TILLAGE EFFECTS ON PLANT AVAILABLE WATER, COTTON PRODUCTION AND SOIL/WATER QUALITY

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INTRODUCTION

Conservation tillage has significant potential as a management tool for cotton production on sandy soils that are drought-prone and susceptible to erosion. Planting directly into a residue cover (no-till) or in narrow rows tilled into a residue cover (strip-till) has been shown to reduce erosion and conserve water by enhancing infiltration. This can reduce irrigation requirements and runoff which transports sediment, nutrients, pesticides and other agrichemical residues into surface waters.

While potential benefits of conservation tillage are widely recognized, actual benefits in terms of water conservation and quality vary, depending on numerous factors including soil characteristics, topography, pest pressure, agrichemical use and weather. There is a continuing need for systematic research to provide growers with the best available information on benefits of different tillage systems so that they can make informed choices which will enhance profitability and sustainability while minimizing adverse environmental impacts. To meet this need, a collaborative research effort was established between USDA-ARS-Southeast Watershed Research Laboratory and University of Georgia (UGA) scientists to systematically evaluate impacts of strip-tillage on water quantity and off-site water quality. A 4.6-acre parcel on the UGA Gibbs Farm located in Tift County, GA was selected for the study in 1999. The site was divided into six half-acre plots with a seventh 1-acre plot set aside for companion rainfall simulation studies (Fig. 1). Results of the study are summarized in this report. Differences in water quantity and quality between plots maintained in strip and conventional-tillage are highlighted. Additional details of the study and results can be found in the 1999 and 2000 Georgia Cotton Research and Extension Reports.

MATERIALS AND METHODS

Site Description. The soil is a Tifton loamy sand with a 3 to 4 % slope. Past agronomic practices resulted in substantial soil erosion. General soil properties delineated in a high-intensity soil survey included sandy surface soil to a depth of 10 to 20 inches underlain by dense sandy clay loam and sandy clay whose plinthite concentrations increase with depth. Because of its’ relatively low permeability the subsoil is believed to restrict rooting depth and deep percolation of infiltrating precipitation and to induce lateral subsurface flow.

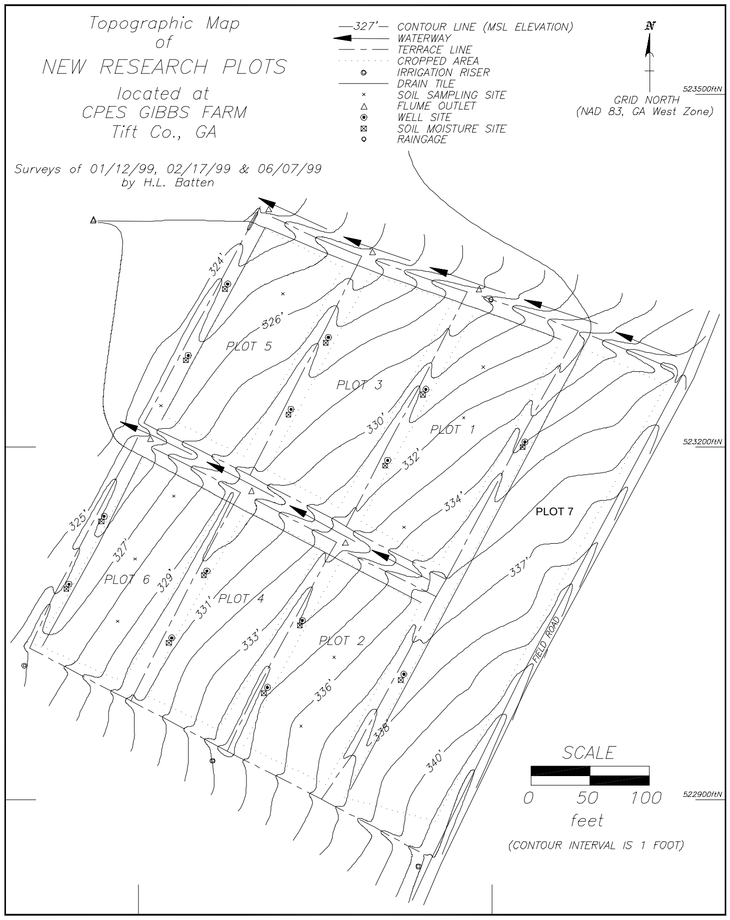


Figure 1. Topographic map of research plots.

