	9.7 a	10.3 a	10.7 a	12.7 a	8.3 a	5.7 a
May	10.5 a	7.5 ab	5.9 ab	10.4 a	4.4 b	3.9 b
June	23.4 a	21.1 a	18.3 ab	24.9 a	11.7 ab	5.4 b
July	0.9 a	0.6 ab	0.2 ab	0.3 ab	0.1 b	0.2 ab
Annual	44.6 a	39.6 ab	35.0 ab	48.3 a	24.6 bc	15.2 c

Table 6. Average annual drainage, flow-weighted NO₃-N concentration and NO₃-N loss in 2006, 2007, and 2008.

Year	Land cover treatments					
	fSfCfS	fCfSfC	rSrCrS	rCrSrC	kKkCkC	PP
----- Drainage inch -----						
2006	4.9 a	4.7 a	4.5 a	3.9 a	3.6 a	4.3 a
2007	19.2 a	15.1 a	21.5 a	22.7 a	21.2 a	17.2 a
2008	17.3 a	13.4 a	13.3 a	19.5 a	17.0 a	18.8 a
Average	13.8 a	11.0 a	13.1 a	15.4 a	13.9 a	13.4 a
----- Flow weighted NO ₃ -N concentration mg L ⁻¹ -----						
2006	15.1 a	13.2 ab	12.6 b	14.8 ab	6.3 c	8.2 bc
2007	13.5 a	12.9 ab	11.5 ab	9.5 bc	7.2 cd	4.8 d
2008	12.0 a	13.1 a	12.2 a	11.4 a	6.4 b	3.4 c
Average	13.6 a	13.7 a	12.1 a	12.2 a	6.9 b	5.4 b
----- NO ₃ -N loss lb-N acre ⁻¹ -----						
2006	16.7 a	14.0 ab	12.9 ab	12.9 ab	5.2 b	7.9 ab
2007	58.7 a	44.3 ab	55.7 a	48.6 ab	34.8 ab	18.7 b
2008	44.6 a	39.6 ab	34.9 ab	48.3 a	24.6 bc	15.2 c
Average	40.0 a	32.6 a	34.5 ab	37.0 a	21.5 bc	13.9 c

Table 7. NO₃-N concentration in suction lysimeters at 1-foot and 2-foot depths in 2007.

Date	Land Cover Treatments					
	fSfCfS	fCfSfC	rSrCrS	rCrSrC	kKkCkC	PP
----- 1-foot depth -----						
April	21.4	25.1	14.8	10.7	8.5	
May	12.2	15.2	13.0	7.5	2.3	1.1
June	8.7	16.6	17.7	4.1	2.9	5.0
July	13.6	17.9	11.0	8.3		
August	5.0	2.0	2.8	3.9	24.9	0.2
September	16.0	6.7	7.5	5.6	23.2	0.0
Average ^[1]	12.8	13.9	11.1	6.6	12.4	1.6
----- 2-foot depth -----						
April	19.8	30.8	7.3	19.3		1.0
May	17.6	26.6	11.7	12.2	2.8	0.2
June	15.3	27.6	10.1	4.7	2.0	2.1
July	13.4	21.4	10.0	4.6	0.6	
August	4.2	8.2	4.1	3.2	22.4	0.6
September	8.7	7.1	12.4	4.5	38.3	0.1
Average ^[1]	13.2	20.3	9.2	8.1	13.2	0.8
Overall average ^[2]	13.0 ab	17.1 a	10.2 bc	7.4 c	12.8 b	1.2 d

[1]. Average over all observed value; [2]. Average over all monthly value.

Table 8. Biomass, nitrogen content and nitrogen uptake by rye, kura clover, and pasture in the spring of 2006.

Date	Biomass (lb acre ⁻¹)		N content (%)		N uptake (lb N acre ⁻¹)	
	rCrSrC	rSrCrS	rCrSrC	rSrCrS	rCrSrC	rSrCrS
4/12/06	221	177	4.4	4.1	10.9	8.1
4/19/06	604	342	3.8	3.8	26.1	13.9
4/26/06	811	539	3.4	3.2	31.1	18.9
5/10/06		1760		2.5		50.1
5/17/06		2670		1.9		58.8
	kKkCkC	PP	kKkCkC	PP	kKkCkC	PP
4/26/06	1595	1750	3.8	3.1	33.1	31.2
6/5/06	5525	5169	2.4	1.7	75.9	39.2

Table 9. Biomass, nitrogen content and nitrogen uptake by rye, kura clover, and pasture in the spring of 2007.

