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Runoff and erosion control with conservation tillage and reduced-input practices on cropped watersheds

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Abstract

The North Appalachian Experimental Watershed near Coshocton, OH was established in 1935 to develop, evaluate, and refine conservation practices that reduce runoff and erosion under the hilly, humid conditions of the northeastern United States. Small (0.5 to 1 ha), single-practice, gaged watersheds comprised of sandstone- and shale-derived residual soils are used to evaluate the interaction of management, climate, and soils. In a 28-year, nine-watershed study, 92% of the erosion occurred during the corn (*Zea mays* L.) years of a 4-year corn/wheat (*Triticum aestivum* L.)/meadow/meadow rotation. These watersheds were moldboard plowed prior to planting corn and cultivation was used for weed control. By tilling and planting on the contour and increasing fertility levels, soil loss was reduced more than 3-fold, but still averaged 4.7 Mg ha^{-1} during corn years. Thus, annual production of row crops on a sustainable basis was not without risk. A 6-year, six-watershed study indicated that by using reduced tillage (no-till, chisel, or paraplow) and herbicides, corn and soybean [*Glycine max* (L.) Merr.] can be grown in rotation with an average soil loss of 0.5 Mg ha^{-1} yr^{-1}, well below the stipulated soil loss tolerance of 7.8 Mg ha^{-1} yr^{-1}, if a winter cover crop of rye (*Secale cereale* L.) followed soybean. Under these conditions, however, concentrations of surface-applied herbicides and nitrate in runoff frequently exceeded drinking water standards, particularly in the first few runoff events after application, and may be a concern. A reduced-input management practice for corn and soybean production with light disking and cultivation for weed control and manure and a legume (red clover, *Trifolium pratense* L.) to supply some of the nitrogen was implemented to determine if a balance between losses of soil and purchased chemical inputs could be obtained. In a 6-year comparison, soil losses were similar to those under conservation tillage, but the risk of yield loss increased due to inability to cultivate in a timely manner due to weather conditions. Regardless of tillage practice, infrequent, severe storms during years when row crops were grown caused most of the soil loss from the watersheds. Erosion prediction models must account for the contribution of such events and management practices must limit erosion caused by these storms if long-term sustainability is to be maintained.

Keywords: Corn/soybean rotation; Infiltration; No-till; Sustainable agriculture; Water quality

1. Introduction

Accelerated soil erosion due to row crop production is a worldwide concern. The effectiveness of various management practices in reducing the potential for soil loss can be highly dependent on the

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characteristics of the climate, crops, and soils in a particular geographic region. Therefore, research information specific to regional conditions is essential in order to develop, evaluate, and refine soil conservation practices. In the case of erosion caused by water, studies can be conducted in the laboratory or in the field using small plots with simulated or natural rainfall. Alternatively, natural watersheds (catchments) can be used to investigate management effects and erosion processes.

The use of plots in soil erosion research has several advantages over a watershed-based approach. Plots uniform in size and shape can be constructed and treatments assigned by randomization, thereby permitting statistical comparisons of management practices. Simulated rain can be readily applied so that responses to a wide range of conditions can be measured within a short period of time. A disadvantage is that erosion processes are a function of plot size (Poesen et al., 1994, 1996) and, in order to use field-scale equipment and thereby obtain conditions indicative of actual production practices, the plots must be relatively large. The construction and maintenance of plot boundaries is an additional source of concern (Evans, 1995). In areas particularly prone to erosion, such as those with dissected landscapes and steep slopes, it is often impossible to establish uniform plots large enough to use field-scale equipment and production practices. Moreover, comparisons of field with plot data indicate that plot studies and models based on plot-derived data overestimate actual erosion rates because non-representative landscape segments are usually monitored and unrealistic simulated rainfall treatments are often imposed (Evans, 1993, 1995).

At the North Appalachian Experimental Watershed (NAEW) near Coshocton, OH, USA (Fig. 1) the effects of a variety of conservation practices on runoff, erosion, and water quality have been investigated for 60 years using small (0.5 to 1 ha), sloping