Plots 1 to 6, approximately 0.5 acre each, were surrounded by 2.0-ft. earthen berms. The berms facilitated installation of metal runoff flumes equipped with automatic water sample collection and flow monitoring devices. On the down-slope side of each of these plots, 2-in (i.d.) PVC groundwater monitoring wells and soil water monitoring access tubes were used to monitor and sample the groundwater. Additional soil moisture sensors were installed in plots 1 and 2 at two, five, and twelve inches depth, both within the cotton rows and between the rows in March of 2000. These sensors measure soil water within the profile every 30 minutes.

A six-inch (i.d.) tile drain was installed across the slope between the lower boundary of plot 7 and the upper berm of plots 1 and 2 (Fig. 1). The drain was designed to intercept lateral subsurface flow originating on plot 7 and redirect it away from other plots lower on the slope. To capture lateral subsurface flow originating on the remaining plots two separate loops of 6-inch drain tile were installed so that they surrounded plots 1, 3 and

5 and 2, 4 and 6 (Fig. 1). Flumes were installed at the tile drain outlets to measure flow and provide a point for manual water sample collection.

Management. Tillage treatments were assigned as follows: plots 1, 3 and 5, conventional-till; plots 2, 4 and 6, strip-till; plot 7, half strip and half conventional. Cotton was planted in 1999, 2000, and 2001. All were planted with a rye grass cover crop in the fall. Fertilizer and pesticide applications and crop management practices were in accordance with the University of Georgia recommendations. A solid set irrigation system was established in the spring of 2000 and used to supply additional water needs. During the growing season, farm managers irrigated all plots on an as needed basis.

Environmental Monitoring. Precipitation, air and soil temperature, soil water content, surface runoff rates and volumes, lateral subsurface flow rates and volumes (tile drain), and water table elevations have been measured over the study period. During each storm event composite water quality samples were collected from the surface runoff from plots 1 to 6. Water quality samples were collected daily at the tile drain outlets whenever flow occurred. Well samples were collected each month for water quality analysis. All water samples were filtered and analyzed for residues of herbicide and defoliant active ingredients. In the case of the runoff samples, both the water and sediment separated from the samples was analyzed. This provided data on both dissolved and sediment bound concentrations of the target compounds.

Soils from each plot have been sampled intensively each year to look at nutrient and pesticide concentrations. Composite soil samples are collected at four depth increments in the plow layer, 0-1 cm, 0-2 cm, 2-8 cm, and 8-15 cm. Samples were collected one-day before, and one-hour, one-, four-, and seven-days after planting and herbicide application, and every two weeks thereafter until 90 days after planting. This was done so that dissipation of the active ingredients in two pre-emergence herbicides, Cotoran® and Prowl®, could be monitored under field conditions. Fluometuron is the active ingredient in Cotoran® and pendimethalin in Prowl®. Soil samples were collected on a similar schedule after defoliant application in the Fall so that dissipation of the compounds, tribufos and thidiazuron, could be monitored. They are the active ingredients in the defoliants, DEF® and Dropp®. All soil samples were frozen after collection and were being analyzed for fluometuron, pendimethalin, tribufos and thidiazuron, and two fluometuron degradates, desmethylfluometuron (DMF) and trifluormethylaniline (TFA). Selected sub-samples were tested for organic matter content and other physical and chemical properties.

Rainfall Simulation Studies. In the fall (post harvest) of 1999 and 2000 and also in the spring (pre-plant) of 2000 and 2001, a series of 2X3-m subplots were established on plot 7 using aluminum frames. Impacts of tillage on runoff volume and rate, sediment delivery and transport of agrichemicals were evaluated utilizing simulated rainfall applied at 2 inches per hour for one hour. The source of the water was a deep well on the farm. Runoff was collected in 5-minute intervals and analyzed for total suspended sediment and residues of either defoliants or pre-emergence herbicides.

