WATER BALANCE IN A CECIL SOIL UNDER CONTROLLED IRRIGATION IN LARGE NO-TILL AND CONVENTIONAL TILLAGE PLOTS

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ABSTRACT

There is continuing need for systematic research under site-specific conditions to quantify soil water availability in different soils and tillage practices to help growers make informed decisions. We conducted an irrigation study from June 4 to 7, 2002, on twelve 33 x 100-ft plots on Cecil soil at the USDA-ARS, J. Phil Campbell Sr. Natural Resource Conservation Center in Watkinsville, GA, to quantify differences in the soil hydrologic balance between no-till (NT) and conventional tillage (CT). The plots had been in either CT or NT for eleven years. We found significant differences in hydrology between CT and NT. Following 2.2 in. of irrigation and 0.5 in. of rainfall on June 4, there was about 38% more drainage from NT. No runoff was recorded. The soil profile retained about 1.7 in. of the water input. Runoff and drainage occurred following 2.6 in. of irrigation and 0.5 in. of rainfall on June 5. Runoff from CT was about 4 times that from NT, while drainage from NT was about double that from CT. Soil water content did not rise much as the soil was close to saturation. For the two days, there was 89% more drainage from NT while runoff was again about 4 times more from CT. In an area where short or longer-term drought is common, this is an important result for growers and water resource planners seeking to improve water use and mitigate drought. The finding has great regional importance since Cecil soils occupy over 50% of the 41 million acre Southern Piedmont.

INTRODUCTION

Cecil and related soils occupy over 50% of the 41 million acre Southern Piedmont in Southeastern United States (Radcliffe and West, 2000). Conventional tillage practices, such as moldboard plowing, chisel plowing and disking, that break soil aggregates and leave little or no residue on the surface, have exacerbated soil degradation problems in these highly erodible soils. In addition to degraded soils, growers in the Southern Piedmont must contend with short-term drought common during critical crop growth periods and periodic multi-year droughts. Similar problems across the country led to concerted efforts to develop alternative tillage and residue management methods to protect the land while providing a technically and economically viable solution for growers. Hence, the conservation tillage revolution was born. Use of conservation tillage with cover crops causes minimal soil disturbance and builds soil organic matter, which helps soil to aggregate and increase biological activity. The net effect, often, is increased infiltration, reduced evaporation, and improved water and nutrient availability (Bradley, 1995; Endale et al., 2002; Fawcett et al., 1994; Golabi et al., 1995; Radcliffe et al., 1988). In the US, conservation tillage use grew to 41% of all cropland by 2004 about 23% of which is no-till (CTIC, 2005).

There is continuing need for systematic research under site-specific conditions to quantify soil water availability in different soils in different tillage practices to help growers make informed decision between tillage choices. Our objective was to quantify differences in runoff and drainage of soil water following two long irrigation events in large plots that have been under either eleven years of no-till (NT) or conventional tillage (CT). The soil belonged to the Cecil series.

MATERIALS AND METHODS

The research was conducted from June 4 to 7, 2002, at the USDA-ARS, J. Phil Campbell Sr. Natural Resource Conservation Center in Watkinsville, GA (83°24' W and 33°54' N). The site consisted of twelve 33-ft x 100-ft plots, with subsurface drainage, located on nearly level (0-2% slope) Cecil sandy loam (fine, kaolinitic, thermic Typic Kanhapludults). Cecil soils are deep, well drained and moderately permeable. When not eroded, they have a sandy loam to sandy clay loam surface texture underlain by clay subsoil on top of a saprolite. Bruce et al. (1983) have described in detail the characteristics of the soil at the site.