Date	Biomass (lb acre ⁻¹)		N content (%)		N uptake (lb N acre ⁻¹)	
	rCrSrC	rSrCrS	rCrSrC	rSrCrS	rCrSrC	rSrCrS
3/29/07	49	50	5.7	6.0	3.2	3.3
4/5/07	56	85	4.8	5.0	3.0	4.8
4/13/07	64	86	5.1	5.2	3.7	5.1
4/19/07	100	89	4.5	4.9	5.1	4.9
4/27/07	176	211	4.3	4.5	8.4	10.6
4/30/07	332	294	3.3	3.4	12.2	11.3
5/10/07	617	0	2.9		19.8	
5/17/07	974	0	2.3		24.4	
5/25/07	1502	0	1.9		31.8	
	kKkCkC	PP	kKkCkC	PP	kKkCkC	PP
4/27/07	863	160	4.7	3.6	45.5	6.4
6/7/07	1474	1849	2.6	1.3	43.9	27.2

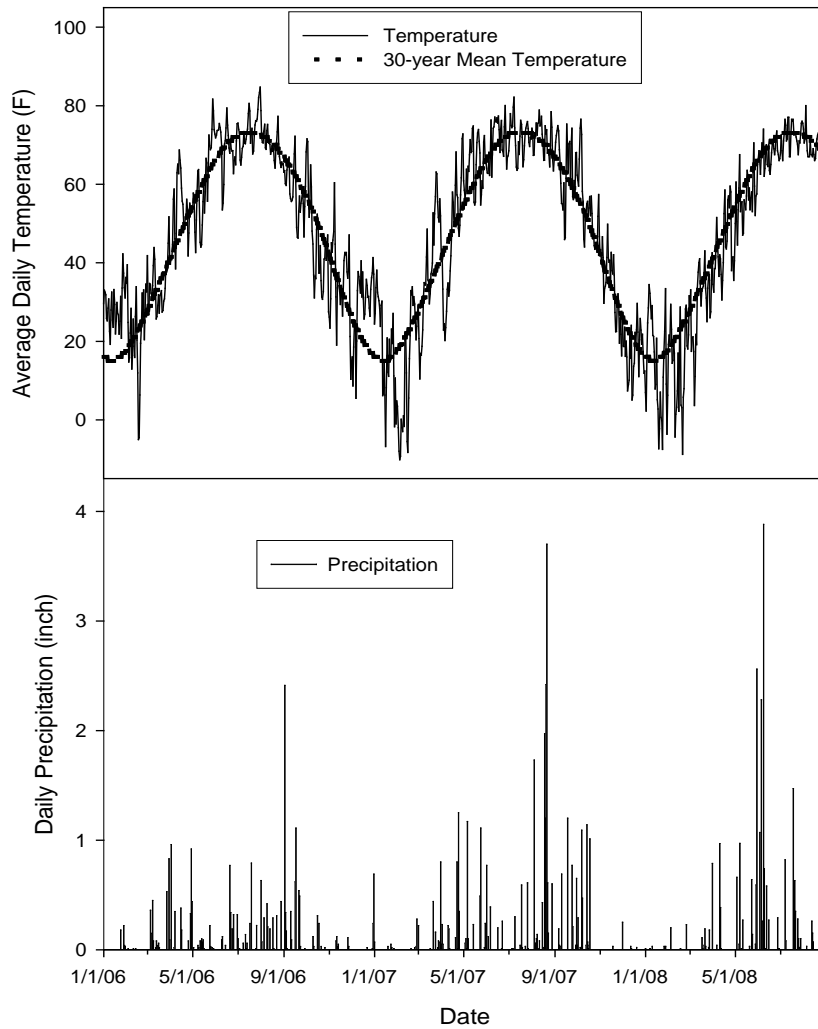


Figure 1. Daily temperature and precipitation: 2006-2008.

Tillage considerations on previously flooded soils

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Introduction

Many Iowa fields had wet or underwater areas during part of the growing season. Many wet areas were planted late which resulted in late-maturing crop. Yields have been variable in these areas, sometimes significantly below that of yields in areas not subject to wet soil conditions.

In these conditions a frequent concern of growers is that excessive rainfall, wet soil, and/or lower crop yield have damaged soil structure and that these damages may warrant significant tillage operations prior to next season's crop to loosen soil and ameliorate damage to soil structure.

Similar concerns after the 1993 crop season prompted a field study with farmer cooperators to compare tillage effects on soil conditions and crop yield during the following 1994 crop season. Although 1993's excessive rainfall events occurred more during mid-season (June-July-August) rather than 2008 (excessive rain during April-May-June), in both cases significant tillage was not able to be done during the growing season in most instances.

Field study

During fall 1993, four farmer cooperators on five different sites in the Henry-Des Moines-Louisa county area in southeast Iowa agreed to establish replicated strips of tillage trials in production corn-soybean fields to be planted in spring 1994 (Table 1). According to rainfall records at nearby weather recording stations, the fields had received 66 – 85% above normal rainfall during the April – October 1993 growing season.

Table 1. County, soil type, and crop of farmer cooperator sites

Site	County	Soil type	Crop
1	Henry	Mahaska/Taintor silty clay loam	Corn
2	Des Moines	Mahaska/Taintor silty clay loam	Corn
3	Henry	Kalona silty clay loam	Soybean
4	Louisa	Mahaska/Otley silty clay loam	Corn
5	Louisa	Mahaska/Otley silty clay loam	Soybean

Each grower compared three tillage management schemes during fall field preparation for the subsequent crop: 1) deep tillage using a subsoiler (ripper) to a depth of approximately 12 in., 2) moderate tillage with a chisel plow or disk operating at a depth of 6 – 7 in., or 3) no fall tillage. During the spring prior to planting both the subsoiled and chiseled or disked ground was field cultivated to level the soil for planting. A field cultivator was also used at a very shallow (2 in.) depth by some of the operators in previously untilled soil areas as they were concerned about their planter's ability to function in an unprepared seedbed. This resulted in a comparison of three tillage treatments ('shallow', 'moderate', and 'deep').