RESULTS AND DISCUSSION

Water Quantity. Rainfall and irrigation totals for the three year study period are shown in Table 1. The long term average rainfall for the area is 48 inches. Total plot water was less than this average for each of the three study years. Rainfall timing, as well as volume, has a significant impact on water losses. In 2000, little rainfall occurred from March to July, the period where runoff would be the most likely and would have the greatest water quality implications. Greater rainfall was received in July through September, 2000. The plots with good cover did not experience significant surface runoff at this time. In 2001, greater rainfall was received early in the growing season, from March through April. As a consequence, this led to greater early season runoff and greater subsurface tile flow. Timely precipitation was received in mid-2001, but the fall was very dry.

Annual plot runoff, expressed as a percentage of rainfall, varied from 3 to 22%. In most years, surface runoff from the conventionally tilled plots was considerably greater than that from the strip-till plots (Table 1). While problems with the instrumentation limited the data collected in 1999, the data that were collected that year indicated there was not the disparity between runoff volume from the two different tillages in the first year of the study that was observed in the later two years. Other studies have indicated that improved infiltration rates often observed with minimum till systems are not immediate. Subsurface runoff as measured from the tile outflow was approximately the same for both the conventionally tilled plots and the strip-till plots. Annual surface runoff losses from the plots varied from 16 to 28% for the conventional-till plots and from 5 to 13% for the strip-till plots.

Table 1. Rainfall and irrigation totals over the study period.

Year	Rainfall (in.)	Irrigation (in.)	Surface Runoff		Subsurface Runoff	
			Conv.-till (% of rainfall)	Strip-till (% of rainfall)	Conv.-till (% of rainfall)	Strip-till (% of rainfall)
1999	36.05	2.64	md*	md	md	md
2000	41.02	4.16	12	3	5	6
2001	34.89	6.00	22	3	14	13
Long term average	47.8	-	-	-	-	-

* md - missing data

Peak surface runoff rates observed from the conventional-till plots were up to 5 times greater than those observed from the strip-till plots when runoff occurred. During individual runoff events, surface runoff volumes were up to 10 times greater from the conventional-till plots.

Soil-water measurements made in the top 12 inches of the profile in plot 1 (conventional-till) and plot 2 (strip-till) indicated that available soil-water in the conventional-till plot was consistently greater than that observed in the strip-till plot. In the fall and spring following tillage the soil-water in the conventional-till plots can be as great as twice that in the strip-till plots (Fig. 2). This difference was observed in both 2000 and 2001. The surface runoff measurements indicate that the strip-till system increased infiltration. This increased infiltration led to decreased runoff, and would theoretically lead to greater plant available water. Our soil-water measurements indicate that this was not the case for the upper root zone. Other studies have found that no-till and minimum-till systems can lead to increased preferential flow. The preferential flow causes the infiltrating water to by-pass the upper root zone. This could lead to the observations we have made at this site. Because we are not observing greater tile flow from the strip-till plots, it appears the water is being held in the vadose zone below the upper 12 inches of the profile. In addition, the soil in the strip-till plots is more compacted. This reduces the pore space available for soil-water.

