Impact of Reservoir Tillage on Runoff Quality and Quantity

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Abstract. *The effects of reservoir tillage on runoff and water quality were studied under two levels of soil compaction in the production of cotton. A wide frame tractive vehicle was used during plot establishment and during all farm operations to provide the desired soil compactions. LEPA (Low Energy Precision Application) irrigation was used to apply supplemental water as required. Runoff quantity was monitored with flumes and runoff samples were taken using Coshocton-type runoff samplers. Thirteen runoff events were monitored and analyzed over a two-year period for the replicated, four-treatment study. Reservoir tillage decreased runoff and total discharges of organic nitrogen and phosphate. Differences in concentrations of water quality parameters (total solids, ammonium, total kjeldahl nitrogen, nitrate, phosphate, and COD) were not statistically significant. Although not statistically different, total runoff and total discharge of water quality parameters (except phosphate) were lower for the low compacted treatments compared to the high compacted treatments.* ***Keywords.** Runoff, Water quality, Tillage system, Pollution control.*

Furrow diking and reservoir tillage are methods of modifying the soil surface and near surface to increase water storage and to improve water use efficiency in cropping systems. Furrow diking and reservoir tillage are different in the way that water storage is achieved. Furrow diking generally refers to the building of dikes across the furrow while reservoir tillage generally refers to the formation of surface depressions. The first machine capable of making dikes was developed in 1931 (Lyle and Dixon, 1977). Interest in this and other early machines was limited. In 1975, a furrow diking machine was developed for use in the High Plains of Texas for dryland crops (Lyle and Dixon, 1977). Interest in the concept increased when substantial yield increases were reported for cotton and sorghum (Clark and Hudspeth, 1976). The furrow diking machine is also used in conjunction with LEPA (Low Energy Precision Application) irrigation (Lyle and Bordovsky, 1981; Bordovsky et al., 1992). And recently, furrow diking has been used in reduced tillage in the production of cotton (Clark et al., 1991).

An early reservoir tillage machine was developed in 1980 in Idaho (Wiser, undated) with the objective of holding water on the soil where it fell. This machine formed reservoirs at the surface of the soil profile. Yield increases have also been documented with the use of this concept (Longley, 1984). In the late 1980s, a research effort was initiated to evaluate the value of reservoir tillage in a high-intensity rainfall area (Hackwell et al., 1991). This study included production systems with and without reservoirs on highly compacted and on uncompacted soils. In the first year of the study, 1989, a series of LEPA irrigation applications was used to characterize the potential water savings of reservoir tillage. Runoff was decreased by the use of reservoirs for both levels of compaction. The decrease, however, was much greater for the highly compacted soils. After the first year, we expanded the study to include chemical analyses of the surface runoff and continued the study through two additional growing seasons. The objective of this study was to determine the effect of reservoir tillage in a high-intensity rainfall area on surface runoff quantity and quality under varying soil compaction levels.

Experimental Procedures

In 1989, 12 experimental plots were established at the E. V. Smith Research Center, Alabama Agricultural Experiment Station, Shorter, Alabama. Details of plot design and construction have been presented (Hackwell et al., 1991) and are summarized here. The plots were constructed between previously prepared traffic lanes (Monroe and Taylor, 1989) to accommodate a Wide Framed Tractive Vehicle (WFTV) (Monroe and Burt, 1989). All field operations were conducted with this vehicle, thus eliminating any unwanted traffic in the plots.

The 6.0-m-wide plots were designed to accommodate eight rows of crop with a 0.76-m row spacing. The plots were initially 29.0 m long, but were reduced in subsequent years to 24.4 m to better accommodate the field equipment. Surface water flow into and out of the plots was eliminated by the use of vertical steel strips which extended approximately 150 mm above the soil surface. Each plot was equipped with a 180-mm HS flume, model N-1 Coshocton-type runoff sampler and collector tank. Two CR10 dataloggers (Campbell Scientific, Inc., Logan, Utah) were used in conjunction with potentiometers to monitor and record flow at 1-min increments. Runoff samples were collected manually from the collecting tank after each

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runoff event. Collected samples were transported to the laboratory for analysis. Samples were stored at 3° C and analyzed within one week of collection.

