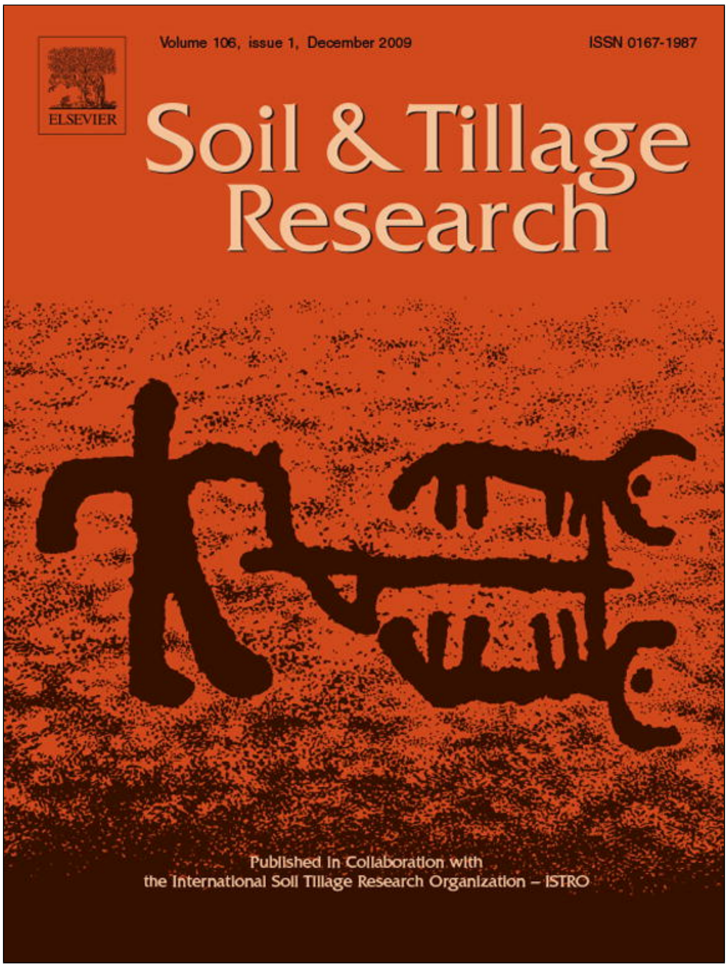
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Cost effectiveness of conservation practices in controlling water erosion in Iowa

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ABSTRACT

Iowa has severe water-induced soil erosion and associated water quality concerns because of intense agricultural activities. The objective of this study was to determine the effectiveness and economic benefits of selected conservation practices in sediment reduction by water erosion in major soil areas of Iowa. One farm was selected to represent the typical soil and slope gradient in each of the eight Major Land Resource Areas (MLRAs) in Iowa. Three tillage systems [no-tillage (NT), strip-tillage (ST), and chisel-plow tillage (CP)] and three conservation structures [grassed waterways (GS), grass filter strips (FS), and terrace systems (TS)] were investigated under a corn–soybean rotation using the Water Erosion Prediction Project (WEPP) model. Corn yields of some areas were statistically lower under NT than under CP while soybeans showed little response to tillage operations. Estimated annual sediment yield with the chisel plow system ranged between 0.7 and 56.9 T ha^{-1}. The WEPP simulations showed that NT and ST systems were very effective in reducing soil erosion and sediment yield by approximately 90% in highly erodible lands compared to the CP system. The combination of conservation tillage with soil erosion control structures further mitigated soil loss and was more effective in areas with high water erosion potential than in the flat areas. The costs and benefits analysis indicated that the simulated conservation practices could increase the net benefit by up to \$300 ha^{-1} compared to the CP system after the cost of eroded soil was taken into account. The findings suggest that NT and conservation structures have greater environmental and economic benefits in areas with high water erosion potential. The use of no-till in flat areas such as central Iowa may not be economically favorable because of the limited benefit in reducing soil water erosion. Overall, the study findings suggest that structural conservation practices coupled with tillage systems effectiveness were area-specific based on the soil and landscape in each area.

1. Introduction

The transport of nutrients and pollutants from agricultural lands via soil water erosion has been identified as a major contributor to the impairment of receiving water systems in the Midwestern United States and the northern Gulf of Mexico. Iowa along with eight other states accounted for 75% of the nitrogen and phosphorus delivery to the Gulf of Mexico (Alexander et al., 2008). It has been well recognized that reducing soil erosion is critical to minimizing nonpoint source pollution from agricultural lands (Nearing et al., 2001).

Soil erosion can be reduced through better field residue management and other conservation practices, including reduced tillage, crop rotation, contour cropping, terracing, vegetative filtering (Baker et al., 2006). The effectiveness of a given conservation practice depends on a number of factors, including climate, soil, topography, cropping systems, and other existing conservation practices in that area. Despite the general perception that Iowa landscape and land formations appear to be uniform, the state of Iowa consists of different landforms that vary in slope, parent materials, drainage class and rainfall distribution across different areas in the state (Prior, 1991). The dominant parent materials of most Iowa soils are glacial drift, loess, and alluvium. These soils are classified into 20 major soil associations with soil depth ranging from a few centimeters to two meters. Some of these soils are more susceptible to water erosion than others, and subsequently their productivity can be affected. It was documented that the impact of soil erosion on crop yield due to erosion is greater on till-derived soils than loess-derived soils in Iowa particularly on major crops in Iowa such as, corn and soybean (Fenton et al., 2005). Another contributing factor to soil erosion is annual precipitation, which also varies across the state, with the highest in the southeast and the lowest in the northwest. Therefore, a conservation practice may be cost effective in one area, but less effective in others.