Effects on both soil compaction and crop yield were measured during the 1994 growing season. Soil compaction measurements included soil sampling in April prior to planting (and prior to tillage in the shallow treatment), in mid-June as crop vegetative growth was accelerating, and post-harvest in October.

Results and discussion

Fall tillage after the wet soil conditions did not have a statistically significant effect on the resulting soil bulk density, either as measured during pre-plant conditions in April or post-harvest conditions in October (Figure 1).

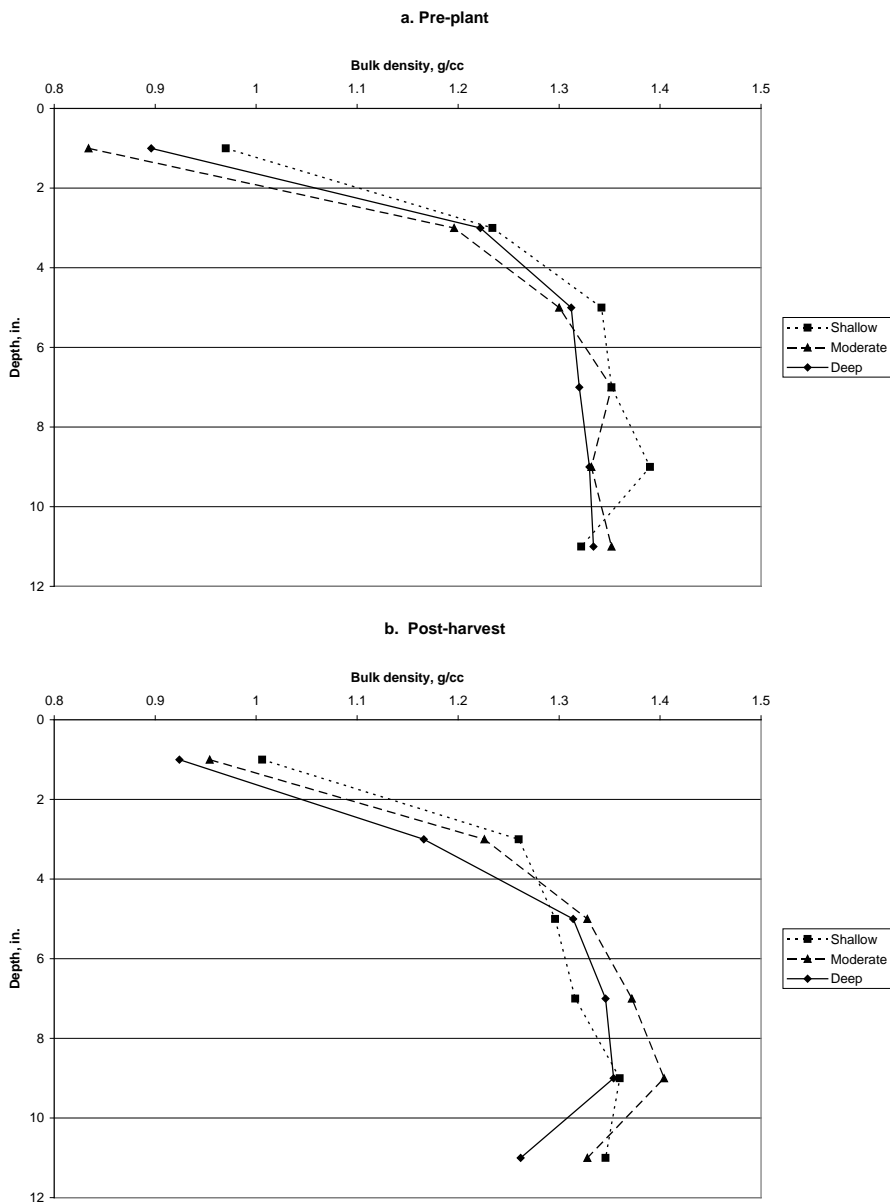


Figure 1. Average pre-plant and post-harvest soil bulk density from field-scale plots receiving shallow, moderate, or deep tillage.

Other natural factors such as over-winter freeze-thaw cycles in the soil prior to the April measurement or effects of shrink cracks propagating as soil moisture was used during the crop season prior to the October measurement may have done as much or more than tillage to loosen the soil.

Penetrometer resistance was, however, statistically less with tillage before planting in April (Figure 2). Just after harvest, penetration resistance for shallow and moderate tillage was similar, but both were greater than that of deep tillage.