Water quality parameters of total solids (TS), total ortho-phosphate (T-PO_4), ammonium nitrogen (NH_4-N), and chemical oxygen demand (COD) were analyzed according to procedures outlined in *Standard Methods for the Examination of Water and Wastewater* (APHA, 1989). Nitrate nitrogen (NO_3-N) was analyzed by the DeVarda's alloy method. Total Kjeldahl nitrogen (TKN) was analyzed according to the micro-Kjeldahl technique of AOAC (1984). Runoff water quality analyses were performed after the collected runoff samples were completely mixed.

The above parameters (TS, T-PO_4, NH_4-N, and TKN) are of major concern in surface water runoff and are known to cause various health or pollutional problems. The U.S. Public Health Service has established a drinking water standard of 10 mg/L for NO_3-N as the upper health limit. COD levels over about 500 mg-O_2/L pose serious problems when runoff reaches surface water streams and TS levels of more than 10 g/L (1%) signal a serious erosion event. Excessive phosphorus levels (i.e., > 10 mg-P/L) cause serious algal blooms in surface water impoundments. All of these parameters, taken as a whole, can be used to determine processes occurring in the soil and during runoff events. However, the most important use of these data will be in an analysis of variance for the two-year study to determine if and what significant differences exist between the factors of compaction and tillage.

The soil is a Bassfield sandy loam (Typic Hapludult, 67% sand, 18% silt, 15% clay, 1.2% organic matter). Prior to initiation of tests in 1989, the top 200 mm of soil profile was extensively tilled to minimize compaction and then recompacted using a double-wheeled compactor according to treatment needs. A hardpan was left undisturbed in the 200- to 300-mm profile range. This modified soil profile was left undisturbed during the three-year test period except for surface preparations during planting. Soil compaction was quantified annually utilizing a hydraulically operated cone penetrometer to determine the cone index of the soil profiles in the different treatments. Plot slope is 0.2% in the direction of the traffic lanes and rows.

In addition to natural rainfall, supplemental irrigation was applied as needed according to soil moisture tension obtained from resistance-type sensors and from gravimetric soil-moisture sampling. A traveling LEPA irrigation system was used to apply water to each of the seven inside furrows of the eight-row cropping system with depth of application controlled by travel speed. Volume of water applied by irrigation was monitored using a mainline flowmeter. Volume applied by rainfall was monitored by on-site tipping bucket and total volume rain gages.

The experiment included four treatments, each having three replications arranged in a randomized complete block design as follows: 1) high compaction without reservoirs; 2) high compaction with reservoirs; 3) low compaction without reservoirs; and 4) low compaction with reservoirs. At planting, all plots were disked and cultivated twice to form a seed bed. Cotton (*Gossypium hirsutim* L.) was planted at a seeding rate of 20 seeds/m. Reservoirs were then created (in the appropriate treatments) in each of the seven inside furrows using commercially available equipment (Dammer Diker manufactured by Ag Engineering and Development Co., Tri-Cities, Wash.). The reservoirs were an average of 250 mm deep and spaced at 600-mm intervals along the furrow. A late season water-holding volume ranged from 2.9 to 4.6 L per reservoir (5.6 to 9.0 mm effective storage depth).

All plots received the same commercial fertilizer applications based upon soil tests and recommendations from the Auburn University Soil Test Laboratory. Applications during the 1989 growing season included a common broadcast of 44 kg-N/ha and 44 kg-P/ha incorporated with a field cultivator on 18 May (planting) followed by a broadcast on 27 July of 95 kg-N/ha as NH_4NO_3. In the 1990 growing season, 27 kg-N/ha and 81 kg-P/ha were broadcast and incorporated at planting (24 April) followed by a broadcast application of 101 kg-N/ha as NH_4NO_3 on 6 June, 43 days after planting. In the final cropping year (1991), 99 kg-N/ha was applied as NH_4NO_3 on 13 June, 21 days after planting.

At season end, plots were hand-harvested and yields measured. After harvest, the soil surface was tilled and winter wheat planted as a ground cover.

Results and Discussion

Water quality and quantity data were collected for 17 events over the two-year study period (table 1). These events represent most of the runoff events that occurred during the growing seasons, and included two events after harvest, and two events prior to planting for 1990 and 1991, respectively. Two irrigation events, one in each year, resulted in runoff as noted by footnote 1. All reported events occurred in the months May through November.