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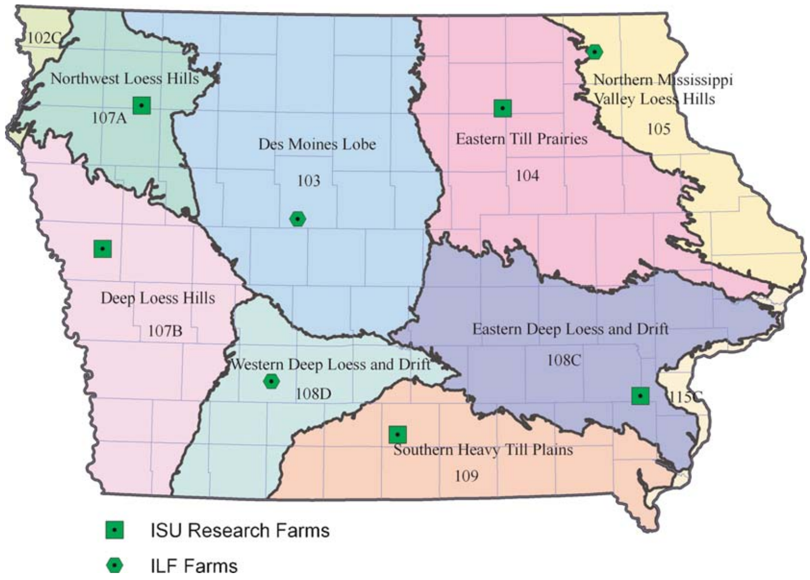

Fig. 1. Major Land Resource Area and location of study sites.

In addition to the expected benefits of conservation practices in reducing soil erosion, the implementation of such practices may result in changes in many agricultural practices and their associated costs or benefits, such as crop yield, field operation costs, and investment in conservation structures (Uri, 2000; Yuan et al., 2002). The tillage system effect on crop yield is often site-specific, and can be influenced by climate, soil, and tillage history. The type of tillage system can influence labor, related fuel, and machinery costs. The investments in conservation structures (e.g., grassed waterways and terraces) are often costly, but they can protect soils and provide both on- and off-farm benefits. All of those costs and benefits should be taken into account when evaluating the cost effectiveness of any conservation practices (Zhou et al., 2009).

The objective of this study was to estimate the benefits of selected conservation practices (conservation tillage systems and erosion control structures) on sediment reduction under a corn–soybean rotation in major soil association areas of Iowa from both environmental and economic perspectives.

2. Materials and methods

2.1. Study sites description

The study sites were located in the eight MLRAs in Iowa, one in each area: Northwest Loess Hill (NLH), Deep Loess Hills (DLH), Des Moines Lobe (DML), Western Deep Loess and Drift (WDLD), Eastern Deep Loess and Drift (EDLD), Eastern Till Prairies (ETP), Northern Mississippi Valley Loess Hills (NMVLH), and Southern Heavy Till Plain (SHTP) (Fig. 1). The MLRAs' boundaries are delineated based on soil and landscape characteristics, land use and climate (Table 1). Approximately 86% of Iowa land is farmland with 75% of the farmland in corn and soybean (USDA-NASS, 2008).

Iowa Soil Properties and Interpretation Database (ISPAID, version 7.0) was used to identify the major soil and dominant slope ranges within each MLRA. Farms from the Iowa Learning Farm (ILF) project (http://www.extension.iastate.edu/ilf) and long-term tillage studies at the Iowa State University (ISU) Research and Demonstration Farms (http://www.ag.iastate.edu/farms) were

Table 1
Characteristics of Major Land Resource Areas in Iowa.

MLRA	Geology	Physiography	Precipitation (mm year^{-1})	Major crops
NLH (107A)	Till surface covered by loess on the hillslopes and by Holocene alluvium in the drainageways	Undulating to rolling with some nearly level and broad ridgetops	660–790	Corn, soybeans, hay, and other feed grains
DLH (107B)	Overlain by deep loess deposits that can reach a thickness of 20–60 m	Mostly rolling to hilly with some nearly level and broad ridgetops	660–1040	Corn and soybeans with hay and pasture in steeper areas
DML (103)	Covered with glacial till, outwash, and glacial lake deposits	A nearly level to gently rolling till plain	585–890	Corn and soybeans with some cropland in hay
WDLD (108D)	Till surface covered by a mantle of Peoria Loess on the hillslopes and by Holocene alluvium in the drainageways	Mostly rolling to hilly with some nearly level to undulating broad ridgetops	840–940	Corn, soybeans, and pasture
EDLD (108C)	Till surface covered by a mantle of Peoria Loess on the hillslopes and by Holocene alluvium in the drainageways	Undulating to rolling with some nearly level and broad ridgetops	840–965	Corn and soybeans with hay and pasture in steeper areas
ETP (104)	Covered with glacial till and outwash deposits	Nearly level to gently rolling with long slopes	735–940	Corn and soybeans
NMVLH (105)	With limited landscape formation by glacial ice	Scenic landscapes with deep valleys, caves and sinkholes	760–965	Feed grains and forage
SHTP (109)	Loess covers the surface of most of the uplands	Steep rolling hills interspersed with areas of level alluvial lowlands	865–1040	Corn, soybeans, hay, and other feed grains

Abbreviations: NLH, Northwest Loess Hills; DLH, Deep Loess Hills; DML, Des Moines Lobe; WDLD, Western Deep Loess and Drift; EDLD, Eastern Deep Loess and Drift; ETP, Eastern Till Prairies; NMVLH, Northern Mississippi Valley Loess Hills; SHTP, Southern Heavy Till Plain.