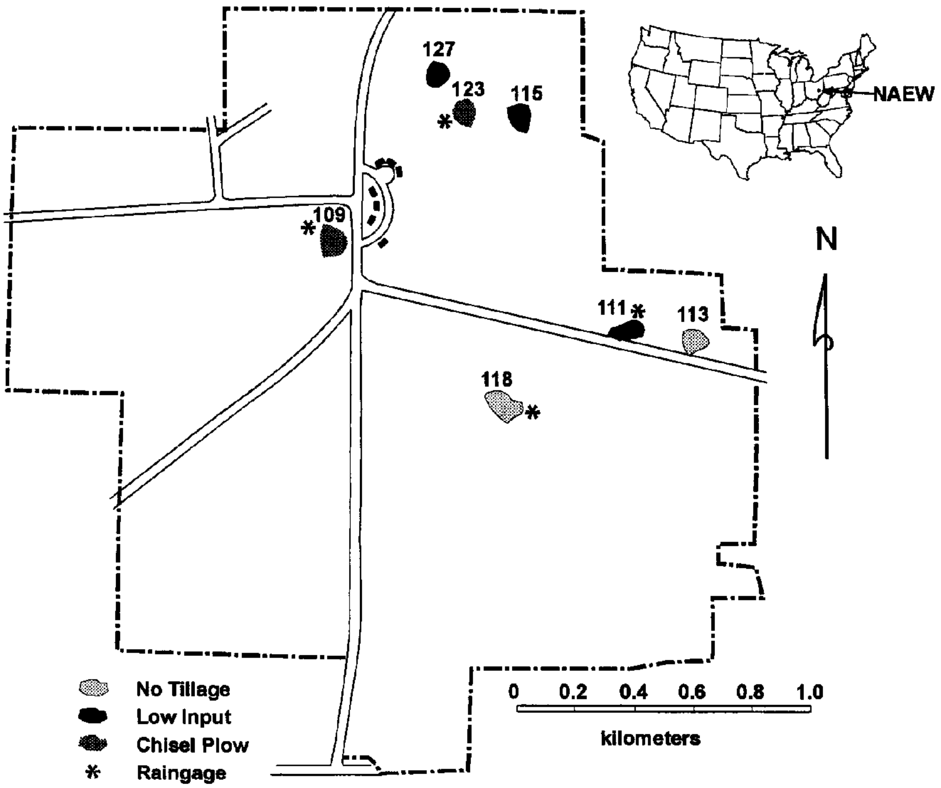

Fig. 1. Location of the North Appalachian Experimental Watershed and the seven watersheds and four rain gages used in the study.

(6 to 23%), natural watersheds farmed using the practices and machinery characteristic of the day (Fig. 2). This extensive database allows us to draw some general conclusions regarding the effectiveness of conservation tillage practices, irrespective of differences in watershed characteristics and year-to-year