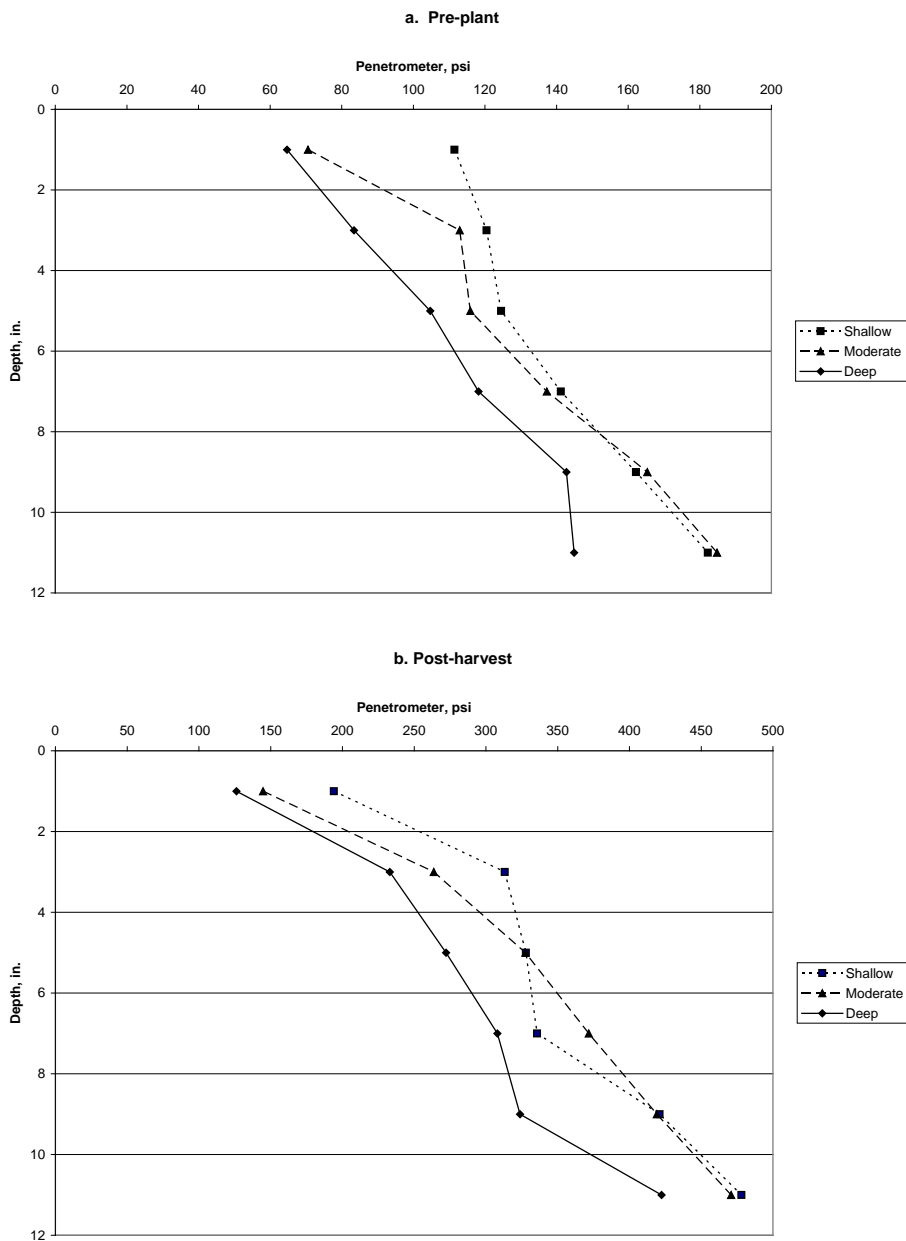


Figure 2. Average pre-plant and post-harvest penetrometer resistance from field-scale plots receiving shallow, moderate, or deep tillage.

A rainfall event during mid-June soil sampling after soil measurements had been taken at two of the sites precluded sampling at other locations as crops were rapidly developing. Data not shown from these post-plant measurements at these two sites agreed with pre-plant and post-harvest measurements. Bulk density was not different among tillage systems and although penetration resistance was less in deep tilled soil, there was no difference in penetration resistance by this time of rapidly developing root systems between shallow and moderate tillage.

Yield was unaffected by tillage (Table 2) in the year after extremely wet or ponded soil conditions. Growing conditions were relatively good despite rainfall during the crop season that was only about 2/3 that of a normal year. Soil conditions were dry at harvest as evidenced by high penetrometer readings (Figure 2b).

Table 2. Average crop yields for shallow, moderate, and deep tillage after 'rain-compacted' soil.

Tillage	Yield, bu/acre	
	Corn	Soybean
Shallow	204	60
Moderate	193	59
Deep	197	56
Least significant difference	NS ^[a]	NS

^[a]Yields were not statistically different

Although there was some difference in penetrometer readings between tillage systems, crop root growth is typically not inhibited below 300 psi as was measured during April and June. High post-harvest penetrometer readings were likely due to dry soil conditions rather than a sign of late-season rooting difficulty.

Tillage generally had a limited effect in loosening soil. Because yields were equivalent if not higher with reduced tillage, input costs for extra tillage passes decreased the potential for profitability. Current custom rates for subsoiling and chisel plowing are in the range of \$15 - \$20 and \$10 - \$15 per acre, respectively. Costs with owned equipment are often similar to custom costs unless equipment is well depreciated.

Results observed in this study may not be unusual. Some growers worry about the weight of standing, ponded water on soil. Although there is a certain amount of pressure associated with increasing depth of standing water, the pressure is hydrostatic and exerted equally in all directions (i.e., both 'up' and 'down') so that soil voids are not compacted by water weight. Caution should always be used when attempting to extrapolate results to different situations (e.g., rainfall patterns during the prior year, different soil and weather growing conditions during the subsequent crop season), but these results suggest being cautious before spending time, fuel, and money tilling to ameliorate poor, wet soil growing conditions from a prior season.