The plots have been under CT and NT treatment since 1991 in a randomized complete block (split plot) arrangement with three replications. Main plots were divided into CT and NT. Subplots were divided into two fertilizer treatments. In this paper we discuss the main plot arrangements only. The CT consisted of a 12-in. deep chisel plowing followed by one to two diskings to a depth of 8 in. and a subsequent disking to 3 in. to smooth the seedbed. The only soil disturbance in NT was a coulter disk at planting. For the first five years beginning in 1991, CT plots were fallowed in winter while NT plots were under rye (*Secale cereale* L.). Summer crop was corn (*Zea Mays*). During the following 5 years, cotton (*Gossypium hirsutum* L.) was grown in summer and a rye cover crop in winter on both tillage treatments. Another corn-rye cycle was started in 2001. In 2002 corn was planted on May 22.

In this study eight sets of laterals at 33-ft spacing, each with ten risers and sprinkler heads spaced approximately 30 ft, were used for irrigation. Overall, sprinkler heads were on a triangular grid which was expected to give even distribution of irrigation. A set of seventy rain gauges on an approximately 25 x 44-ft grid were used to measure spatial distribution of irrigation and estimate irrigation for each plot. Plots were irrigated from 10:15 AM to 4:15 PM on June 4. A total of 2.2 in. was applied at constant rate. A 0.52 in. rain fell during the night. On June 5, irrigation lasted from 10:00 AM to 5:00 PM and a total of 2.6 in. was applied at constant rate. A 0.48-in. rain fell during the night. Rain gauges were read approximately hourly during irrigation as well as in the mornings of June 5 and June 6 to determine irrigation and rainfall amount and distribution. The irrigation rates were the maximum the system could deliver for the number of sprinkler heads. The two-year, 24-hour maximum rainfall for the area is approximately 3.75 in. (GSWCC, 2000).

To monitor drainage, five 100-ft long drain lines made of flexible, slotted 4-in. diameter PVC had been installed in each plot at 7.5 ft spacing. Drain lines lie on a 1% grade, 2.5 ft deep at the shallow end. All five lines terminate at a collector drain, which delivers the drainage for measurement to a pair of tipping buckets located in a pit. Polyethylene sheeting installed around each plot to the depth of the drain lines isolates each plot from lateral flow. A 33-ft galvanized metal pan installed at the lower end of each plot collects and directs runoff into a 13-ft flume approach. This approach empties into a 0.6-in. HS type flume where runoff is measured.

A CR10X data logger (Campbell Scientific Inc; Logan, Utah) integrated with appropriate sensors automatically monitored runoff and drainage from a pair of plots. Runoff height was measured in the stilling well of the flume with a 2.5 psi depth sensing transducer (Druck Incorporated, New Fairfield, CT). Standard calibration curves were used to convert depth of flow to rate of flow. For drainage, the tipping buckets were calibrated to tip every 1.1 cubic foot (3 L) and were fitted with an encapsulated reed switch to measure the tips. Actual evaporanspiration was estimated by first calculating potential evapotranspiration by the Penman-Monteith method (Allen, 1994), and then applying a crop coefficient of 0.3 – corn about two weeks old.

The soil water balance was calculated as:

$$\text{Input} - \text{Output} = \text{Sink}$$

The input is the sum of the irrigation and drainage. Runoff, drainage and evapotranspiration make up the output. The sink term would then represent change in soil water storage, percolation and errors in measurement. Occasionally there were leaks around the drainage delivery pipe suggesting erosion of soil around some of the drain lines. Sensors sometime malfunction and estimates from a plot have to be made based on values in others under similar treatment. Occasionally manual checks were made for runoff height and the output from the CR10X adjusted accordingly.

To estimate soil water storage directly and compare it with that obtained from water balance calculations, the following approach was adopted. Soil water was measured at one location in each plot on the morning of June 4 prior to start of irrigation using the TDR-based MoisturePoint system (model MP-917, ESI, Vic., BC, Canada). From this measurement average soil water content for each of the 0-6, 6-12, 12-24, 24-36, 36-48 in. depths was determined. Bruce et al (1983) give extensive data set for the soil at the research site for soil water content by depth measured at soil water potentials varying from 0.005 to 15 bar. By 10:00 AM on June 7, drainage was down to about 1.1 cubic feet per hour (one 3 L tip per hour). So this date and time was taken as the cutoff for water balance calculations – about 40hours after the last irrigation. The soil was very wet following about 5.75 in. of rainfall and irrigation in a period of about 48 hours. We did not take soil water readings. Instead we estimated soil water to be that equivalent at 0.030 bar soil water potential for each depth; i.e. between field capacity and total saturation. The net storage was thus estimated as the difference between the initial soil water content and these values integrated down to 48-in. depth.