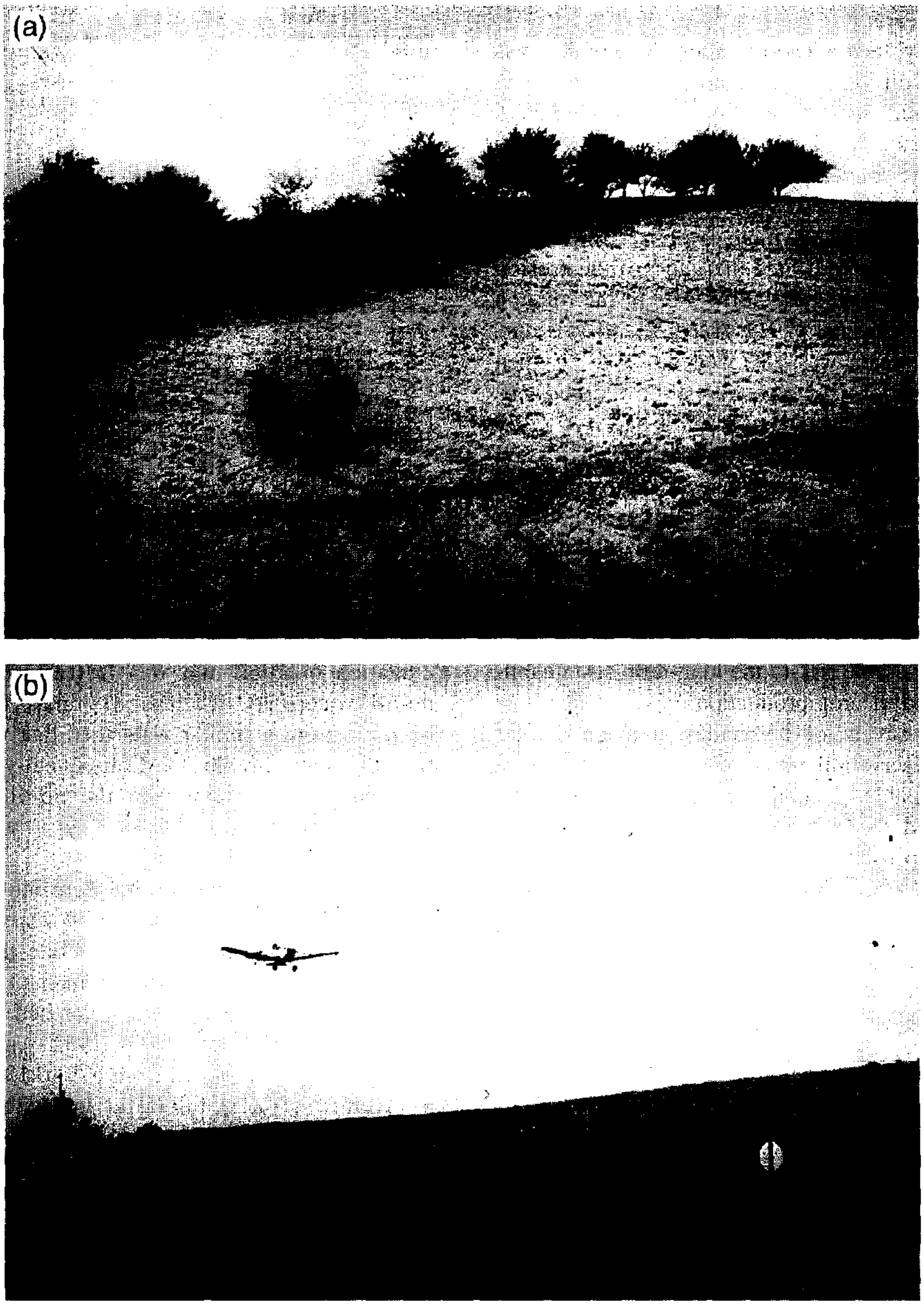

Fig. 2. Conservation tillage practices in the 1940s (i.e., tilling and planting on the contour) and in the 1980s (i.e., aerial seeding of rye into a standing soybean) on research watersheds at the NAEW.

variation in the weather. A particular watershed can be compared to other watersheds that responded similarly when subjected to the same treatment and to its past record of performance during a wide range of weather years.

In a study begun shortly after the facility was established, soil loss was measured from nine watersheds farmed using a 4-year corn/wheat/meadow/meadow rotation, in which corn was produced using conventional tillage practices (i.e., moldboard plowing, disking, and cultivation for weed control). The records, which comprise 229 watershed-years, clearly indicated that most of the erosion (92%) occurred during the corn years of the rotation (Edwards and Owens, 1991). Average soil loss during the corn years was 15.7 Mg ha^{-1} yr^{-1} when normal production practices were followed and was reduced more than 3-fold, to 4.7 Mg ha^{-1} yr^{-1}, by tilling and planting on the contour and increasing fertility levels (Fig. 2). Nevertheless, even with these improved practices, soil losses during some corn years were well above the established tolerance of 7.8 Mg ha^{-1} yr^{-1} for the soil types occurring on the watersheds (Soil Conservation Service, 1990). Under these conditions, annual planting of row crops represents a considerable risk to the long-term sustainability of the land of crop production.

With the advent of herbicides, a much greater range of conservation measures for erosion control became available. Under our climatic conditions, no-till proved to be a very effective management practice when used for corn production, particularly with well-drained soils. In a 4-year comparison, an average of only 2.2 mm of the average annual precipitation of 1062 mm was lost as runoff from a no-till watershed, whereas 81 times more runoff occurred from a similar watershed that was conventionally tilled (Table 1). Consequently, there was essentially no erosion from the no-till watershed, while an average of 5.3 Mg ha^{-1} yr^{-1} was lost from the tilled watershed (Table 1).

Table 1
A 4-year comparison of the amount of runoff and erosion from a no-till watershed (WS 191, 9% slope) and a conventionally tilled watershed (WS 123, 6% slope) when used for continuous production of corn

Year	Rainfall (mm)	Runoff (mm)		Erosion (kg/ha)	
		No-till	Conventional	No-till	Conventional
1979	1124	3.8	140.2	9	490
1980	1176	4.9	316.8	17	9500
1981	1057	0.2	142.2	1	8590
1982	889	0	113.2	0	2765
4-Year total	4246	8.9	712.4	27	21345
Average	1062	2.2	178.1	7	5335

Table 2
A 17-year record of rainfall, runoff, and erosion from a long-term, continuous, no-till corn, watershed (WS 191)

Year	Rainfall (mm)		Runoff (mm)	Erosion (kg/ha)
	Total	≥ 25 mm h^{-1}		
1979	1124	208	3.8	9.5
1980	1175	332	4.9	16.8
1981	1057	293	0.2	0.7
1982	889	211	0	0
1983	1028	186	0	0
1984	907	158	2.3	0.5
1985	929	155	0	0
1986	980	316	9.2	15.8
1987	841	230	0.2	0.2
1988	833	156	0	0
1989	964	152	7.4	38.1
1990	1321	266	0.3	0.6
1991	679	155	0	0
1992	915	203	0	0
1993	941	157	1.0	3.0
1994	888	182	0	0
1995	911	180	0	0
17-Year total	16382	3540	29.3	85.2
Average	964	208	1.7	5.0

Moldboard plowing of the conventionally tilled watershed was discontinued after 4 years to preserve its usefulness for future studies while the treatment of the no-till watershed has remained unchanged. The 17-year record for this watershed upholds the pattern observed from 1979 to 1982. Annual rainfall during this period ranged from 679 to 1321 mm with an average of 22% falling at intensities ≥ 25 mm h^{-1}, but runoff was always $< 1\%$ of annual rainfall and soil loss for the entire period was only 85 kg ha^{-1} (Table 2). While the annual reduction in runoff due to no-tillage was not as dramatic on watersheds with soils with impeded drainage, runoff from high-intensity, short-duration, localized, convective rainstorms that occur primarily during the growing season was nearly eliminated (Edwards and Amerman, 1984). This type of storm causes more than 80% of the average annual soil loss from our small watersheds (Kelley et al., 1975).