Conclusions

Based on these results following fall primary tillage after a year of excessive rainfall and standing water on silty clay loam textured fields in southeast Iowa:

- As measured by soil bulk density (the mass of soil particles within a given volume) tillage did not physically loosen soil any more than soil that was left untilled.
- Tillage lessened penetration resistance the spring after fall tillage, but the effect did not linger into the growing season unless tillage was deep (~12 in.).
- Crop yield was unaffected the next year by the depth or amount of tillage that was done.

Because there was no increase of crop yield with tillage (in fact a slight decrease), growers should carefully consider the amount of extra yield required to cover tillage costs and whether benefits exist for tilling soil after a season of significant rainfall. Tillage was counter-productive and lowered profit potential in this study.

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Tillage and crop rotation management impact on yield and soil quality

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Introduction

Tillage decision is only one concern farmers have to make every fall. There are many other factors need to be considered in selecting a tillage system for any given field or region within the state. Those factors are soil conditions, which can include, soil slope, soil drainage, topsoil depth or the A-horizon depth. Other factors need to be considered, which are equally important such as hybrid selection, crop rotation, and management factors, such as, residue cover, type of residue (corn or soybean), soil moisture condition at the time of making the decision, timing of tillage operation, fertilizer management in conjunction with tillage operation, type of residue management equipment, planting and harvesting equipment, compliance with conservation plans, and above all, is the economic return and benefits of selecting any tillage system.

The variability in soil conditions will be a key factor in selecting a tillage system that will influence crop response and ultimately yield expectations. However, crop response to tillage systems has been demonstrated to be different for the same tillage system in a different part of the state or different regions elsewhere. Different tillage systems affect soil temperature, soil moisture conditions, soil compaction, soil productivity, and nitrogen movement and N availability differently. These effects will be indicated in crop response to different tillage systems, where soil temperature plays a significant role in early seed germination, organic N mineralization, nutrient and residue incorporation, and weed and pest control.

Understanding site specific effect of tillage can help significantly reducing input cost and reduce the negative impact on water, air, and soil quality. Conservation tillage systems continue to be a very important component of a crop production system in terms of economic return and environmental benefits. However, the challenges in managing such systems, and namely no-tillage, are related to the proper management practices, such as the availability of drainage in poorly drained soils, use of residue management residue attachments, seeding depth, and fertilizer management. Also, the timing of conducting field operations, N application, manure injection, etc., has to be done when soil moisture condition is below field capacity to avoid serious soil compaction problems.

Soil moisture and soil temperature conditions in the seedbed zone (top 2-6 inches) can promote or delay seed germination and plant emergence (Kaspar et al., 1990; Schneider and Gupta, 1985). Therefore, healthy plant growth and development require soil conditions that have adequate soil moisture and minimal root penetration resistance (Phillips and Kirkham, 1962). Soil temperature can be affected by surface residue cover, causing cooler surface soil temperature and slower soil drying in the spring (Fortin, 1993; Kaspar et al., 1990) in spite of reducing soil erosion and surface runoff (Cruse et al., 2001). Removal of residue from the row can reduce in-row soil moisture content in the seedbed, while conserving interrow soil moisture. Unlike soil moisture, soil temperature has an inverse relationship with the amount of residue cover.

Tillage systems have a significant effect on N dynamics by affecting N pools in the soil system. Soil disturbance during the tillage process and the incorporation of surface residue increases soil aeration, which can increase the rate of residue decomposition (McCarthy et al., 1995).

This process impacts soil organic N mineralization whereby readily available N for plant use is increased (Dinnes et al., 2002). The type of tillage system can influence the amount of N available for loss in the soil profile. Deep accumulation of NO₃-N in the soil profile represents a potential for NO₃-N leaching into shallow water tables (Keeney and Follett, 1991).

Results and discussion

Productivity and profitability

A long-term study comparing different tillage and crop rotation systems across Iowa showed that no-tillage corn and soybean yields were competitive with moldboard plowing, deep-rip, chisel plowing, and ridge tillage for more than 8 years after no-tillage was established (Al-Kaisi and Yin, 2004; Yin and Al-Kaisi, 2004). No-tillage typically yielded 5 percent less, especially in poorly drained areas compared to other tillage systems. However, the economic return of different tillage systems showed no-tillage had an advantage over other tillage systems due to the lower input cost associated with no-tillage (Table 1) (Al-Kaisi and Yin, 2004; Yin and Al-Kaisi, 2004). On average, No-tillage system reduced input cost for corn production by approximately \$18/acre under corn-soybean rotation and \$18.50/acre for corn following corn compared to all conventional tillage systems (Table 1). These input costs in Table 1 did not include the land cost and they may vary from one farm to another based on level of management and other additional inputs. No-tillage shows saving in input cost for soybean production of \$12/acre compared to conventional tillage systems as well. At the mean time, conventional tillage systems show no advantages in soybean yield over no-tillage across the state (Tables 2-5).

In a more recent tillage study from eight locations across Iowa, no-tillage corn and soybean yields generally were not significantly different at Crawfordsville and Kanawha (Tables 2 through 5). This is encouraging for producers who are reluctant to switch to no-tillage due to concerns of poor crop performance. An effective no-tillage system depends on properly selecting and setting up the planter, adequate fertility program, and efficient drainage system especially in poorly drained soils. The success of any conservation system depends heavily on how the system is managed. Generally, conservation systems require less input costs. The advantage of conservation systems is in the fuel saving, where no-tillage generally requires one gal per acre compared to 4.1 gal per acre for conventional tillage operations. The reduction in the number of implements and horsepower needed is also a significant savings in capital and maintenance costs. Fewer trips across the field reduce the fuel and labor needed.