Table 2
Watershed characteristics derived from GeoWEPP for each study site.

Site	NLH	DLH	DML	WDLD	EDLD	ETP	NMVLH	SHTP
Number of hillslopes	8	8	8	8	13	21	25	8
Number of channels	3	3	3	3	5	8	10	3
Total area (ha)	44.9	39.6	45.7	35.9	77.5	79.6	122.1	22.8
Mean slope (%)	2.1	10.8	1.0	7.1	0.9	3.2	9.5	7.5

Abbreviations: NLH, Northwest Loess Hills; DLH, Deep Loess Hills; DML, Des Moines Lobe; WDLD, Western Deep Loess and Drift; EDLD, Eastern Deep Loess and Drift; ETP, Eastern Till Prairies; NMVLH, Northern Mississippi Valley Loess Hills; SHTP, Southern Heavy Till Plain.

Table 3
WEPP model soil characteristics.

Area	Soil	Interrill erodibility ($\times 10^6$ kg s m^{-4})	Rill erodibility ($\times 10^{-3}$ s m^{-1})	Critical shear (N m^{-2})	Effective hydraulic conductivity (mm h^{-1})
NLH	Galva silty clay loam (Typic Hapludolls)	4.04	6.99	3.50	0.58
DLH	Ida silt loam (Typic Udorthents)	4.70	7.90	3.50	1.37
DML	Nicollet loam (Aquic Hapludolls)	4.81	5.23	4.17	4.20
WDLD	Sharpsburg silty clay loam (Typic Argiudolls)	4.24	7.09	3.50	0.98
EDLD	Nira silty clay loam (Aquic Argiudolls)	4.44	7.28	3.50	1.81
ETP	Kenyon loam (Typic Hapludolls)	6.11	7.32	3.18	4.99
NMVLH	Fayette silt loam (Typic Hapludalfs)	4.70	7.90	3.50	1.37
SHTP	Grundy silt loam (Aquertic Argiudolls)	5.06	10.50	3.50	2.46

Abbreviations: NLH, Northwest Loess Hills; DLH, Deep Loess Hills; DML, Des Moines Lobe; WDLD, Western Deep Loess and Drift; EDLD, Eastern Deep Loess and Drift; ETP, Eastern Till Prairies; NMVLH, Northern Mississippi Valley Loess Hills; SHTP, Southern Heavy Till Plain.

selected to represent the typical soil and slope gradient for each area. Research site data from all sites used in this study were for the period of 2002–2008. A total of three ILF farms and five ISU research farms were used in this study (Fig. 1).

2.2. WEPP model description and validation

The WEPP model was used as part of this study to estimate the annual sediment yield over a 50-year period under various scenarios, including three commonly used tillage systems (NT, ST, and CP) in Iowa and three conservation structures (GW, FS, and TS). It is a process-based, distributed parameter prediction model for soil erosion and sediment delivery from hillslopes and small watersheds (Flanagan and Nearing, 1995). Processes implemented in WEPP include rill and interrill erosion, infiltration, percolation, sediment transport and deposition, surface runoff, evapotranspiration, snow accumulation and melt, irrigation, channel erosion, residue and canopy effects, and tillage effects. It is useful to simulate the impact of land use and/or field management practices on soil loss and sediment transport on hillslopes and in small watersheds. The WEPP model not only can predict the long-term average erosion, but can also provide predictions for individual events.

The performance of WEPP model (v2006.5) in predicting soil erosion and sediment yield was validated at two neighboring experimental sites within the Four Mile Creek watershed in Eastern Iowa using the field measured surface runoff and sediment data during 1976–1980 (Johnson and Baker, 1982, 1984). In spite of the fact that the model was validated only in one MRLA, the model had sound performance as indicated by the values of the Nash–Sutcliffe (NS) model efficiency coefficient as well as the coefficient of determination (r^2). The NS value was 0.62 and 0.82, and r^2 value was 0.70 and 0.84, for sites-1 and -2, respectively. More information on model validation can be found in Zhou et al. (2009).

2.3. WEPP model input parameters

Five main input files need to be developed for WEPP: climate, topography, crop management, soil, and watershed structure. A 100-year climate file was generated for each site using the climate generator, CLIGEN version 4.3 (Nicks et al., 1995) using the meteorological data at the nearest weather station to that site.

The topography as well as watershed structure was derived from the 10 m Digital Elevation Model (DEM) data through the TOPAZ application in GeoWEPP (version 2.2008), which has a geospatial interface for the WEPP model (Renschler, 2003). TOPAZ uses the D8 algorithm to define the flow direction and resulted channel networks. The values of Critical Source Area (CSA) and Minimum Source Channel Length (MSCL) were chosen to match the derived channel networks well with USGS Digital Raster Graphic (DRG) maps: MSCL = 100 m; CSA = 5 ha for NP, DML, EDLD and ETP, and CSA = 2.5 ha for DLH, WDLD, NIS and SHTP. The derived watershed generally covered a majority of each study area. Table 2 presents some derived watershed characteristics including the number of hillslopes, the number of channels, the total watershed area, and the mean slope steepness. Such information was used to build the watershed structure in the WEPP model for each site.