There are problems, however, with the long-term use of no-till and other conservation tillage practices for row crop production. A number of crops, including soybean, do not produce enough residue to be effective for erosion control (Moldenhauer et al., 1983; Bellinder and Gaffney, 1995). On the highly erodible farmlands of our region, this has favored the production of corn in monoculture. Yet, yields of both corn and soybean can be higher when grown in rotation (Crookston and Kurle, 1989) and a corn/soybean rotation can reduce losses of NO_3–N to groundwater (Owens et al., 1995). Additionally, when corn is grown continuously in monoculture, weed, disease, and pest problems can develop that would otherwise not occur under rotation.

Fortunately, the results of a 6-year, six-watershed study at the NAEW indicated that reduced tillage (no-till, chisel, or paraplow) can successfully be used to grow soybean in rotation with corn if a cereal rye cover crop was used to provide additional erosion control following soybean harvest (Fig. 2). Under these conditions, average annual soil loss was only 0.5 Mg ha^{-1} yr^{-1} with no obvious differences among the three conservation practices (Edwards et al., 1993). There are, however, concerns over chemical losses in runoff. Although average NO_3–N losses for each of the tillage systems were $< 5\%$ of the amount applied as fertilizer, flow-weighted annual concentrations of NO_3–N in the runoff frequently exceeded the regulatory maximum of 10 mg l^{-1} for drinking water during the corn years and concentrations were particularly high in the first few storms following fertilization (Owens and Edwards, 1993). Likewise, herbicide losses in runoff were small as a percentage of applied chemical, but flow-weighted annual concentrations of some materials exceeded the stipulated tolerances for drinking water and concentrations were frequently excessive in the first few events following application (Shipitalo et al., 1997).

Because of concern over chemical losses in runoff and the perception that conservation tillage relies more heavily on pesticides to control weeds, insects, and diseases than does conventional tillage, a position that conservation tillage be used only on the most erodible lands has been advocated (Hinkle, 1983). Recently, however, Bull et al. (1993) documented few consistent differences in pesticide usage among conventional and conservation tillage systems in a multi-year survey that covered 80% of the land resource used for corn and soybean production in the United States. Nevertheless, modifications to current conservation tillage practices that might reduce the potential for chemical losses in runoff should be considered (Baker et al., 1987; Fawcett et al., 1994).

Our objective was to determine if a balance between losses of soil and purchased chemical inputs could be obtained by using a reduced-input management practice for the production of row crops. Under the reduced-input practice, cultivation substituted for some of the herbicide input and manure and a legume were used to supply most of the nitrogen requirement for the crops. We compared runoff, erosion, and crop yields of watersheds farmed with reduced-input practices to the response of watersheds farmed using conservation tillage (chisel or no-till) and compared all practices with the past record of performance of these watersheds. Profitability of the two systems, although important to long-term economic sustainability, was not investigated in this study.

2. Materials and methods

2.1. Watershed characteristics

Runoff and sediment losses from seven watersheds at the NAEW (two chisel-plowed, two no-till, and three reduced-input) were monitored for 6 years beginning with planting in spring 1990 and ending 1 June 1996. General characteristics and tillage treatments of the watersheds are outlined in Table 3. Tillage treatments were assigned to the watersheds based on long-term records of hydrologic performance with one watershed in each treatment having a history of less than average runoff production. Consequently, tillage treatments were not randomized and statistical comparisons among treatments were not performed. All seven watersheds were within 1 km of each other and there was a standard recording rain gage near each watershed (Fig. 1). The soils formed in residuum and colluvium derived from the underlying sandstone and shale bedrock and have an admixture of loess in surficial horizons. The B horizon of the Rayne series contains less clay than

Table 3
Tillage treatments and selected landscape and soil characteristics of the seven watersheds

Watershed no.	Tillage	Area (ha)	Average slope (%)	Maximum length (m)	Shape	Dominant soil[a]
WS 109[b]	Chisel	0.68	13	110	Pentagonal	Rayne sil
WS 123	Chisel	0.55	7	107	Fan	Keene sil
WS 113[b]	No-till	0.59	11	118	Triangular	Coshocton sil
WS 118	No-till	0.79	10	132	Triangular	Coshocton sil
WS 111	Reduced-input	0.45	6	143	Pentagonal	Keene sil
WS 115[b]	Reduced-input	0.65	7	119	Triangular	Coshocton sil
WS 127	Reduced-input	0.68	9	104	Fan	Coshocton sil

[a]Rayne = fine-loamy, mixed, mesic Typic Hapludult; Keene = fine-silty, mixed, mesic Aquic Hapludalf; Coshocton = fine-loamy, mixed, mesic Aquultic Hapludalf.
[b]Low-runoff-producing watershed based on historical records.

B horizons of the Coshocton or Keene series, hence, the Rayne has better internal drainage. Detailed information on soil properties and soil distribution in the watersheds is presented elsewhere (Edwards et al., 1993; Kelley et al., 1975).