Table 1. Total production input costs per acre for different tillage systems for corn and soybean under different crop rotations.

Tillage System	Corn after Soybean (\$/acre)	Corn After Corn (\$/acre)	Soybean After Corn (\$/acre)
No-tillage	348	392	186
Strip tillage	355	399	193
Chisel Plow	366	411	196
Deep Rip	372	417	202
Moldboard Plow	366	415	201

- Input costs account for machinery costs, labor, seed, nutrients, chemicals, and insurance. Input cost does not include land rental (\$190 cash rent equivalent).
- Labor was figured at \$11.00/hr, nutrients are based on crop removal rates, and insecticides were accounted for in corn after corn.
- Herbicide tolerant soybeans were used in input costs considerations.
- Input costs based from ISU Extension publication FM 1712 and Ag Decision Maker file A1-20.

Table 2. Corn and soybean yields under a corn-soybean rotation at the ISU Crawfordsville Research Farm. Yields are corrected to 15.5 and 13.0% for corn and soybean respectively.

	Corn (C/s)					Soybean (c/S)				
	2003	2004	2005	2006	2007	2003	2004	2005	2006	2007
	-----bushels / acre-----									
No-Tillage	212.8	180.0	171.3	189.1	159.3	38.7	55.1	71.8	56.8	59.4
Strip-Tillage	205.9	190.7	168.3	182.1	161.1	39.5	55.9	69.8	55.1	58.9
Deep Rip	209.7	200.2	171.0	185.7	170.8	42.2	57.7	70.2	56.0	59.6
Chisel Plow	211.6	207.9	177.4	184.6	168.8	40.6	55.7	69.5	58.5	57.5
Moldboard Plow	202.7	214.1	179.2	209.3	185.9	41.7	58.3	69.8	64.6	60.1
LSD _(0.05) ^a	16.1	22.8	13.9	25	14.8	3.2	3.3	5.4	4.2	3.5
5-Tillage Average	208.5	198.6	173.4	190.2	169.2	40.5	56.5	70.2	58.2	59.1

^a Least significant differences (LSD_(0.05)) are based on a Fisher test. Yield differences greater than the least significant difference are significantly different.

Table 3. Yields are corrected to 15.5 and 13.0% for corn and soybean respectively.

	Corn (C-c-s)		Corn (c-C-s)		Soybean (c-c-S)	
	2005	2003	2006	2004	2007	
	-----bushels / acre-----					
No-Tillage	165.6	129.8	208.3	57.6	64.1	
Strip-Tillage	158.8	149.2	205.4	59.7	64.0	
Deep Rip	163.9	146.1	201.0	60.0	62.7	
Chisel Plow	163.3	157.7	196.4	59.8	60.2	
Moldboard Plow	164.3	149.4	218.4	58.8	63.2	
LSD _(0.05) ^a	8.6	25.6	10.6	2.6	2.6	
5-Tillage Average	163.2	146.4	205.9	59.2	62.8	

^a Least significant differences (LSD_(0.05)) are based on a Fisher test. Yield differences greater than the least significant difference are significantly different.

Table 4. Corn and soybean yields under a corn-soybean rotation at the ISU Kanawha Research Farm. Yields are corrected to 15.5 and 13.0% for corn and soybean respectively.

	Corn (C/s)				Soybean (c/S)				
	2003	2004	2005	2006	2003	2004	2005	2006	2007
	-----bushels / acre-----								
No-Tillage	187.7	172.4	136.6	189.1	38.2	56.5	54.6	63.2	56.1
Strip-Tillage	191.7	181.1	146.0	188.2	38.0	57.8	54.1	59.9	56.3
Deep Rip	190.7	188.8	181.3	191.1	39.4	57.1	53.1	57.9	58.8
Chisel Plow	198.3	192.2	189.2	190.9	39.9	56.8	52.2	59.7	56.5
Moldboard Plow	196.7	191.2	188.5	196.0	40.7	57.8	53.5	57.4	56.7
LSD _(0.05) ^a	32.2	11.2	24.7	9.3	3.7	4.4	3.5	3.4	8.4
5-Tillage Average	193.0	185.1	168.3	191.1	39.2	57.2	53.5	59.6	56.88

^a Least significant differences (LSD_(0.05)) are based on a Fisher test. Yield differences greater than the least significant difference are significantly different.

Table 5. Corn and soybean yields under a corn-corn-soybean rotation at the ISU Kanawha Research Farm. Yields are corrected to 15.5 and 13.0% for corn and soybean respectively.

	Corn (C-c-s)		Corn (c-C-s)	Soybean (c-c-S)	
	2004	2007	2005	2003	2006
	-----bushels / acre-----				
No-Tillage	174.1	172.8	214.0	37.4	63.4
Strip-Tillage	192.3	177.7	220.1	34.9	53.4
Deep Rip	188.5	196.8	223.2	38.9	59.4
Chisel Plow	198.6	221.9	218.3	37.5	60.5
Moldboard Plow	200.9	208.3	232.0	39.3	60.3
LSD _(0.05) ^a	14.5	47.2	9.7	2.4	12
5-Tillage Average	190.9	191.94	221.5	37.6	59.4

^a Least significant differences (LSD_(0.05)) are based on a Fisher test. Yield differences greater than the least significant

Tillage effect on soil quality

- Carbon storage: Intensive tillage operations can have negative effect on soil organic carbon by oxidizing organic matter. Results from tillage studies in Iowa shows consistent decline in organic carbon with increase intensity in tillage operations (Fig. 1). Aerating soil increases the rate of soil organic matter decomposition and emission of carbon dioxide. Soil carbon is beneficial to improve soil structure and nutrient and water holding capacity.