Runoff

Runoff, as a percentage of water applied, varied to a maximum of approximately 30%. Runoff from plots with reservoirs was significantly (denotes statistically significant differences at the 0.05 level or better) reduced compared to plots without reservoirs. Average runoff percentage over both compacted and uncompacted treatments for events which occurred during the crop growing period were 7.0 and 4.0% for treatments without and with reservoirs, respectively. Differences between the two treatments were more pronounced for events with high percentage runoff, such as events 5 and 15. These high runoff events were caused by high intensity storms of 75 and 70 mm/h, and total applications of 39 and 34 mm, respectively. Other runoff events with higher application totals, such as events 9 and 12 (51 mm and 86 mm, respectively), had lower runoff percentages because of lower application intensities (28 and 40 mm/h, respectively). Reservoirs had a more pronounced effect on runoff percentage for the highly compacted soils than with the uncompacted soils. Reservoirs reduced total runoff from 8.5 to 3.7% for the compacted soils as compared to a reduction of 7.0 to 4.0% for the uncompacted soils.

Total Solids

Total solids (TS) measures all dissolved and suspended solids, including fixed (mineral) and volatile (organic matter). Concentration of TS in the runoff varied from approximately 0.1-4.3 g/L (table 1) and averaged

1.6 g/L for the 13 cropping-season events. Differences between treatments were not significant. Computed on a mass per unit area basis (table 1), trends, although not statistically significant, indicated slightly lower amounts of TS discharged for plots with reservoirs compared to nonreservoir plots. Events 5 and 14 produced the most losses. Event 5 was a high-intensity rainfall, while event 14 was an irrigation applied immediately after installing the reservoirs during a time in which the surface soil was loose.

Nitrogen

The three forms of N (NH_4-N, organic nitrogen (ON-N), and NO_3-N) represent the most mobile forms and, also, NO_3-N poses the greatest health hazard in drinking water. Highest average concentration of NO_3-N was 23.8 mg/L (event 14, table 2). Runoff event 14 occurred just four days after a broadcast application of NH_4NO_3 at a rate of 99 kg N/ha. Differences in NO_3-N concentrations of the runoff were not significant between treatments. Average concentration of NO_3-N over all treatments was 3.5 mg/L.

Total discharge of NO_3-N (table 2) on a unit area basis again demonstrated the sharp impact of the first runoff event after the N application (event 14) with an average discharge over all treatments of 0.3 kg N/ha. Differences in discharge values were not significant between treatments.

NH_4-N demonstrated trends similar to NO_3-N (table 2) with average peak concentrations and total discharge occurring at event 14 (21.8 mg/L and 1.0 kg/ha). Differences between treatments were not significant, but total discharge of NH_4-N was lower for events 5, a high runoff event, and 14, the event just after a N application.

Concentrations of ON-N showed no significant differences between treatments (table 2) with an average concentration of 4.9 mg/L. Total discharge of ON-N, however, was significantly different between treatments. Event averages were 0.14 and 0.09 kg/ha, for without and with reservoirs, respectively. Highest discharge of ON-N occurred in event 5, the runoff event with a high rainfall intensity.

The TKN reflects the combination of ON-N and NH_4-N. Concentration differences were not significant between treatments and averaged 7.7 mg/L. Peak discharges occurred during events 5 and 14 for similar reasons as previously discussed for other N parameters.

Table 1. Average runoff and total solids concentrations and losses*

Event†	Days After Planting	Rain or Irr.	Runoff		Total Solids			
					Conc.		Loss	
			WR‡	NR	WR	NR	WR	NR
	(d)	(mm)			(g/L)		(kg/ha)	
	(1990)							
1	15	31	0.00	0.00	0.7	0.7	0.0	0.0
2	23	17	0.01	0.01	1.4	1.2	0.7	0.6
3	59	13	0.03	0.05	1.8	2.2	3.4	6.7
4	75	26	0.06	0.41	1.1	1.3	3.9	30.9
5	78	39	1.10	2.20	1.8	1.7	117.2	199.9
6	117	18	0.06	0.08	2.9	1.8	10.2	8.1
7	125	33	0.04	0.11	1.5	1.4	3.8	8.7
8	129	19	0.13	0.15	0.6	1.3	4.6	11.4
9	138	51	0.29	0.43	3.2	1.8	54.0	46.2
10	181	18	0.01	0.00	2.0	3.0	0.8	0.3
11	199	35	0.04	0.06	0.4	1.4	0.9	4.4
	(1991)							
12	–55	86	0.83	1.15	1.0	1.3	55.9	96.7
13	–4	33	0.03	0.05	0.4	1.2	0.8	4.0
14	25	63	0.57	0.81	4.3	3.8	162.3	202.4
15	80	34	0.53	1.06	0.5	0.6	18.7	42.5
16	83	17	0.18	0.27	0.3	0.7	3.9	12.6
17	124	51	0.12	0.10	0.1	0.2	0.4	1.2
Average§			0.22a	0.39b	1.7a	1.5a	34.0a	41.0a

* Values are averages of three replications and two levels of compaction.
† All events are rainfall except for irrigation event 7.
‡ WR – with reservoirs, NR – no reservoirs.
§ Averages within each variable followed by different letters are significantly different at the 0.05 level.
Averages exclude events 10, 11, 12, 13 which did not occur during the growing season.
Averages are based upon individual replications and may differ from averages of table data.