2.2. Cropping sequence

Prior to the study, all of the watersheds, except WS 111, were in a corn/soybean rotation for 6 years starting in spring 1984 with all watersheds in corn. Rye was aerially seeded into the soybean prior to leaf drop and killed with herbicide prior to sowing corn in the spring. Watersheds 109 and 123 were chiselled each spring, WS 113 and WS 118 were no-till, and WS 115 and WS 127 were paraplowed each fall. At the beginning of the current study in 1990, the cropping sequence was altered so that one watershed in each tillage treatment was planted to each crop each year. Additionally, the paraplow treatment was eliminated in favor of a 3-year, reduced-input rotation. In this rotation, winter wheat was drilled into soybean residue each fall after harvest and red clover was seeded into the standing wheat the following spring. After wheat harvest in the summer, the clover was allowed to grow until the next spring when it was disked in along with manure to provide most of the nitrogen requirement for the corn. In order to have a watershed in each stage of the rotation each year, WS 111 was added to the study. Previously, this watershed had been used for hay production.

The timing of planting, tillage, and harvest operations varied from year-to-year as dictated by weather conditions. In general, the watersheds were planted to corn or soybean in late April or early May. Soybean was planted at an 18-cm row spacing in the chisel and no-till watersheds and a 76-cm spacing in the reduced-input watersheds. Corn was planted at a 76-cm spacing in all watersheds. The reduced-input watersheds were disked three to four times prior to planting and during the corn years 4 to 9 Mg ha^{-1} of strawy cattle manure was incorporated along with the red clover. To reduce the adverse consequences noted with moldboard plowing, only light, shallow disking was performed in order to leave some of the residue cover intact and to confine and concentrate the buried residue near the soil surface. Tillage and planting operations on all watersheds were performed parallel to the contour.

Pre-emergence herbicides were applied at recommended rates to control weeds on the chisel and no-till watersheds. A half rate of herbicide was used on the reduced-input watersheds when sown with corn and herbicide was applied only to a band over the row when soybean was planted. The corn and soybean crops in the reduced-input watersheds were cultivated for additional weed control twice during the growing season, usually once in June and once in July. The reduced-input corn crop was side-dressed with nitrogen fertilizer at cultivation if necessary. Wheat was drilled into the reduced-input watersheds following soybean harvest in October and rye was either drilled or broadcast seeded into the chisel and no-till watersheds in September or October. Red clover was broadcast seeded into the standing wheat in the reduced-input watersheds in March or April. Soil fertility and pH in all watersheds was monitored with soil tests and the levels were adjusted as recommended to achieve moderate yield goals (Ohio State University Cooperative Extension Service, 1990). Corn yields were measured by hand harvesting 10 random plots in each watershed. Soybean and wheat yields were determined by weighing the entire harvest from each watershed.

2.3. Sampling and analytical procedures

Runoff volumes were measured using H flumes and water stage recorders housed within enclosures that permitted year-round operation of each watershed. Flow-proportional, composite, runoff samples were obtained automatically using Coshocton wheel samplers (Brakensiek et al., 1979). Usually, separate samples were obtained for each runoff event unless storms occurred less than a few hours apart. Soil losses were determined by filtering the runoff samples to ascertain sediment concentrations and multiplying by runoff volumes calculated from the hydrographs. Infrequently, sediment was deposited in the flume and flume approach. In these instances, the sediment was collected and weighed with the amount added to the total for that particular event.

In order to assess the effect of the cropping and tillage practices on runoff and sediment transport, yearly losses were calculated from planting date to planting date for the chisel and no-till watersheds. With the reduced-input watersheds, these parameters were calculated from first disking in the spring to the first disking the following spring. In crop years when the watersheds were not disked because wheat and red clover had been planted, the end of the soybean/wheat year and the beginning of the red clover year was set as 1 May. Prior to 1 May we assumed that runoff and erosion were influenced more by the soybean residue and the standing wheat than by the red clover that had been planted in March or April. Consequently, variation in precipitation totals among watersheds within crop years was attributable to small variations in crop year length in addition to slight differences in actual precipitation at each site. The end of the last crop year for all watersheds was 1 June 1996.

3. Results and discussion

3.1. Historical performance

The seven watersheds selected for this study were in a 4-year, corn/wheat/meadow/meadow rotation for either seven cycles (28 years) or six cycles (24 years) beginning in 1945 or 1947. During this period, conventional tillage (i.e., moldboard plowing, disking, and cultivation) was used for corn production and the watersheds were disked after corn harvest in the fall prior to planting wheat. No other tillage operations were performed during the rotation and almost all of the soil loss occurred during the corn years. Soil losses for the corn years of this rotation are presented in Table 4 and, for all watersheds and years, averaged 4.2 Mg ha^{-1} yr^{-1}. More important to note, however, was the extreme variability among years. With the same tillage practice on the same watershed, but different weather years, soil loss varied from nil to well above the soil loss

