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Sediment Loading and Water Quality of Field Run-off Water

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Abstract

Intensive tillage is commonly employed in many agronomic production systems in the United States. Tillage operations may include disking the field, re-smoothing the soil, seedbed formation, reducing the seedbeds, and shallow cultivation for weed control. Tillage practices in conjunction with rainfall have been linked to soil erosion, which may adversely affect the environment. The soil erosion dynamics of two large-scale production cotton fields that utilized both modern-conventional and conservation-tillage technology were examined. Studies were conducted in the cotton-producing region of southeast Arkansas in the Bayou Bartholomew watershed. Bayou Bartholomew is currently listed by the United States Environmental Protection Agency as an impacted stream. The soils at these sites were related, coarse-textured alfisols. One field was cropped to conventionally tilled cotton and intensively tilled. The second field was cropped to cotton using modern conservation tillage technology. Both fields were furrow-flow irrigated using piped water. Intense rainfall usually occurs in the Mississippi River Delta Region, particularly in the winter and spring months. Conservation tillage proved to be immediately beneficial in controlling soil erosion and sediment loss due to field run-off water from rainfall. Sediment content of run-off water induced by rainfall from the conventionally tilled cotton field was significantly greater than the sediments found in run-off water from the conservation tilled cotton field. The amount of sediment found in rainfall run-off water decreased more rapidly with time under conservation tillage than under conventional tillage. The tillage system made little difference in sediment content of run-off water from irrigation. The water flow from furrow irrigation is typically slow and steady. There is no droplet impact on the ground from furrow-flow irrigation as there would be from rainfall. Apparently, the gentle flow of the water down the furrows was insufficient to dislodge large numbers of soil particles.

Introduction

The Soil Erosion Process.–Soil erosion by water is a two-step process (Brady and Weil, 2002). First, water droplets from rainfall strike the soil surface and tear away primary soil particles–this process is the detachment phase. Second, as the water collects and recedes, the soil particles are carried away from their native site with run-off water–this is called the transportation phase. Some soil erosion occurs on all soils. Normal rates of soil erosion range from 228 to 456 kg ha-1 (0.1 to 0.2 ton acre-1) every year. Accelerated erosion occurs when the normal rates of soil erosion are exceeded (Wild, 1993). Accelerated erosion in the Arkansas Delta region is typically caused by water run-off from intense winter and spring rainfall.

Farmers and agricultural producers in the Mississippi River Delta region typically prepare seed beds for crops in early spring. Conventional tillage operations used for seedbed formation are primarily disking and raised crown seedbed formation (Bonner, 1993; Waddle, 1984). The finished beds allow the soil to warm rapidly and promote drainage of excess surface water. The weather conditions in the Delta region vary widely from season to season, and early spring rains frequently occur as heavy down pours. Heavy, frequent rainfall events on loose, unconsolidated soil surfaces promote accelerated soil erosion (Dendy, 1981). Losses of soil from freshly tilled fields may reach tonnes per hectare depending on field slope and weather. Sediments generated from tillage may result in surface water contamination.

Further, additional nitrogen and phosphorus carried in eroded sediments or as soluble species from fields may ultimately increase the potential for eutrophication of surface waters (Boesch et al., 2000; Goolsby and Battaglin, 2000). Sediments and nutrients that find their way from Arkansas Delta region soils into surface waters could also find their way to tributary rivers and streams and then the Mississippi River. The final and ultimate fate of these sediments and nutrients may be to contribute to the growing hypoxic zone in the Gulf of Mexico.

Conservation Tillage.–Cotton (*Gossypium hirsutum* L.) production in the United States is typically a tillage intensive culture. Tillage operations employed in most cotton production include disking to disrupt the soil surface, re-smoothing the field, bedding, knocking down the beds, and shallow cultivation for weed control during the growing season. These tillage practices have been linked to soil compaction (McConnell et al., 1989) and soil erosion (Mutchler et al., 1985), which may reduce crop yields and adversely affect the environment.