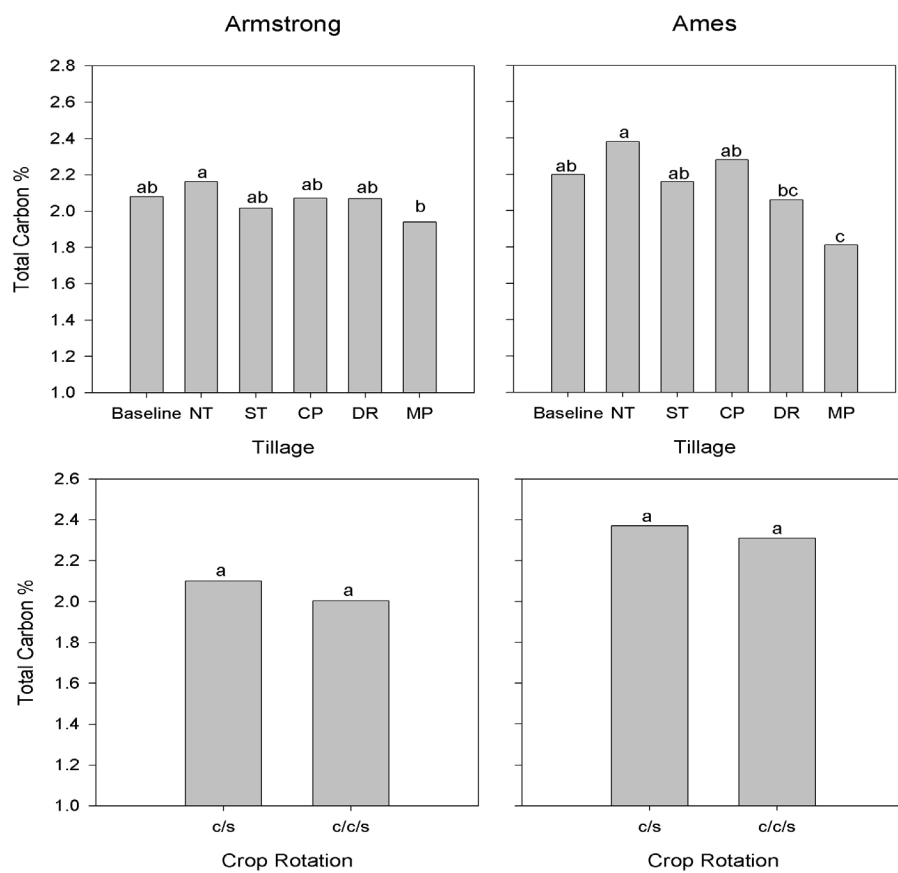


Figure 1. Soil carbon as affected by tillage and crop rotation at the top 6 inches for two sites from 2002 to 2004.

- Erosion and water quality: Surface residues from both corn and soybean provide protection from both wind and water erosion. Cover crops following soybean and corn silage harvest can be used to increase the amount of residue cover and stabilize the surface soil. Additionally, waterways, terraces, and buffer strips provide living protection that controls the flow of surface water runoff and allow for sediments and nutrients to settle out before leaving the field.
- Crop residue: The more intensive a tillage pass is, the more residue will be broken down and buried. Crop residue is important to hold surface soil in place and protect the soil surface from raindrop and wind impacts. Crop residue also helps hold snowfall in place, which in the spring will contribute to subsurface soil moisture.
- Soil structure: Tillage operations break soil aggregates and decrease pore spaces that are responsible for enhancing water infiltration. By switching to conservation tillage and using cover crops the soil will build better soil structure due to less soil disturbance and increased soil organic matter.
- Soil compaction: There is a misconception of increased soil compaction with conservation systems. Research shows, fields under conservation systems have much better developed soil structure and pore spaces than conventional systems. The improved soil structure provides soil the strength to withstand heavy field equipment load.

- Soil moisture: A major benefits of conservation systems is the enhancement of subsurface soil moisture due to improvement of soil organic matter and water holding capacity. This is critical in areas where precipitation is limited and conservation of soil moisture is a priority.

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Using GIS technology for Iowa pesticide distribution and transport modeling

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The patterns of pesticide occurrence in surface and ground waters are linked to agricultural practices and the product's susceptibility to leaching and runoff. Pesticide use information has historically been catalogued in relation to points of sale from agrichemical dealerships. In an effort to provide a wide audience with an understanding of these occurrences and patterns, an atlas was developed during 2006 that provided a web-based front end to the data. The atlas links pesticide calculations of pounds of active ingredients sold with geographic information and water monitoring data using Geographic Information System (GIS) software.

Pesticide transport is also being studied through computer modeling in Iowa, Kansas, Missouri, and Nebraska. The work uses a GIS-based pesticide "favorability" model that uses soil characteristics to predict where pesticides will create the least amount of potential environmental impact based on leaching, runoff, and particle-adsorbed runoff potential.