Table 4
Annual soil loss from the seven watersheds during the corn years of a 4-year, corn/wheat/meadow/meadow rotation

Year	WS 109 (kg/ha)	WS 115 (kg/ha)	WS 123 (kg/ha)	WS 127 (kg/ha)	Year	WS 111 (kg/ha)	WS 113 (kg/ha)	WS 118 (kg/ha)
1945	747	866	63	nd[a]	1947	152	908	3074
1949	3046	3099	562	2652	1951	12	2092	1848
1953	0	3504	1	12	1955	0	0	16
1957	7768	15968	15649	5140	1959	2	10	1396
1961	772	828	0	0	1963	17	579	2915
1965	145	0	0	0	1967	2	2175	1552
1969	11409	74168	10040	17591				
Average	3412	14062	3759	4233		31	961	1800
Top five storms[b]	74%	85%	80%	81%		94%	54%	57%

[a]Not determined.
[b]Soil loss resulting from the five largest erosion events on each watershed as a percentage of total soil loss during the time period.

tolerance of 7.8 Mg ha^{-1} yr^{-1}. This observation reinforces the dependence of field erosion research on the weather and the need to collect many years of data before judging the adequacy of a management practice. This data also provides a benchmark on which to gage the effectiveness of the tillage practices investigated as part of the current study.

Also presented in Table 4 is the percentage of the total soil loss in the corn years attributable to the five storms that caused the most erosion in either 28 or 24 years. With an average of approximately 150 storms per year (4200 in 28 years) the five most severe storms caused half or more of the total soil loss. If the erosion from just these five storms could have been eliminated, the average soil losses from all the watersheds would have been well within the acceptable range. Similarly, Burwell and Kramer (1983) noted that 60% of the total soil loss from conventionally tilled corn plots occurred during 2 years of a 24-year study, highlighting the need for long-term experiments. Our data further emphasize the point that not only is erosion dominated by the weather year, but that a few, infrequent, severe storms cause most of the soil loss. Other researchers have reported similar findings (Evans, 1995; Poesen et al., 1996). Consequently, management practices must be able to protect the soil from erosion caused by severe storms in order to maintain long-term sustainability.

3.2. Conservation tillage vs. reduced-input, crop yields

Yields for corn and soybean for each watershed and crop year are presented in Table 5. Yields of winter wheat from the reduced-input watersheds ranged from 1.9 to 2.6 Mg ha^{-1} (data not shown). The data suggested that there were strong differences in yields among watersheds within tillage treatments, particularly with corn. The yearly average yields for all watersheds combined indicated, however, that the variability in yield among watersheds was similar in magnitude to the variability among years. This suggested that the apparent differences among watersheds was probably largely due to differences in the weather during the growing season.

No obvious differences in yield among the three tillage systems were apparent based on the 6-year, treatment averages (Table 5). It is interesting to note, however, that highest yields for corn (WS 115, 1992)

Table 5
Comparison of crop yields by year and tillage treatment for the seven watersheds

Crop year	Chisel (Mg/ha)		No-till (Mg/ha)		Reduced-input (Mg/ha)			Average (Mg/ha)
	WS 109	WS 123	WS 113	WS 118	WS 111	WS 115	WS 127	
Corn								
1990	9.5	–	9.8	–	6.7	–	–	8.7
1991	–	5.4	–	6.0	–	–	6.5	6.0
1992	10.7	–	11.1	–	–	11.8	–	11.2
1993	–	4.6	–	6.9	4.6	–	–	5.4
1994	11.2	–	11.0	–	–	–	11.6	11.3
1995	–	9.3	–	10.8	–	10.7	–	10.3
Average	10.5	6.4	10.6	7.9	5.7	11.3	9.1	8.8
	8.5		**9.3**		**8.7**			
Soybean								
1990	–	2.3	–	1.6	–	1.7	–	1.9
1991	1.3	–	0.8	–	0.8	–	–	1.0
1992	–	1.8	–	1.7	–	–	lost[a]	1.2
1993	1.7	–	1.3	–	–	1.4	–	1.5
1994	–	2.6	–	2.3	3.4	–	–	2.8
1995	2.7	–	2.5	–	–	–	2.6	2.6
Average	1.9	2.2	1.5	1.9	2.1	1.6	1.3	1.8
	2.1		**1.7**		**1.7**			

[a]Due to weather conditions the crop could not be cultivated and the soybean and weeds were cut, baled, and removed from the watershed.

and soybean (WS 111, 1994) as well as the lowest yields for corn (WS 111, 1993) and soybean (WS 127, 1992) occurred on the reduced-input watersheds. Thus, although the yields for the reduced-input treatment were comparable to the chisel and no-till treatments, the variability in yield was greater. A contributing factor to this variability was the loss of the soybean crop on WS 127 in 1992. In July 1992, rainfall totalled 260 mm and measurable rainfall was recorded 20 out of 31 days. Under these conditions, it was impossible to perform the second cultivation for weed control. Weeds out competed the soybean and the entire crop was cut, baled, and removed from the watershed so that the winter wheat crop could be successfully established in the fall. Although the reduced-input watershed planted to corn (WS 115) was also too wet in July to receive the second cultivation, the half rate of herbicide used on this watershed and a quicker closure of the canopy compared to soybean permitted the crop to outgrow the weed pressure. The abundance of soil moisture probably contributes to the fact that the highest corn yield recorded during the study was obtained from this watershed. Since herbicides were used exclusively to control weeds in the chisel and no-till watersheds, risk of yield lost due to inability to cultivate was not a factor.