Utilizing conservation tillage systems in cotton production has been shown to substantially reduce soil erosion (Mutchler et al., 1985). However, residue cover of the soil surface from cotton is usually less than from high residue crops such as corn or grain sorghum. Production systems that include winter cover crops further reduce soil loss by reducing raindrop impact, slowing run-off, and holding soil in place when winter rainfall becomes intense (Stallings, 1957).

Experimental Objectives.–These studies were designed to determine the impact of conventional tillage and conservation tillage on sediment loss from cotton fields near a stream (Bayou Bartholomew) that is currently listed as "impacted" by the United State Environmental Protection Agency (EPA). The rate of sediment loss as a function of tillage system, time of year, and within each rainfall event was also investigated.

Experimental Methods

Field and laboratory studies of run-off water quality from agricultural fields employing modern, conservation-tillage technology and conventional-tillage technology were conducted. The site for the demonstrations was within the cotton-producing region of Southeast Arkansas on producer fields in the Bayou Bartholomew watershed. The Bayou Bartholomew has been classed as impacted by the EPA, primarily for sediment content of the water. Two large, producer fields cropped to cotton were utilized in these studies. The fields were approximately 16 hectares in area and rectangular. The soils at these sites were related, coarse-textured alfisols. One field was in conventional cotton production and intensively tilled. The second field utilized conservation tillage production technology. Both fields were furrow-flow irrigated. Furrow-flow irrigation requires that water be pumped to the field through pipe, either plastic or metal, and released upslope in the furrows of a field. The water then moves slowly down slope by gravity and replenishes the crop.

Run-off water from rainfall and from irrigation events was sampled from low points at the drainage ends of the fields. The water samples were collected with an ISCO 6700 automated sampler at various times during the growing season. All samples were collected from the sites within 24 hours and analyzed at the Arkansas Water Quality Lab using EPA approved analysis and QNQC procedures within 48 hours. The water samples were analyzed for sediments, N, P, K, electrical conductivity, and soluble pesticides. Only the sediment content of the run-off water is reported here.

Field-wide sediment loss was calculated using sediment concentration of the run-off water, average water infiltration rates, and historical precipitation data. The soils at the test sites infiltrate an average of 1.1 cm of water hr^{-1} (Soil Cons. Service, 1972). Historical precipitation data was found from the National Oceanic and Atmospheric Administration (NOAA, 2001). We estimate that 50% of the total rainfall infiltrated the soil, while 50% of the rainfall left the fields as run-off water. The average sediment content of the run-off water was multiplied by the estimated volume of run-off water to calculate estimated sediment losses.

Results and Discussion

Soil Erosion and Sediment Loss–Prior to Planting. Total average rainfall during the months of March and April in southeastern Arkansas is 18.5 cm (NOAA, 2001). Rainfall infiltration is assumed to average 50%, while the other half of the water is assumed to leave the field as run-off. Runoff water samples were collected in conjunction with precipitation on 4 April 2000. Run-off water, particularly under conventional tillage, contained large amounts of sediments that slowly declined with time (Fig. 1). The conventionally tilled field had run-off water containing an average of 491 mg of sediment L^{-1} (Table 1). This translates into 4,302 kg of sediment ha-1 lost from the field. This is calculated to be 68.8 tonnes of sediments lost from the 16-ha field during the early growing season. The run-off water from the field utilizing conservation tillage technology contained an average of 491 mg of sediment L^{-1}. Calculations show the field loss to be 454 kg of sediment ha-1 or 7.3 tonnes of sediment for the entire 16-ha field. Conservation tillage reduced sediment content of the March and April run-off water by 3,848 kg ha^{-1} or 89%.

Winter weeds and debris from the previous year's crop protected the soil surface of the conservation-tilled field in the spring. Prior to planting in the spring, the soil on the conventionally tilled field was loose and bare, with no plant life to block direct impact of rain droplets onto the soil surface. Loose, bare soil produced by conventional tillage was especially vulnerable to soil erosion from intense rainfall compared to conservation tillage prior to planting. Sediment loading of run-off water prior to planting was excessive under conventional tillage, and moderate under conservation tillage.