The predominant soil of each site was identified using the Soil Survey Geographic (SSURGO) database. For each soil, the predetermined values provided by WEPP were used for erodibility characteristics and effective hydraulic conductivity due to the absence of field measurements (Table 3).

A crop management input file was developed for each simulated tillage system. Under no-tillage soil or crop residue disturbance only occurred during seed planting and N fertilizer application. Strip-tillage preformed in the fall, resulting in a disturbed soil zone of 20 cm in width and 10–15 cm in depth and a soil mound of 7–10 cm in height, where spring planting and fertilizer applications took place (Al-Kaisi and Licht, 2004). Chisel-plow tillage consisted of a fall chisel plow operation followed by field cultivation in the spring before planting.

In the watershed structure input file, all water channels received the same tillage as the row-cropped field, except for simulating grassed waterways. The channel parameters for channels and grassed waterways are presented in Table 4. The initial depth to the nonerodible layer (tillage pan) on was assumed to be close to the tillage depth (0.2 m) of moldboard plow, which has been the primary tillage tool in the Midwest (Reicosky and Archer, 2007). The estimated Manning roughness coefficients for water channels

Table 4
WEPP model channel characteristics.

Parameter	Waterway	Grassed waterway
Channel shape	Naturally eroded	Triangular
Manning roughness coefficient for bare soil channel	0.025	0.03
Total manning roughness coefficient allowing for vegetation	0.10	0.15
Channel erodibility factor ($\times 10^{-3}$ s m^{-1})	Same as soil	Same as soil
Channel critical shear stress (N m^{-2})	Same as soil	Same as soil
Depth to nonerodible layer in mid-channel (m)	0.2	0.2
Depth to nonerodible layer on side (m)	0.2	0.2

covered with bare soil or vegetation were from Chow (1959) and Knisel (1980). The width of water channels was 3 m.

2.4. Crop yields and economic returns

Yields of corn and soybean from 2002 to 2008 were obtained from the experimental plots at the ISU Research and Demonstration Farms in each study area. Due to the absence of long-term yield information, the yield data of ETP and DLH were also used to represent the yields in NMVLH and WDLD, respectively. The experimental design at all these farms was a randomized complete block design with three or four replications. The lengths of plots were between 20 and 30 m with a width of about 10 m. Each tillage treatment was applied on the same plot during the study period. The crops in the center three to six rows of each corn plot and five rows of each soybean plot were used to estimate yield. The statistical effect of tillage type on corn and soybean yields in each study area was analyzed using the GLM procedure in the SAS program (SAS Institute Inc, 2001). Fisher's least significant difference (LSD) test was used to separate means at the 0.05 level.

The market prices of corn ($0.14 per kg) and soybeans ($0.35 per kg) in February 2009 were used to calculate crop revenue. Crop yields for scenarios with conservation practices and additional conservation structures were adjusted proportionally to the actual cropped area.

2.5. Costs of crop production

The costs of crop production were estimated based on the average production costs of 2007–2009 from the Ag Decision Maker (Duffy and Smith, 2008). The total expense was calculated by combining the costs of machinery, labor, seeds, chemicals and land rent for corn-following-soybeans and soybeans-following-corn, respectively. Since production costs are also affected by crop yield, the total expense was calculated for three yield groups separately (<8.8, 8.8–11.2, >11.2 Mg ha^{-1} for corn, and <3.0, 3.0–3.7, >3.7 Mg ha^{-1} for soybeans) (Table 5). The same costs of labor, seeds and chemicals, and land rent were assumed for NT and ST. The mean annual cost of crop production under a corn–soybean rotation was obtained by averaging the total expenses of corn-following-soybeans and soybeans-following-corn.

2.6. Costs of conservation structures

The impact of conservation structures (GW, FS and TS) on sediment reduction was simulated in the WEPP for each tillage system. In GW simulations, the water channel was 8 m in width and vegetated with grass. For each hillslope, a 10% of the total area was converted to perennial grasses at the bottom of the hillslope in FS simulations. When simulating TS, each hillslope was divided into a series of parallel terraces along the slope. The spacing interval of terraces was determined based on the standards adopted by the American Society of Agricultural and Biological Engineers (ASABE, 2008). A grassed terrace channel was placed along the bottom edge of each terrace with a width of 2 m and a gradient of 0.5%. Water from each terrace hillslope drains to the terrace channel below and then drains laterally to the watershed channels.

The average initial establishment costs per unit area of conservation structures were determined based on the estimates from Kling et al. (2007) (Table 6). Data from several major conservation programs in Iowa, including the Iowa Financial

Table 5
Production cost ($ ha^{-1}) for different tillage systems in a corn–soybean rotation based on the estimates average costs during 2007–2009 (Duffy and Smith, 2008).

	Corn yield range[a] (Mg ha^{-1})			Soybean yield range (Mg ha^{-1})		
	<8.8	8.8–11.2	>11.2	<3.0	3.0–3.7	>3.7
No-tillage						
Machinery	231.9	247.3	262.8	104.4	105.4	106.4
Labor	62.5	62.5	62.5	47.6	47.6	47.6
Seeds and chemicals	548.6	604.3	658.9	364.7	382.5	402.4
Land rent	377.3	453.0	524.7	377.2	453.0	524.7
Total expense	1220.2	1367.2	1508.9	894.0	988.5	1081.0
Strip-tillage						
Machinery	242.2	257.5	272.4	94.0	94.9	95.9
Labor	62.5	62.5	62.5	62.5	62.5	62.5
Seeds and chemicals	548.6	604.3	658.9	364.7	382.5	402.4
Land rent	377.3	453.0	524.7	377.2	453.0	524.7
Total expense	1230.5	1377.3	1518.6	883.5	978.0	1070.6
Chisel-plow						
Machinery	254.2	269.7	288.5	122.9	123.9	124.8
Labor	70.7	70.7	70.7	70.7	70.7	70.7
Seeds and chemicals	576.7	629.0	683.8	340.9	357.9	377.8
Land rent	377.2	453.0	524.7	377.2	453.0	524.7
Total expense	1278.8	1422.4	1567.6	911.7	1005.5	1098.0

[a] Since production cost is generally affected by crop yield, the total expense of crop production was calculated for three corn/soybeans yield groups separately.