Analysis of variance was carried out with the General Linear Models Procedure of SAS (SAS Inst., 1990) by separating the data into three 'events'. The first event was represented by irrigation, rainfall and subsequent change in hydrology on June 4. Similarly the second event was for June 5. Event three was taken as the combined hydrologic event of June 4 and 5.

RESULTS AND DISCUSSION

Consistent with previous studies on these soils (Endale et al, 2002; Radcliffe et al, 1988), there was more runoff and less drainage from CT compared to NT plots (Table 1). On June 4, about

2.2 in. of irrigation was applied in six hours (0.37 in. per hour). About 0.5 in. of rain fell during the night. The rain gauge data indicated that both the irrigation and rainfall had a fairly even distribution across the plots. Potential evapotranspiration was about 0.2 in. per day during the experiment. Actual evapotranspiration was estimated as 0.06 in. per day. There was no runoff but drainage occurred both from the day irrigation and night rainfall. There was about 38% more drainage from NT than CT. The sink term in the water balance calculation was about 1.8 in. for CT and 1.6 in. for NT which are statistically different at $\alpha = 0.1$. The larger value in CT suggests these plots possibly had less soil water than NT plots prior to irrigation (Fig. 1).

The next day, about 2.6 in. of irrigation was applied in seven hours. The rate was thus the same as the previous day and indicates the irrigation system to be fairly reliable. Another 0.5 in. of rain fell during the night. In contrast to the previous day, the sink term was now much smaller (0.35 in. CT; 0.04 in. NT – no statistical difference) indicating the soil was near saturation from the previous day of irrigation and rainfall. As a result there was much runoff and drainage. Runoff from CT was about 4 times that from NT, while drainage from NT was about double that from CT (Table 1). The output term of the water balance was about 14% larger from NT.

For the combined irrigation and rainfall events over the two days, there was 89% more drainage from NT while runoff was again about 4 times more from CT. The mean sink term of the water balance equation was 2.2 in. for CT and 1.6 in. for NT, a 36% difference. The net change in soil water content between start of irrigation on June 4 and 10:00 PM on June 7 estimated according to the details given above was 2.68 in. for CT and 1.32 in. for NT. The differences in value between the two approaches fall within experimental errors – about 10% of input in CT and 5% in NT.

CONCLUSIONS

Results from our study support previous findings that no-till in Cecil soils enhances infiltration and reduces runoff. In an area plagued with common short-term drought during critical crop growth periods and periodic multi-year droughts, this is an important confirmation for growers and water resource planners that this system of cropping ought to be embraced and expanded. The finding has a regional application since Cecil soils occupy over 50% of the 41 million acre Southern Piedmont. Two to four fold differences in runoff and/or drainage between no-till and conventional tillage cropping suggests that significant irrigation water and cost savings could be gained by adopting no-till in croplands under irrigation in the region. The data generated in this research could also be used in testing and validating several hydrologic models, and scale issues. Many models are developed from data generated in small plots. Our data were generated from plots several orders of magnitude larger.

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REFERENCES

Allen R.G. 1994. Reference Evapotranspiration Calculator. V2.15. Utah State University Foundation, Utah State University, Logan, UT.

Bradley, J.F. 1995. Success with no-till cotton. p. 31-38. *In* M.R. McClelland, T.D. Valco, and F.E. Frans (ed.) Conservation-tillage systems for cotton: A review of research and demonstration results from across the cotton belt. Arkansas Agric. Exp. Stn., Fayetteville, AR.

Bruce, R.R., J.H. Dane, V.L. Quisenberry, N.L. Powell, and A.W. Thomas. 1983. Physical characterization of soils in the southern region: Cecil. Southern Coop. Series Bull. No. 267. University of Georgia, Athens, GA.