Soil Erosion and Sediment Loss–Early Season.–Total average rainfall during May in southeastern Arkansas when the soil would generally be tilled and bare is 12.1 cm (NOAA, 2001). Runoff water samples were collected in conjunction with precipitation on 4 May 2000. With less than 5% of the soil surface covered, accelerated erosion still occurred in the conventionally tilled field. Run-off water from rainfall averaged 3,200 mg of sediment L^{-1} or 1,936 kg of sediment ha^{-1} from the conventional tillage field (Table 1). The net field loss was calculated to be 31.0 tonnes of sediment from the 16-ha conventionally tilled field.

Table 1. Calculated yearly sediment losses from cotton fields employing conservation and conventional tillage in the Bayou Bartholomew watershed.

		Run-off Sediment Content		Sediments Lost Through Erosion	
Type of Event	Average Rainfall (cm)	Conservation Tillage ($mg\ L^{-1}$)	Conventional Tillage ($mg\ L^{-1}$)	Conservation Tillage ($kg\ ha^{-1}$)	Conventional Tillage ($kg\ ha^{-1}$)
Early Spring					
Rainfall[1]	18.5	491	4,651	454	4,302
Mid-Spring					
Rainfall[2]	12.1	580	3,200	351	1,936
Early Summer					
Rainfall[3]	8.9	597	951	266	424
Irrigation[4]	10.2–25.45	≤ 10	≤ 10	0	0
Total Calculated Yearly Sediment Loss				**1,071**	**6,662**

[1]March 15 through April.

[2]May.

[3]June.

[4]Non-rainfall water. Typically irrigations are required in late June, July, and August.

[5]Between 2 and 5 irrigations of approximately 5.1 cm of water applied per irrigation.

Run-off water under conventional tillage contained larger amounts of sediment that slowly declined with time, while conservation tillage run-off water contained less sediment and declined faster with time (Fig. 2). Run-off water from the conservation tillage field on 4 May contained an average of 580 mg of sediment L-1. Using the total rainfall and estimated total run-off, the conservation-tilled field was determined to have lost 351 kg of sediment ha-1. The calculated net field loss was 5.6 tonnes of sediment from the 16-ha conservation tilled field. Conservation tillage reduced sediment content of run-off water and soil erosion by 1,585 kg ha-1 or 82% during May.

After planting on 4 May 2000, the soil on the conventionally tilled field was still bare, with only small cotton seedlings, which did little to block the direct impact of rain droplets onto the soil surface. Dead winter weeds and previous crop residues protected the soil of the conservation tillage field. Cotton seedlings alone did little to impede droplet impact, hold the soil together, or slow run-off water.

Soil Erosion and Sediment Loss–Mid-Season.–Total average rainfall during June in southeastern Arkansas when there would generally be actively growing cotton plants is 8.9 cm (NOAA, 2001). Runoff water samples were collected in conjunction with precipitation on 5 June 2000. Run-off water from the conventionally tilled field averaged 951 mg of sediment L-1 or 424 kg of sediment ha-1 (Table 1). The net field loss from the conventionally tilled field was calculated to be 6.8 tonnes of sediment from the 16-ha field. Run-off water from the conservation tillage field on 5 June contained an average of 597 mg of sediment L -1 or 226 kg of sediment ha-1. The calculated net field loss was 3.6 tonnes of sediment from the 16-ha field. Sediment tended to erratically decline with time under both tillage systems (Fig. 3). Conservation tillage reduced sediment content of the run-off water and soil erosion by 189 kg ha-1 or 47%.

As the cotton plants continued to grow they provided better protection of the soil surface by intercepting more droplets of rain. Additionally, easily eroded soil had already been removed by prior rainfall events. Run-off water under conventional tillage contained larger amounts of sediments han run-off water from conservation tillage. The soil in the onventionally tilled field on 5 June was only partially rotected by the cotton plants. Conservation tillage better rotected the soil with dead residue of the previous crop, and older, larger cotton plants than on 4 May.