Table 2. Average NH_4-N, NO_3-N, and ON-N concentrations and losses*

Event	Days After Planting	NH_4-N				NO_3-N				ON-N			
		Conc.		Loss		Conc.		Loss		Conc.		Loss	
		WR†	NR	WR	NR	WR	NR	WR	NR	WR	NR	WR	NR
	(d)	(mg/L)		(kg/ha)		(mg/L)		(kg/ha)		(mg/L)		(kg/ha)	
	(1990)												
1	15	0.1	0.2	0.00	0.00	0.72	1.06	0.00	0.00	2.38	1.03	0.00	0.00
2	23	1.1	0.5	0.00	0.00	0.00	0.50	0.00	0.00	7.19	6.07	0.00	0.00
3	59	0.6	1.1	0.00	0.00	0.81	0.33	0.00	0.00	3.26	5.45	0.01	0.02
4	75	2.9	1.8	0.01	0.04	2.91	1.46	0.01	0.03	5.12	4.82	0.02	0.12
5	78	2.3	2.4	0.15	0.28	2.10	1.69	0.14	0.20	8.26	7.07	0.54	0.84
6	117	0.8	1.1	0.00	0.00	0.45	1.35	0.00	0.01	6.37	6.37	0.02	0.03
7	125	1.8	0.9	0.00	0.01	1.25	1.03	0.00	0.01	5.03	4.70	0.01	0.03
8	129	0.4	0.8	0.00	0.01	0.95	2.04	0.01	0.02	3.24	3.96	0.02	0.04
9	138	1.4	0.7	0.02	0.02	1.99	0.83	0.03	0.02	8.69	5.68	0.15	0.14
10	181	1.3	1.2	0.00	0.00	0.88	0.41	0.00	0.00	5.60	7.94	0.00	0.00
11	199	1.0	1.2	0.00	0.00	1.25	0.41	0.00	0.00	1.75	4.33	0.00	0.01
	(1991)												
12	–55	0.1	0.1	0.01	0.01	0.37	0.30	0.02	0.02	3.10	3.27	0.17	0.25
13	–4	0.4	0.5	0.00	0.00	0.44	1.57	0.00	0.01	2.05	4.25	0.00	0.01
14	25	22.6	21.1	0.85	1.14	26.83	20.80	1.02	1.02	6.32	5.65	0.24	0.30
15	80	0.4	0.6	0.01	0.04	2.55	5.20	0.14	0.26	1.49	1.91	0.05	0.14
16	83	0.5	0.8	0.01	0.01	2.23	2.01	0.03	0.04	1.47	2.54	0.02	0.05
17	124	0.5	0.3	0.00	0.00	0.25	0.53	0.00	0.00	0.54	1.75	0.00	0.01
Average‡		3.1a	2.6a	0.09a	0.11a	3.85a	3.11a	0.12a	0.13a	5.23a	4.56a	0.09a	0.14b

* Values are averages of three replications and two levels of compaction.
† WR – with reservoirs, NR – no reservoirs.
‡ Averages within each variable followed by different letters are significantly different at the 0.05 level.
Averages exclude events 10, 11, 12, 13 which did not occur during the growing season.
Averages are based upon individual replications and may differ from averages of table data.

Phosphorus

Because P tends to be adsorbed onto soil particles, less movement in the aqueous phase would be expected with more movement associated with erosion. Therefore, lower erosion would affect the movement of P more than N. Concentrations of PO_4-P (table 3, mean = 4.0 mg/L) appear to be unaffected by reservoir tillage. Total losses (table 3) of PO_4-P through runoff were decreased by the addition of reservoirs from 0.08 to 0.04 kg/L. The PO_4-P losses closely track losses of TS (table 1) with the exception of event 14. No superfluous events were associated with event 14, therefore no explanation can be given for PO_4-P not tracking TS data.