3.3. *Conservation tillage vs. reduced-input, runoff and erosion*

The 6-year comparison included two extreme weather years. Calendar year 1990, with 1338 mm of precipitation, was the wettest and 1991, with only 665 mm of precipitation, was the driest in the 60-year record of the NAEW. Precipitation during the other years more closely approximated the long-term average of 950 mm yr^{-1}. Not surprisingly, more runoff occurred from all watersheds during the 1990 crop year than any other crop year (Table 6). Likewise, less runoff occurred during the 1991 crop year than any of the other 5 years of the study.

The differences in average runoff from the three tillage treatments were less than the differences in the yearly average runoff indicating that, in this instance, yearly variation in precipitation had a much greater effect on runoff than did the management practices (Table 6). Without exception, the watershed in each treatment identified a priori as low-runoff-producing yielded less runoff each crop year than the other watersheds assigned the same tillage treatment. This reflects the unique soil and topographic characteristics of the watersheds that have a large influence on runoff production. Hence, even though the average runoff from the reduced-input watersheds was slightly greater than the chisel or no-till watersheds, the differences were not substantial enough to warrant a conclusion that the reduced-input practice contributed to an increase in runoff. In fact, runoff from the reduced-input watersheds when they were in the red clover year of the 3-year rotation and neither tilled nor cultivated was 36% of the total (Table 6). Had the surface conditions of the reduced-input practice during the corn and soybean years contributed to a marked decrease in infiltration then runoff during these years should have exceeded two-thirds of the total.

Soil losses from the watersheds reflected the variation in weather years. The wettest crop year (i.e., 1990) that produced the most runoff on all watersheds resulted in the greatest soil loss of the 6-year study on four of the seven watersheds (Table 7). Average soil loss during this crop year was more than three times greater than the average loss during the next highest crop year, 1995. Under these unusually wet conditions, erosion from only two of the watersheds (WS 109, chisel and WS 115, reduced-input) exceeded the soil loss tolerance. At no other time during the study did the yearly soil losses approach the tolerance level. Moreover, averaged for the 6-year study, soil losses from each watershed and each of the three tillage treatments were well below the tolerance level and the average losses measured during the years of conventional tillage (Table 4). These observations suggested that each of the management practices should maintain long-term sustainability for crop production.

Noteworthy, however, is that the 6-year average soil loss from the no-till watersheds was about half the average losses from the chisel and reduced-input watersheds that involved some tillage each spring prior to the planting of corn or soybean (Table 7). Additionally, as opposed to the other two tillage treatments, soil losses from the no-till watersheds never exceeded the tolerance level any crop year, even though WS 118 (no-till) was the second largest

Table 6
Range of recorded precipitation at the seven watersheds and equivalent depth of runoff by crop year and tillage treatment

Crop average year	Rainfall (mm)	Chisel (mm)		No-till (mm)		Reduced-input (mm)			Average runoff (mm)
		WS 109[a]	WS 123	WS 113[a]	WS 118	WS 111	WS 115[a]	WS 127	
1990	(1305–1363)	86 cn[b]	274 sy	156 cn	295 sy	298 cn	185 sy	307 cl	229
1991	(609–686)	< 1 sy	9 cn	3 sy	19 cn	16 sy	6 cl	15 cn	10
1992	(966–1025)	< 1 cn	58 sy	22 cn	88 sy	88 cl	3 cn	134 sy	56
1993	(906–1025)	7 sy	107 cn	106 sy	152 cn	172 cn	100 sy	215 cl	123
1994	(803–1003)	< 1 cn	40 sy	34 cn	48 sy	55 sy	18 cl	69 cn	38
1995	(941–1180)	12 sy	185 cn	60 sy	169 cn	122 cl	69 sy	215 sy	119
Average		18	112	64	129	125	64	159	96
		65		**96**		**116**			

[a]Low-runoff-producing watershed based on historical records.
[b]Crop years designated as follows: cn = corn, sy = soybean/rye (conservation watersheds) or soybean/wheat (reduced-input watersheds), cl = red clover.

producer of runoff during the 6 years (Tables 6 and 7). Given the design of the experiment, it is not possible to determine whether there was a statistical difference in soil losses among tillage treatments. Nevertheless, these findings suggested that the surface conditions under no-till were better suited to preventing soil loss during years in which row crops were produced than the other two tillage treatments.