CTIC, 2005. National crop residue management survey. Conservation Technology Information Center, West Lafayette, IN.

Endale, D.M., D.E. Radcliffe, J.L. Steiner, and M.L. Cabrera. 2002. Drainage characteristics of a Southern Piedmont soil following six years of conventionally tilled or no-till cropping systems. Transactions of the ASAE: 45(5): 1423-1432.

Fawcett, R.S., B.R. Christensen, and D.P. Tierney. 1994. The impact of conservation tillage on pesticide runoff into surface water: A review and analysis. J. Soil and Water Cons. 49(2):126-135.

Golabi, M.H., D.E. Radcliffe, W.L. Hargrove, and E.W.Tollner. 1995. Macropore effects in conventional-tilland no-tillage soils. J. Soil and Water Cons. 50 (2):205-210.

GSWCC, 2000. Manual for erosion and sediment control in Georgia, 5th edition. Georgia Soil and Water Conservation Commission. Athens, GA.

Radcliffe, D.E., E.W. Tollner, W.L. Hargrove, R.L. Clark, and M.H. Golabi. 1988. Effect of tillage practices on infiltration and soil strength of a Typic Hapludult soil after ten years. Soil Sci. Soc. Am. J. 52 (3):798-804.

Radcliffe, D.E., and L.T. West. 2000. MLRA 136: Southern Piedmont. Southern Cooperative Series Bulletin #395. University of Georgia, Athens, GA.

SAS Institute, Inc. 1990. SAS/STAT User’s Guide, Ver. 6. 4th ed. SAS Institute Inc. Cary, NC:

Table 1. Statistics for soil water balance in CT and NT plots following irrigation on June 4 and 5, 2006.
All values except count are in inches[1].

	INPUT			OUTPUT				SINK	INPUT			OUTPUT				SINK
Stat	R	I	RI	Ro	Drain	ET	RDP	Delta	R	I	RI	Ro	Drain	ET	RDP	Delta
	June 4, 2006 - CT								June 4, 2006 - NT							
Mean	0.52	2.13	2.65	0.00	0.79	0.06	0.85	1.80	0.51	2.19	2.70	0.00	1.09**	0.06	1.15**	1.56*
STDER	0.00	0.05	0.06	0.00	0.05	0.00	0.05	0.06	0.00	0.05	0.05	0.00	0.10	0.00	0.10	0.09
STDEV	0.01	0.13	0.14	0.00	0.11	0.00	0.11	0.15	0.01	0.11	0.11	0.00	0.25	0.00	0.25	0.23
Min	0.50	1.93	2.43	0.00	0.69	0.06	0.74	1.63	0.50	2.05	2.56	0.00	0.82	0.06	0.88	1.22
Max	0.53	2.28	2.80	0.00	0.98	0.06	1.04	1.99	0.53	2.37	2.88	0.00	1.39	0.06	1.45	1.79
Count	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	June 5, 2006 - CT								June 5, 2006 - NT							
Mean	0.48	2.58	3.06	1.45	1.20	0.06	2.71	0.35	0.48	2.66	3.14	0.36***	2.67***	0.06	3.10*	0.04
STDER	0.00	0.06	0.06	0.16	0.13	0.00	0.19	0.22	0.00	0.05	0.05	0.11	0.14	0.00	0.07	0.09
STDEV	0.00	0.14	0.14	0.39	0.31	0.00	0.46	0.54	0.00	0.13	0.13	0.26	0.34	0.00	0.16	0.22
Min	0.48	2.45	2.93	0.81	0.89	0.06	2.19	-0.41	0.48	2.54	3.02	0.03	2.23	0.06	2.92	-0.22
Max	0.48	2.83	3.31	1.80	1.58	0.06	3.40	0.91	0.48	2.89	3.37	0.76	3.12	0.06	3.36	0.45
Count	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	June 4+5, 2006 - CT								June 4+5, 2006 - NT							
Mean	1.00	4.72	5.71	1.45	1.99	0.12	3.56	2.16	0.99	4.85	5.84	0.36***	3.76***	0.12	4.25**	1.59*
STDER	0.00	0.10	0.10	0.16	0.10	0.00	0.18	0.25	0.00	0.09	0.09	0.11	0.19	0.00	0.13	0.14
STDEV	0.01	0.24	0.25	0.39	0.24	0.00	0.45	0.62	0.01	0.22	0.22	0.26	0.47	0.00	0.31	0.35
Min	0.98	4.43	5.42	0.81	1.69	0.12	2.99	1.22	0.98	4.68	5.68	0.03	3.05	0.12	3.93	1.11
Max	1.01	5.11	6.11	1.80	2.28	0.12	4.20	2.9	1.01	5.26	6.25	0.76	4.41	0.12	4.81	2.12
Count	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6