COD

The importance of COD is in measuring the reduced organic matter contained in the runoff. It has long been recognized as an important parameter in measuring pollution based on oxygen demand. Neither concentration nor total discharge of COD were significantly different between the two reservoir tillage treatments. Mean values of 101 mg/L and 2.3 kg/ha were obtained (table 3).

Summary and Conclusions

The effects of reservoir tillage on runoff quantity and water quality parameters were studied in the production of cotton. A wide frame tractive vehicle was used during plot establishment and during all farm operations to provide two levels of soil compaction in the replicated treatments. LEPA irrigation was used to apply supplemental water as required. Runoff quantity was monitored with flumes and runoff samples taken using Coshocton-type samplers.

The experiment included four treatments: 1) low compaction without reservoirs, 2) low compaction with reservoirs, 3) high compaction without reservoirs, and 4) high compaction with reservoirs. In these discussions, the combined results of low and high compaction are presented for simplicity and clarity, as differences between compaction treatments were generally not statistically significant. Seventeen runoff events were monitored and analyzed during the study period. Thirteen of the events occurred during the growing season and were used to determine effects of reservoir tillage on quantity and quality of runoff.

Reservoir tillage decreased runoff and total mass discharges of ON-N and PO_4-P as compared to similar plots without reservoirs. This decrease was as expected because reservoirs impede flow and, since these two parameters are more closely associated with the non-soluble phase, their discharge was reduced. Differences in concentrations of water quality parameters (TS, NH_4-N, ON-N, NO_3-N, PO_4-P, and COD) were not statistically significant. Although there are no statistical differences in the concentration of water quality parameters for reservoir tillage compared to no reservoir tillage, there is a significant improvement in pollution control due to the reduction in runoff quantity. As a result, total mass discharge of pollutants was less for the plots with reservoir tillage. Although the primary use of reservoir tillage will not likely be pollution abatement, this benefit will accompany its use as a crop cultural practice and will benefit the environment significantly.

Table 3. Average PO_4-P and COD concentrations and losses*

Event	Days After Planting	PO_4-P Conc. WR†	PO_4-P Conc. NR	PO_4-P Loss WR	PO_4-P Loss NR	COD Conc. WR	COD Conc. NR	COD Loss WR	COD Loss NR
	(d)	(mg/L)		(kg/ha)		(mg/L)		(kg/ha)	
	(1990)								
1	15	2.86	2.06	0.00	0.00	36.5	33.3	0.0	0.0
2	23	4.75	6.80	0.00	0.00	121.2	70.2	0.1	0.0
3	59	4.40	6.71	0.01	0.02	67.0	66.3	0.1	0.2
4	75	4.56	4.48	0.02	0.11	73.6	67.8	0.3	1.6
5	78	5.30	5.61	0.34	0.67	134.4	119.9	8.7	14.2
6	117	5.34	5.15	0.02	0.02	129.2	128.8	0.5	0.6
7	125	5.06	4.49	0.01	0.03	116.0	103.9	0.3	0.7
8	129	1.29	4.08	0.01	0.04	44.0	76.0	0.3	0.7
9	138	7.50	4.51	0.13	0.11	346.7	197.3	6.0	5.0
10	181	5.39	6.97	0.00	0.00	157.8	257.8	0.1	0.0
11	199	1.65	3.46	0.00	0.01	20.9	96.5	0.1	0.3
	(1991)								
12	−55	2.34	2.76	0.13	0.21	40.5	54.9	2.2	4.2
13	−4	1.28	1.49	0.00	0.00	28.7	66.5	0.1	0.2
14	25	1.62	1.72	0.06	0.09	160.0	127.6	6.0	6.9
15	80	1.10	1.67	0.04	0.12	24.2	43.6	0.9	3.1
16	83	1.04	1.58	0.01	0.03	11.3	24.2	0.1	0.4
17	124	0.39	0.82	0.00	0.01	19.5	41.3	0.2	0.3
Average‡		4.04a	4.03a	0.06a	0.10a	113.2a	88.0a	2.0a	2.5a

* Values are averages of three replications and two levels of compaction.
† WR = with reservoirs, NR = no reservoirs.
‡ Averages are based upon individual replications and may differ from averages of table data.
Averages exclude events 10, 11, 12, 13 which did not occur during the growing season.
Treatment differences for phosphate and COD are not significant.
Averages within each variable followed by different letters are significantly different at the 0.05 level.

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