Table 6
Establishment cost of conservation structures based on the estimates from Kling et al. (2007).

Site	NLH	DLH	DML	WDLD	EDLD	ETP	NMVLH	SHTP
Grassed waterways ($\$\,ha^{-1}$)	5068	8614	11,384	5318	3813	5080	2844	5451
Filter strips ($\$\,ha^{-1}$)	222	282	301	287	297	183	217	232
Terrace systems ($\$\,m^{-1}$)	7.15	3.97	14.92	5.87	13.22	10.86	10.97	14.04

Abbreviations: NLH, Northwest Loess Hills; DLH, Deep Loess Hills; DML, Des Moines Lobe; WDLD, Western Deep Loess and Drift; EDLD, Eastern Deep Loess and Drift; ETP, Eastern Till Prairies; NMVLH, Northern Mississippi Valley Loess Hills; SHTP, Southern Heavy Till Plain.

Incentive Program (IFIP), Conservation Reserve Program (CRP), and Environmental Quality Incentives Program (EQIP), was used to estimate the county-level average costs. The average cost was based on the area of installed conservation structure installed but not the area impacted. The additional annual maintenance cost was estimated to be 3%, 5%, and 3% of the establishment cost for GW, FS, and TS, respectively. The assumed life spans were 10 years for GW and FS and 25 years for TS (USDA-NRCS, 2008). The actual cost of each conservation structure in the study site was calculated by multiplying the unit cost per year ($\$\,ha^{-1}\,year^{-1}$ or $\$\,m^{-1}\,year^{-1}$) by the actual units of structures per hectare ($ha\,ha^{-1}$ or $m\,ha^{-1}$).

2.7. Costs of soil loss

The impacts of soil erosion from agricultural lands occur both on and off the farm. The on-site soil erosion can potentially reduce soil productivity and sustainability due to plant nutrients and organic matter losses from topsoil (Williams and Tanaka, 1996; Smith et al., 2000). The off-site impacts include the potential downstream damages to water quality, air quality, and water-based recreational activities (Clark et al., 1985). The total cost of both on-site and off-site of soil erosion can be estimated by multiplying the unit cost of eroded soil ($\$\,T^{-1}$) by the estimated sediment production ($T\,ha^{-1}$) from the WEPP model. The USDA estimates of unit cost for soil loss were used for each study site (Hansen and Ribaudo, 2008).

3. Results and discussion

3.1. Impacts of tillage and landscape on sediment yield

The WEPP-estimated annual sediment yield showed a wide range among different Iowa areas, from 0.62 $T\,ha^{-1}$ for the EDLD to 42.47 $T\,ha^{-1}$ for the NMVLH with the CP system (Table 7). Four areas including DLH, WDLD, NMVLH and SHTP, had greater sediment yield than the others. These four areas generally had greater slopes and consequently greater soil erosion potential. Soils in DLH are extremely fragile and have one of the highest erosion rates in the U.S. With steep slopes and high relief, the soils in the NMVLH area are highly susceptible to water erosion. The Karst features such as sinkholes, caves and springs also make groundwater vulnerable to contamination. The poorly drained soils (Table 3) and high precipitation (Table 1) in the WDLD and SHTP may partly contribute to the high soil erosion rate in these steep areas.

Overall, fewer and shallower tillage passes greatly reduced sediment yield regardless of soil and field topography. The estimated annual sediment yields under NT and ST were much lower than that of CP due to greater residue cover and less soil disturbance (Table 7), especially for the areas with steep gradients. The results showed that the mean annual sediment yield decreased from 42.47 to 4.63 $T\,ha^{-1}$ at the DLH site, an approximately 90% reduction due to the use of NT and ST compared to CP, even though under the NT or ST system the annual sediment yield in these areas of highly erodible soils was still very high. Therefore, the implementation of additional conservation practices is needed to further reduce soil loss (Morgan, 2005).

3.2. Soil erosion control using conservation structures

The impact of combinations of conservation structures (GW, FS, and TS) and tillage systems on soil erosion was also investigated to examine the performance of conservation structures in the various areas. Grassed waterways were very effective in reducing sediment yield through minimizing channel erosion and retaining sediments from upland fields, particularly where excessive erosion occurred, especially in areas such as, DLH, WDLD, NMVLH and SHTP. The reduction in annual sediment yield was approximately 16 $T\,ha^{-1}$ (40%) at the DLH site, when a combination of GW and CP system were used (Table 7). A properly maintained GW can reduce sediment delivery by 97% as indicated in another study (Fiener and Auerswald, 2003). It is not unexpected that GW were less effective in relatively flat areas (e.g., NLH, DML, EDLD, and ETP). This can be

Table 7
Estimated annual sediment yield ($T\,ha^{-1}\,year^{-1}$) from the WEPP model.