[1]Statistically significant difference between CT and NT are indicated as * ($\alpha = 0.1$), ** ($\alpha = 0.05$), and *** ($\alpha = 0.001$) in highlighted cells

INPUT: R-rainfall; I-irrigation; RI-I+R. OUTPUT: Ro-runoff; Drain-drainage; ET-evapotranspiration; RDP-ΣOUTPUT

SINK: Delta-difference between INPUT and OUTPUT

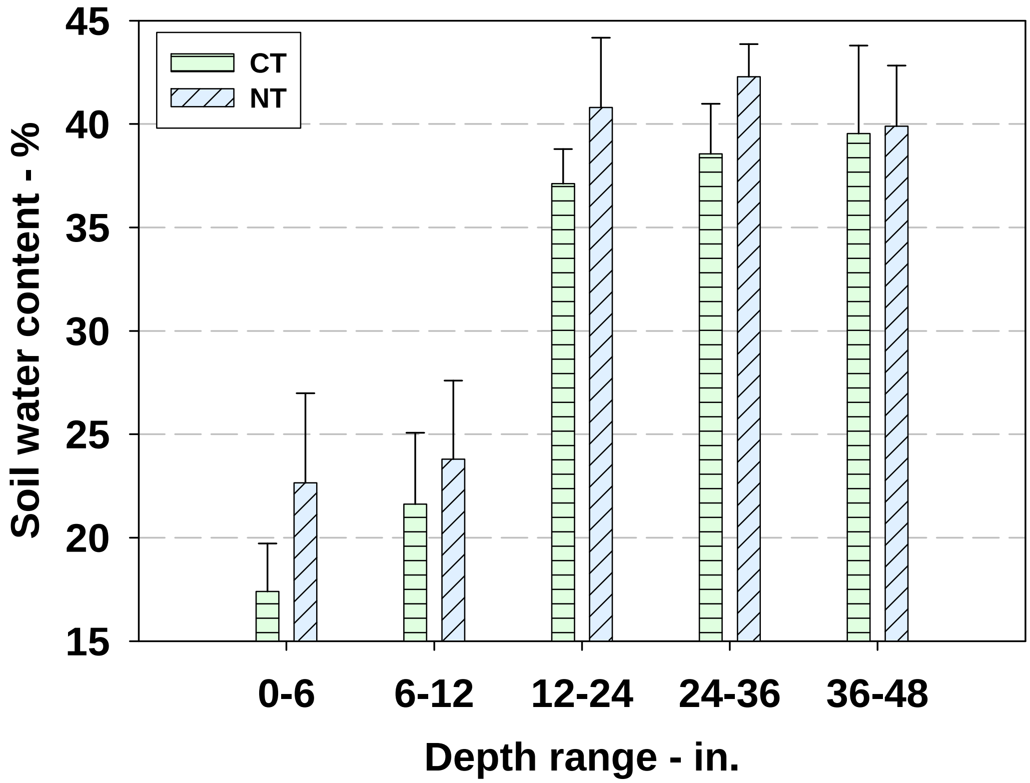

Fig. 1. Mean soil water content in CT and NT plots with standard deviation bars before start of irrigation on June 4, 2002