Iowa established the Iowa Pesticide Sales Database in the 1987 Groundwater Protection Act. The database is an ongoing collection of data on pesticide sales that are submitted from licensed dealers as a requirement of licensure. From these sales data, trends in pesticide use can be tracked by region through the years, which coupled with water monitoring data, allow for targeted educational programming. At least three pesticide use or distribution data sources exist, namely the Iowa Pesticide Sales Database, Iowa Geologic Survey database (IAPEST) on water contaminants in Iowa, and a recently conducted pesticide use survey conducted by ISU Extension. From these data sources it is possible to generate graphics to illustrate trends and use patterns as summaries that will be shared with the originating agencies and prepared for dissemination to the public.

Soils 101: How to apply the information in the Clay County Soil Survey for Northwest Iowa farmers and ag-professionals.

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The Soil Survey of Clay County, Iowa is a publication of the National Cooperative Soil Survey. Major field work was completed in 1999. Soil names and descriptions were approved in 2002. The survey was made cooperatively by the Natural Resources Conservation Service; the Iowa Agriculture and Home Economics Experiment Station and the Cooperative Extension Service, Iowa State University; the division of Soil Conservation, Iowa Department of Agriculture and Land Stewardship; and the Clay County Conference Board.

Soil survey information has many useful purposes, including such diverse items as suitability for building site development, wildlife habitat selection, and selection of construction materials. Differences in crop production and crop suitability can also be explained by soil survey information. Agronomists who work with production agriculture can use the information in the soil survey report for many purposes. Some scenarios and possible soil survey report information are listed below.

Possible Scenarios	Reference tables are available for
Troubleshooting crop yields	Corn Suitability Rating, subsoil nutrients
Suitability for alfalfa	alfalfa yields, water table
Subsoil soil fertility levels	subsoil P, subsoil K
Troubleshooting problem fields	clay content, water holding capacity
Drainage problems	subsoil clay content

A production agronomist might be asked to troubleshoot low corn or soybean yields in a field. For example, Wadena, Webster and Collinwood soils would appear in a similar position on the landscape and could be described by a casual observer as 'good black soil'. Furthermore, these soils could be present in the same field. However, major differences in the subsoil will affect crop production. The Wadena soil has mostly gravel in the subsoil (clay content 1-5% 26 to 80 inches deep). Webster soils have clay loam in the subsoil (clay content 12-22% 32-60 inches deep). Collinwood soils are formed in old lakebeds and have a high clay content in the subsoil (clay content 34-60% 15-33 inches deep). Corn Suitability Ratings (CSR) are therefore very different for these three soils. The Webster soil has an ideal amount of clay in the subsoil and has a CSR of 77. The Wadena soil has a CSR of 52 since the low subsoil clay content does not retain moisture during dry summer months. Conversely, the Collinwood soil has a CSR of 67 because the excessive clay in the subsoil restricts root growth. The example of the Wadena soil is likely fairly obvious to anyone involved in production agriculture. Water holding capacity is listed for each soil mapping unit for the topsoil and subsoil. The information on water holding capacity further explains the differences in crop productivity between a Wadena, Webster and a Collinwood soil.

Information in the soil survey report can be useful for selecting fields for different crops. For example, the expected corn and soybean yields from a Webster soil and a Clarion soil (SMS 138) would be similar. However, the alfalfa yield from a Clarion soil would be reported as 5.5 ton per acre versus 3.9 ton per acre for the Webster soil. Past experience would likely confirm these production figures. However, the soil survey would give some explanation as to the cause. The seasonal high water table for a Webster soil is listed as 0 to 1.0 foot deep during the early growing season. Clarion soils would have a high water table listed as 4.0 to 6.0 foot deep for most of the growing season.

Clay County has three major soil associations; Galva-Primghar, Everly-Wilmonton-Letri, and Clarion-Nicollet-Webster associations. There are several minor associations in Clay County. One of these is the Wilmonton-Ransom-Afton association which occupies 20 percent of the county. Another association is the Clarion-Nicollet-Webster association which occupies 25 percent of the county.

Galva-Primghar-Marcus soils were the predominant soils in the western part of the county as reported in the previous soil survey report. The current soil survey report further delineates some soil properties and replaced those soil mapping units. The Galva-Primghar-Marcus soils have over 60 inches of loess over glacial till. The current soil survey actually found that there were very few areas in the county that had more than 60 inches of loess. Therefore, the Annieville, McCreath and Gillett Grove soil mapping units were created. The Annieville-McCreath-Gillett Grove soils have 40-60 inches of loess over glacial till.

The Sac-Ransom-Rushmore soils were mapped in Clay County. The Sac-Ransom-Rushmore soils have 20-40 inches of loess over till. Everly-Wilmonton-Letri soils were also mapped in Clay County. The Everly-Wilmonton-Letri soils have characteristics of loess and erosional sediments over glacial till. The Everly-Wilmonton-Letri would be somewhat similar to the Kenyon-Clyde-Floyd soils in northeast Iowa. Everly soils were mapped in the previous soil survey report. However, the Wilmonton series replaced Nicollet clay loam (soil map symbol Nc), and the Letri series replaced Tripoli (soil map symbol Tr).

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