Site	NLH	DLH	DML	WDLD	EDLD	ETP	NMVLH	SHTP
	($T\,ha^{-1}\,year^{-1}$)							
CP	5.09	42.47	1.39	30.07	0.62	3.53	27.95	39.58
ST	1.20	8.79	0.97	5.77	0.37	1.19	4.72	7.46
NT	0.74	4.63	0.56	3.20	0.36	0.74	2.46	4.83
CP + GW	2.67	25.82	0.64	17.89	0.58	2.47	21.72	19.30
ST + GW	1.09	6.39	0.32	5.24	0.29	1.07	4.47	6.80
NT + GW	0.64	4.21	0.29	2.12	0.27	0.62	1.21	2.07
CP + FS	1.51	23.93	0.63	18.13	0.25	1.63	15.86	18.96
ST + FS	0.92	6.64	0.37	4.85	0.19	1.07	3.78	6.16
NT + FS	0.62	3.47	0.25	2.29	0.16	0.60	1.28	2.24
CP + TS	3.72	12.97	1.51	5.18	1.01	3.07	3.38	5.97
ST + TS	0.99	3.92	1.52	1.89	0.45	1.08	1.24	3.01
NT + TS	1.54	1.51	0.88	1.73	0.55	0.65	0.87	1.79

Abbreviations: CP, chisel-plow tillage; ST, strip-tillage; NT, no-tillage; GW, grassed waterways; FS, filter strips; TS, terrace systems; NLH, Northwest Loess Hills; DLH, Deep Loess Hills; DML, Des Moines Lobe; WDLD, Western Deep Loess and Drift; EDLD, Eastern Deep Loess and Drift; ETP, Eastern Till Prairies; NMVLH, Northern Mississippi Valley Loess Hills; SHTP, Southern Heavy Till Plain.

attributed to relatively small channel erosion and low suspended solid load in surface flow that can be trapped by grass in GW, particularly when combined with the NT or ST system.

Converting a portion of row-cropped field to perennial vegetative strips also greatly reduced the sediment delivery to waterways by restricting the flow of surface runoff and increasing the water infiltration rate. The adoption of FS with CP reduced sediment yield by 40–70% based on the WEPP simulation results (Table 7). Similar to GW, the added value of FS in reducing soil erosion was less in NT and ST due to the already greatly reduced soil loss from upland soils and low suspended solid concentration in the water runoff. It should be noted that the effectiveness of filter strips in reducing sediment yield would depend on the location and width of the filter strips. Properly constructed filter strips can be very effective in reducing sediment loss or delivery by as much as 97% (Lowrance et al., 2002; Lee et al., 2003).

The simulated TS greatly reduced sediment yield in areas with high soil erosion potential (e.g., DLH, WDLD, NMVLH, and SHTP) by reducing the effective slope length and slowing down the flow of surface runoff (Table 7). The TS were more effective in reducing sediment yield in these areas compared to GW and FS. However, the WEPP simulation results indicated that little benefit was gained from terrace systems in sediment reduction for sites with relatively low erosion potential, such as NLH, DML, EDLD, and ETP. In fact, the estimated sediment yield showed some increase when terraces were constructed in those areas (Table 7). The failure of WEPP model in simulating the effect of terraces on soil erosion in the areas with low gradients may be attributed to the different contributions from rill/interrill erosion in different landscapes and tillage systems (personal communication with John Laflen). Terraces can decrease the slope length and thus reduce sediment yield primarily from rill erosion, which is relatively limited in the areas of low soil erosion. Consequently, the effect of terraces may not be well simulated by the WEPP model. Thus the benefits of TS in sediment reduction were only assessed for the four areas (DLH, WDLD, NMVLH and SHTP) with high erosion potential in the later cost–benefit analysis.

3.3. *Economic benefits of conservation practices*

A successful and sustainable adoption of conservation practices greatly depends on the understanding of economics behind these practices. A thorough cost–benefit approach was used to assess the conservation practices from the economic perspective. The six-year (2002–2008) field study showed that CP had 3–23% higher corn yield than NT, and 1–12% higher than ST. Corn yields of the DML, ETH, NMVLH and NLH sites were statistically lower under NT than under CP, but insignificant at other sites (Fig. 2). Soybeans showed little response to more and deeper tillage operations. Compared to other areas in Iowa, corn yields were very low at the