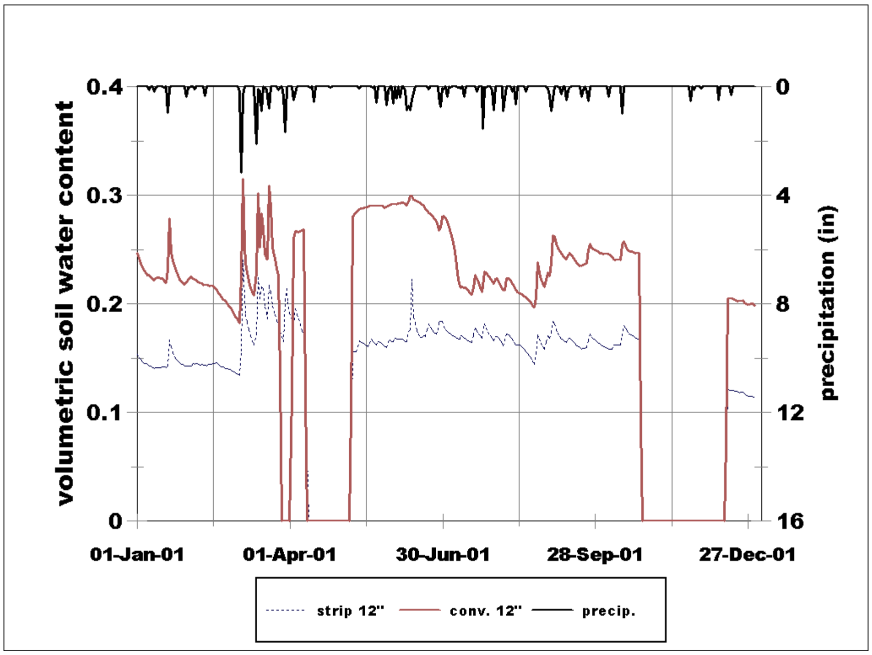


Figure 2. Soil-water differences between the conventional-till and strip-till plots in 2001 at 12 inches depth.

<u>Tillage Effects on Runoff and Erosion</u>. Simulated rainfall studies were used to evaluate how conventional and strip-till systems partition rainfall into infiltration and runoff with subsequent sediment generation. Runoff and sediment were determined gravimetrically, and infiltration was calculated by difference (rainfall–runoff). Data for the rainfall simulation studies are summarized in Table 2. Data collected from the simulation studies indicate the infiltration and runoff characteristics for the different tillages have changed over the course of the study. In the fall of 1999, no differences were observed in the runoff volumes from the two tillage systems. In subsequent

simulations we observed approximately twice the runoff from the conventional-till plots than from the strip-till plots.

Table 2. Summary data for the three simulation experiments, rainfall intensity was 50 mm/hr for 1 hour.

	Fall 1999*		Spring 2000*		Fall 2000*		Spring 2001*	
Property	CT+	ST++	CT+	ST++	CT+	ST++	CT+	ST++
Runoff, mm/hr	13	13	13	6	6	3	12	6
Runoff, %	25	27	27	14	12	6	24	10
Infiltration, mm/hr	38	36	37	38	45	42	38	57
Infiltration, %	75	73	73	86	88	94	76	90
Soil loss, gm	476	257	175	148	339	80	909	190

+ conventional-tillage
++ strip-tillage
* In fall 1999, 3 plots in each tillage were studied. Two plots per tillage treatment were used on all other dates.

Soil loss from the strip-till plots has been consistently lower than from the conventional-till plots. In the spring of 2001 the sediment loss from the conventionally tilled plots was approximately 5 times that lost from the strip-till plots. In the fall of 2000, the soil loss from the conventional-till plots was over 4 times that of the strip-till plots. The lowest differences observed between the sediment lost from the two types of tillages were during the spring of 2000 simulation when we observed only a 15% increase. The strip-till system appears to have the potential to substantially decrease sediment losses.

Herbicide and Defoliant Runoff and Leaching (plot studies). A summary of results obtained for water samples collected in calender year 2000 is shown in Table 3. This was the first year in which sample collection schedules were fully operational. In total, 227 samples were collected and analyzed. A greater number of runoff samples were collected from conventional-till plots while strip-till plots yielded more tile drain samples. Similar trends were observed in 2001. These results will be compiled in next year's report. We also note that thidiazuron results are omitted from Table 3. We have identified a positive interference in its' analysis. Work is on-going to refine the method used for this compound. Our work with Liquid Chromatography-Mass Spectrometry has shown promising results.

In the 2000 samples, two compounds, fluometuron and it's degradate, DMF, were the most frequently detected. They were found in 60 to 70 % of all runoff and tile drain samples. The frequency of detection and maximum residue levels were consistently greater in conventional-till plot samples. Higher residue levels were detected in runoff samples. A preliminary estimate of the fraction of fluometuron lost in runoff indicated that it was 1 to 2 % of that applied. Numerically a greater fraction was lost from the conventional-till plots, but results were not significantly different when compared to strip-till plots. Estimates of the mass loss of fluometruon in the tile drain flow was 0.01 % of that applied. This is reflected in lower tile drain flow when compared to runoff and lower concentrations in the tile drain samples.

Table 3. Herbicide and defoliant residue analysis results of runoff, tile, and well samples: calender year-2000 summary.