Soil loss from the reduced-input watersheds during the red clover crop year, when no tillage was performed, accounted for only 4% of the total soil loss (Table 7) even though 36% of the total runoff occurred during these years (Table 6). This is strong evidence that the tillage operations necessary for row crop production with this management practice resulted in surface conditions that enhanced soil loss. The average soil loss from the reduced-input watersheds based only on those years in which row crops were produced was 1476 kg ha^{-1} yr^{-1}, highest of the three practices. Even so, the average soil loss was well below the tolerance level and only slightly greater than the losses from the chisel tillage, suggesting that the reduced-input practice was a suitable alternative to the two conservative tillage practices in terms of soil loss.

The total number of runoff events recorded for each watershed and the contribution of the five largest erosion events to total erosion and runoff are reported in Table 8. These events accounted for only 1 to 5% of the total number of runoff events from any single watershed yet resulted in an average of 55% of the soil loss, but only 17% of the total

Table 7
Soil loss from the seven watersheds by crop year and tillage treatment

Crop year	Chisel (kg/ha)		No-till (kg/ha)		Reduced-input (kg/ha)			Average (kg/ha)
	WS 109[a]	WS 123	WS 113[a]	WS 118	WS 111	WS 115[a]	WS 127	
1990	11 822 cn[b]	1213 sy	766 cn	1893 sy	1184 cn	7764 sy	353 cl	3571
1991	0 sy	33 cn	12 sy	226 cn	161 sy	7 cl	82 cn	74
1992	2 cn	218 sy	22 cn	1483 sy	32 cl	3 cn	724 sy	355
1993	40 sy	380 cn	272 sy	825 cn	1428 cn	707 sy	194 cl	549
1994	3 cn	85 sy	90 cn	217 sy	367 sy	2 cl	56 cn	117
1995	77 sy	1565 cn	719 sy	396 cn	95 cl	283 cn	4949 sy	1155
Average	1991	582	314	840	545	1461	1059	970
	1287		**577**		**1022**			

[a]Low-runoff-producing watershed based on historical records.
[b]Crop years designated as follows: cn = corn, sy = soybean/rye (conservation watersheds) or soybean/wheat (reduced-input watersheds), cl = red clover.

Table 8
Contribution of the five largest erosion events for each watershed to total runoff and total soil loss from the seven watersheds

	Total events (#)	Total runoff (mm)	Total erosion (kg/ha)	Five largest erosion events (% of total)	
				Sediment	Runoff
Chisel					
WS 109	101	105	11944	68	39
WS 123	118	673	3494	69	18
No-till					
WS 113	231	381	1881	50	15
WS 118	421	771	5040	29	10
Reduced-input					
WS 111	152	751	3267	60	15
WS 115	161	381	8766	62	12
WS 127	361	955	6356	48	9
Average	**221**	**574**	**5821**	**55**	**17**

runoff. Thus, as noted during the years when these watersheds were in conventional tillage (Table 4) a few, infrequent, storms contributed most of the soil loss even with conservation practices in place. Of the 35 events, 29 occurred in the months of April through July when high intensity, short-duration, localized, convective rainstorms are most common (Kelley et al., 1975). The proximity of the major storms to tillage operations performed during this time of the year can have a major effect on long-term, measured, soil losses. The greater period of vulnerability to soil erosion inherent with the reduced-input management system suggests that there is an increased risk of soil loss associated with this practice compared to conservation practices that leave the soil surface better protected against erosion.

4. Summary

Row crop production with conventional tillage practices under the soil and climatic conditions characteristic of the North Appalachian region of the USA, and similar areas throughout the world, is limited by a high potential for excessive soil loss. Conservation tillage practices are an alternative that can greatly reduce the probability of excessive soil loss if cover crops are used to augment row crops that produce insufficient residue to control erosion. Under some circumstances, however, agricultural chemicals necessary to implement conservation tillage practices can be lost in runoff and contribute to the degradation of surface water supplies.

A reduced-input practice that substitutes tillage, a legume, and manure for some of the purchased chemical inputs used with conservation tillage was investigated for its potential to maintain soil losses within acceptable levels. Six-year average soil losses from watersheds farmed using reduced-input practices were similar to those from watersheds farmed with conservation tillage practices of chisel or no-till and averaged $< 15\%$ of the soil loss tolerance. The risk of soil loss during the spring when severe storms occur most frequently, however, was greater for the reduced-input practice than for the conservation tillage practices. In the long-term, most soil loss is due to these infrequent events, with much more numerous low-intensity storms having little potential to erode soil. Models of soil erosion must take into account the contribution of severe storms to adequately predict erosion potential.

Although yields of corn and soybean from the reduced-input watersheds were similar to those obtained with either chisel or no-till watersheds, there was greater variability in yield partially attributable to the inability to perform timely cultivations due to weather conditions. Additionally, row crops were produced every year with the conservation tillage practices, but only two out of 3 years with the reduced-input practice. Thus, a reduction in yield potential occurs concurrent with a slightly increased risk of soil loss when reduced-input management practices that substitute tillage and cultivation for herbicides are used.

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