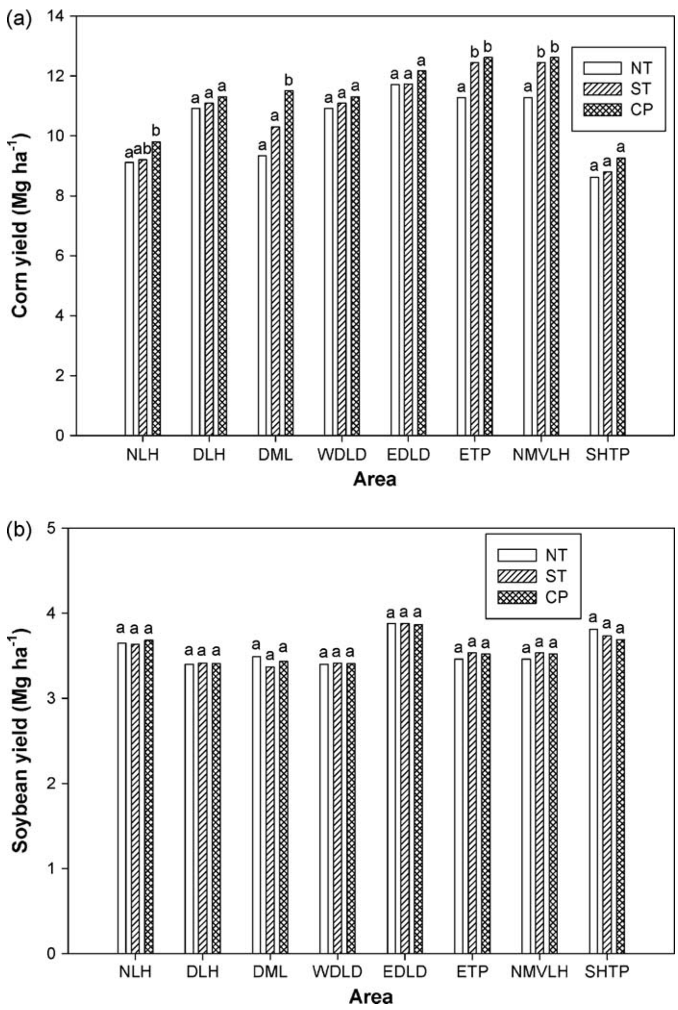

Fig. 2. Mean yields of (a) corn and (b) soybeans during 2002–2008 in a corn–soybean rotation under different tillage systems for each Iowa area. Abbreviations: NT, no-tillage; ST, strip-tillage; CP, chisel-plow tillage; NLH, Northwest Loess Hills; DLH, Deep Loess Hills; DML, Des Moines Lobe; WDLD, Western Deep Loess and Drift; EDLD, Eastern Deep Loess and Drift; ETP, Eastern Till Prairies; NMVLH, Northern Mississippi Valley Loess Hills; SHTP, Southern Heavy Till Plain.

Table 8
Crop revenue, production cost and net return ($ ha^{-1} $year^{-1}$) of each tillage system in a corn–soybean rotation. Net return was calculated by subtracting the production cost from the crop revenue.

Site	NLH	DLH	DML	WDLD	EDLD	ETP	NMVLH	SHTP
	Crop revenue ($ ha^{-1} $year^{-1}$)							
CP	1336.33	1394.51	1413.88	1394.51	1535.70	1507.42	1507.42	1299.25
ST	1285.41	1380.56	1316.30	1380.56	1506.91	1497.31	1497.31	1274.55
NT	1281.98	1366.65	1269.38	1366.65	1505.58	1402.56	1402.56	1275.01
	Production cost[a] ($ ha^{-1} $year^{-1}$)							
CP	1213.95	1286.55	1286.55	1286.55	1332.80	1286.55	1286.55	1213.95
ST	1177.65	1248.30	1177.65	1248.30	1294.60	1248.30	1248.30	1223.95
NT	1170.19	1240.91	1170.19	1240.91	1287.19	1170.19	1170.19	1143.20
	Net return ($ ha^{-1} $year^{-1}$)							
CP	122.38	107.96	127.33	107.96	202.90	220.87	220.87	85.30
ST	107.76	132.26	138.65	132.26	212.31	249.01	249.01	50.60
NT	111.79	125.74	99.18	125.74	218.39	232.37	232.37	131.81

Abbreviations: CP, chisel-plow tillage; ST, strip-tillage; NT, no-tillage; NLH, Northwest Loess Hills; DLH, Deep Loess Hills; DML, Des Moines Lobe; WDLD, Western Deep Loess and Drift; EDLD, Eastern Deep Loess and Drift; ETP, Eastern Till Prairies; NMVLH, Northern Mississippi Valley Loess Hills; SHTP, Southern Heavy Till Plain.
[a] Based on estimated costs from Table 5.

Table 9
Net benefit ($ ha^{-1} year^{-1}) of conservation practices compared to the chisel-plow tillage system when taking into account the cost of eroded soil. Net benefit = Δcrop revenue − (Δproduction cost + Δinvestment on conservation structure + Δcost of eroded soil), where Δ = implemented conservation practices—CP. A positive value indicates a net benefit and a negative value indicates a net cost from adopting the conservation practice(s).

Site	NLH	DLH	DML	WDLD	EDLD	ETP	NMVLH	SHTP
	($ ha^{-1} year^{-1})							
CP	–	–	–	–	–	–	–	–
ST	9.11	229.75	13.88	172.53	10.94	42.42	169.85	161.23
NT	15.94	248.60	−23.08	181.69	17.07	28.52	166.99	258.48
CP + GW	5.93	78.04	−27.76	54.03	−9.55	−8.96	29.58	106.02
ST + GW	1.12	220.39	−14.72	155.03	1.50	27.33	162.79	148.21
NT + GW	6.68	277.29	−53.21	167.66	7.62	13.67	166.13	256.78
CP + FS	6.26	98.07	−12.62	57.74	−22.48	−13.24	48.4	107.67
ST + FS	−3.29	225.41	−0.84	160.62	−13.64	15.51	147.42	160.62
NT + FS	2.16	238.88	−35.63	170.36	−7.99	3.39	147.69	257.61
CP + TS	–[a]	108.36	–	68.11	–	–	−92.36	−72.93
ST + TS	–	186.71	–	111.54	–	–	−52.86	−87.64
NT + TS	–	195.20	–	106.25	–	–	−66.24	−3.51

Abbreviations: CP, chisel-plow tillage; ST, strip-tillage; NT, no-tillage; GW, grassed waterways; FS, filter strips; TS, terrace systems; NLH, Northwest Loess Hills; DLH, Deep Loess Hills; DML, Des Moines Lobe; WDLD, Western Deep Loess and Drift; EDLD, Eastern Deep Loess and Drift; ETP, Eastern Till Prairies; NMVLH, Northern Mississippi Valley Loess Hills; SHTP, Southern Heavy Till Plain.