Soil Erosion and Sediment Loss–Irrigation.– Weather patterns in the Delta region of southeast Arkansas during the mid-summer typically result in less rainfall than in the spring and early summer. During this period, the water requirements of the developing cotton crop are usually met with in-furrow irrigation. Runoff water samples were collected in conjunction with irrigation on 22 July 1999. Run-off water from irrigation of both the conventional-tillage and conservation-tillage field averaged less than 10 mg of sediment L^{-1}, less than 1.0 kg of sediment ha^{-1} (Table 1). The net field loss of sediments due to irrigation was negligible.

In-furrow irrigation is the most common method of providing supplemental water. The water flow from furrow irrigation is slow and steady. There is no droplet impact on the ground as there would be from rainfall. Run-off water from irrigation of both the conservation and conventionally tilled fields contained almost no sediments (Fig. 4). The gentle flow of the water down the furrows was not found to be sufficient to dislodge soil particles. Without droplet impact, the sediment load of the run-off water was greatly reduced.

Total Calculated Sediment Loss.–Calculated soil erosion and sediment loss was less for the conservation-tillage field than the conventional-tillage fields (Table 1). Although estimates of yearly soil erosion for both conservation tillage and conventional tillage exceeded established limits for accelerated erosion, these studies found that conservation tillage was very effective in reducing soil erosion and sediment content of run-off water. The estimated yearly reduction of sediment loss due to soil erosion made possible by employing conservation-tillage practices was found to be 84%.

Conclusions

Conservation tillage was of immediate benefit in controlling soil erosion and sediment loading in run-off water under the intense rainfall conditions that may occur in the Delta Region. Sediment loading was significantly greater in run-off water from conventionally tilled cotton as compared to conservation-tilled cotton. Sediment content of run-off water was found to decline with time. Sediment loading of the run-off water during early months of the growing season was greater than in later, summer months. Generally, sediment content of the run-off water began at its highest level and declined with time within each rainfall event.

The water flow from furrow-flow irrigation was typically slow and steady. There was no droplet impact on the ground from this method of irrigation. The gentle flow of the water down the furrows was not sufficient to dislodge soil particles. Without droplet impact, the run-off water sediment load due to irrigation was greatly reduced.

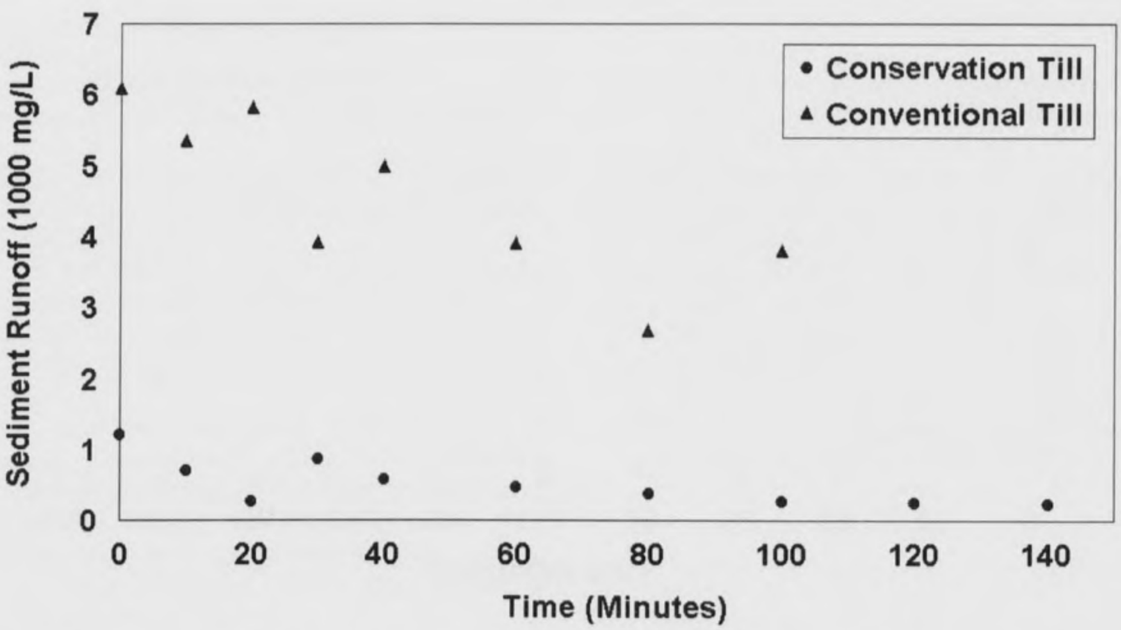

Fig. 1. Sediment losses found in rainfall run-off water on 4 April 2000 (prior to planting) under conservation and conventional tillage.

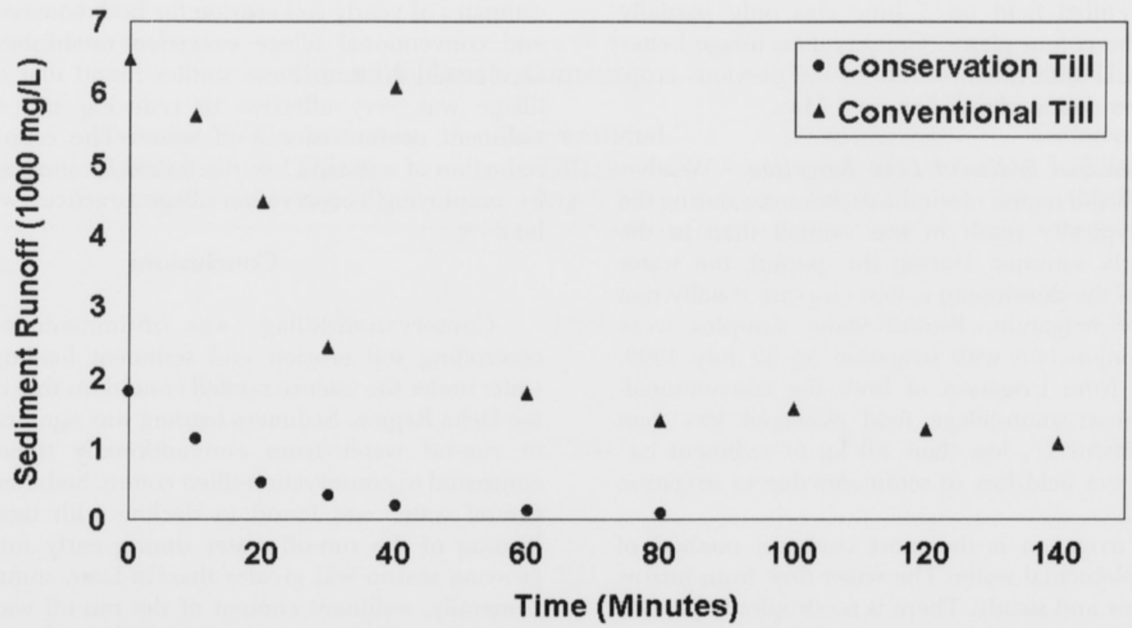

Fig. 2. Sediment losses found in rainfall run-off water and soil erosion on 4 May 2000 (shortly after cotton was emerged) under conservation and conventional tillage.