[a] The benefit of terrace systems in sediment reduction was not included in the cost–benefit analysis due to the overestimation of sediment yield by the WEPP model when soil loss is mainly contributed from interrill erosion.

SHTL site. This is probably due to the limited rooting depth potential and slowly permeable subsoils in southern Iowa (Miller et al., 1988). In general, the till-derived soils have lower water and nutrient holding capacity than the loess-derived soils. Table 8 summaries the annual revenue of crop yield under different tillage systems after averaging over corn and soybean years for each area: about $1299–1536 ha^{-1} for CP, $1274–1507 ha^{-1} for ST, and $1275–1505 ha^{-1} for NT.

Regardless of yield, NT and ST reduced the machinery and labor costs compared to CP. For example, the average machinery cost for corn-following-soybeans was about $263, $272 and $289 ha^{-1} for NT, ST and CP, respectively, when corn yield was greater than 11.2 Mg ha^{-1} (180 bushels acre^{-1}) (Table 5). The cost of seeds and chemicals in CP was also higher than that in NT and ST for corn-following-soybeans, but lower for soybeans-following-corn due to the greater use of herbicides in NT and ST. When adding all the costs together (machinery, labor, seeds and chemicals, and land rent), the total production cost in CP was higher than that in NT and ST for corn-following-soybeans and soybeans-following-corn (Table 5). After averaging over corn and soybean years, the annual production cost of eight study areas range was $1214–$1333 ha^{-1} for CP, $1178–$1295 ha^{-1} for ST, and $1170–$1287 ha^{-1} for NT, in accordance with the yields in each area (Table 8).

Annual net return ($ ha^{-1}) of each tillage system was calculated by subtracting the production cost from the crop revenue for each MLRA. Due to the high cost of seeds and chemicals including fertilizers and herbicide in recent years, 2009 in particular, some areas may only have limited net return from growing corn or soybeans (Table 8). This is particularly true for areas with lower yields, such as SHTP. Overall, the net return in the study areas ranged between $85 and $221 ha^{-1}, $51 and $249 ha^{-1}, and $99 and $232 ha^{-1} for CP, ST, and NT, respectively. It is interesting to note that NT and ST had higher net returns than CP in the areas with high erosion rates, while CP had higher or similar net return in the areas with low erosion rates compared to NT and ST.

Assuming a 3% inflation rate, the area-weighted average cost of eroded soil was estimated to be $6.1 T^{-1} in 2009 dollars. The on-site and off-site cost of eroded soil was estimated as $1.4 and $4.7 T^{-1}, respectively. Other studies also suggested that the economic evaluation of conservation practices should consider the cost of soil loss including both the on-site and off-site costs (Ribaudo, 1986; Hitzhusen, 1991; Feather et al., 1999).

Considering the cost of eroded soil, the benefits of NT and ST in sediment reduction were more evident. Thus, adoption of NT or ST had a net benefit (positive value) in most of the areas. For example, the use of NT or ST in DLH had a net benefit of about $249 and $230, respectively (Table 9). The conservation structures were highly efficient in the areas where significant erosion occurred. Net economic benefit was also obtained in other studies if the economic costs of erosion were considered (Rein, 1999). In flat areas such as central Iowa, however, the benefit of conservation structures in reducing soil loss and sediment delivery was relatively small when only the water-induced erosion was considered. In addition, establishment and continuous maintenance of conservation structures are generally expensive. Therefore, the costs for installing and maintaining the conservation structures may exceed the benefits received by the structures (Bracmort et al., 2004). Therefore, adoption of NT or ST in those areas showed a negative net benefit compared to the CP system due to yield reduction in such areas that are characterized by wet and cold soil conditions.

4. Summary and conclusions

The State of Iowa has a complex landscape with diverse landscape in different areas, which in turn affect the potential of soil erodibility. The WEPP-estimated annual sediment yield under a corn–soybean system with chisel-plow tillage ranged from 0.6 to 42.5 T ha^{-1}. In western and northeastern Iowa, soils are highly susceptible to water erosion and well above the tolerable soil erosion rate due to the steep slopes. The WEPP simulations showed that NT and ST systems were very effective in protecting soil from erosion, reducing sediment yield by 90% in highly erodible lands compared to the CP system. The combination of conservation tillage with erosion control structures such as GW, FS and TS could further reduce sediment production, which was more effective in areas with high erosion potential than in the flat areas.

The costs and benefits analyses indicated that the simulated conservation practices also had economic benefits after the cost of eroded soil was taken into account. Despite the initial investment, the adoption of structural conservation practices showed a net economic benefit in many areas compared to the CP system, increasing the net benefit by $260 ha^{-1} in areas with high soil erosion potential. The findings also showed that the use of no-till in flat areas such as central Iowa may not be economically favorable because of the limited benefit from sediment reduction due to low potential water erosion. However, considering the reduction in soil loss from wind erosion can increase the benefits of NT. Strip-till or a combination of chisel plow with conservation structures could be an alternative in these areas. In the deep loess hills, southern Iowa, and northeastern Iowa where severe soil erosion occurs, no-till and strip-till had significant environmental and economic benefits over chisel plow and would be recommended in those areas perhaps combined with conservation structures. The area-specific cost–benefit analysis provides useful information to state conservation planners to prioritize the areas and types of conservation practices in Iowa.

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