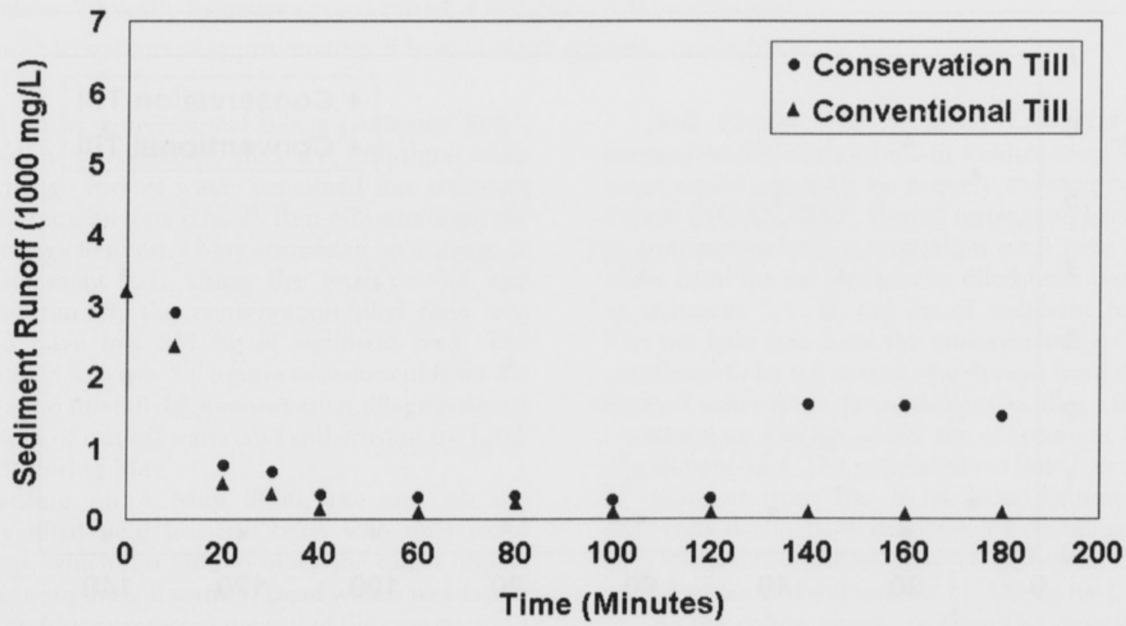

Fig. 3. Sediment losses found in rainfall run-off water on 5 June 2000 under conservation and conventional tillage. The cotton crop was approaching the first square growth stage.

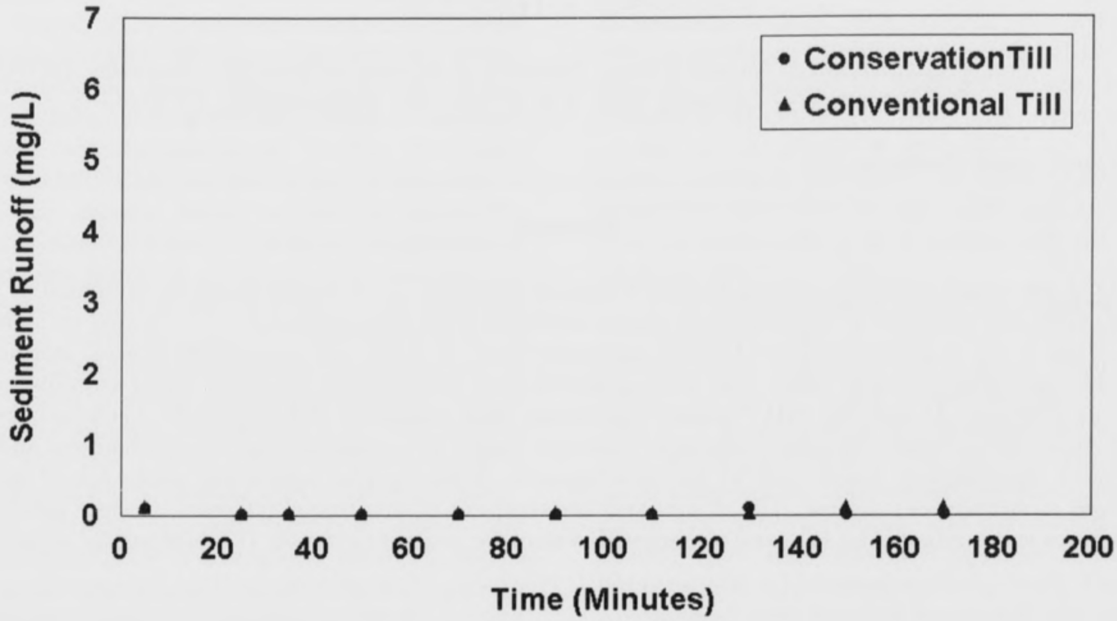

Fig. 4. Sediment losses found in irrigation run-off water found on 22 July 1999 under conservation and conventional tillage. The cotton crop was near mid-bloom stage.

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