	Tile conv.	Tile strip	Well conv.	Well strip	Runoff conv.	Runoff strip
fluometuron						
#detects	28	31	0	0	28	14
max (ug L^{-1})	4.9	2.2	<0.01	<0.01	16.7	8.3
DMF						
#detects	28	33	0	0	22	11
max (ug L^{-1})	2.1	1.4	<0.01	<0.01	6.9	6.9
TFA						
#detects	0	0	0	0	2	1
max (ug L^{-1})	<0.01	<0.01	<0.01	<0.01	0.75	1.2
pendimethalin						
#detects	0	0	0	0	5	1
max (ug L^{-1})	<0.01	<0.01	<0.01	<0.01	0.5	0.2
tribufos						
#detects	0	0	0	0	12	7
max (ug L^{-1})	0.01	<0.01	<0.01	<0.01	11.8	6.8

We conclude from these results that fluometuron is more mobile than the other pre-emergence herbicide used at the study site, pendimethalin. Our data also indicates that DMF forms relatively rapidly after fluometuron application and that it is relatively stable. Formation of TFA from fluometuron was a relatively minor process. It was rarely detected. As we move forward in the study, we expect to refine our picture of fluometuron behavior and develop data which can be used to calibrate simulation models which describe its' fate. These data are critical for accurate risk assessments of fluometuron use.

None of the target compounds were detected in the well samples. This indicates that the slow permeability of the subsurface soil limits downward leaching of pesticides at the site.

<u>Herbicide and Defoliant Runoff (rainfall simulator studies).</u> A summary of results from the fall-1999 rainfall simulation studies are presented in Table 4. Simulated rainfall was applied to three 2X3 meter plots 1 hour after treatment with two defoliant tank mixtures. The short interval between defoliant application and application of simulated rain was designed to determine the maximum amount of the active ingredients which would

runoff. This information is needed for human and ecological risk assessments. As indicated above, tribufos is the active ingredient in DEF®, thidiazuron in Dropp®. We also monitored runoff from some of the small plots for a third compound dimethipin. It is the active ingredient in Harvade®. Taken together, results did not reveal any tillage related differences in chemical runoff losses with the possible exception of dimethpin. The fraction lost in the strip-till treatment was 0.06 whereas it was 0.02 from the conventional-till treatment. However, it is unknown whether the difference was significant since only one plot from each tillage treatment was treated with dimethipin.

Table 4. Summary statistics from the fall-1999 rainfall simulation study: active ingredient application rates, volume-weighted concentrations, and fraction of the chemicals applied lost in runoff.

tillage	strip			conventional		
	avg.	standard dev.	cv %	avg.	standard dev.	cv %
Thidiazuron (n=3 each tillage)						
applied (kg ha^{-1})	0.05	0.008	15	0.04	0.04	100
volume weighted concentration(ug L^{-1})	71	36	51	63	59	94
fraction in runoff	0.17	0.09	52	0.15	0.04	26
Tribufos (n=2 each tillage)						
applied (kg ha^{-1})	0.30	0.05	16	0.06	0.04	61
volume weighted concentration(ug L^{-1})	280	172	61	150	23	15
fraction in runoff	0.14	0.11	82	0.15	0.11	73
Dimethipin (n=1 each tillage)						
applied (kg ha^{-1})	0.39	-	-	0.82	-	-
volume weighted concentration(ug L^{-1})	194	-	-	133	-	-
fraction in runoff	0.06	-	-	0.02	-	-

Notes: cv = coefficient of variation

While tillage did not appear to affect chemical behavior, chemical properties did. This was indicated by comparing the averages (across tillage treatments) of the fraction of each chemical lost. The dimethipin average was 0.04. It was 0.16 for tribufos and 0.15 for thidiazuron. The fraction of dimethpin lost was significantly lower (P=0.001) when compared to the other two chemicals. Possible explanations for the dimethipin behavior include more rapid absorption by the plants. If this were the case, less would be available for wash-off from foliar surfaces. Another possibility was that much more of the dimethpin was leached below the soil surface prior to initiation of runoff, thus becoming unavailable for runoff. Dimethipin is 100 times more soluble in water than thidiazuron and 1000 times more soluble than tribufos.

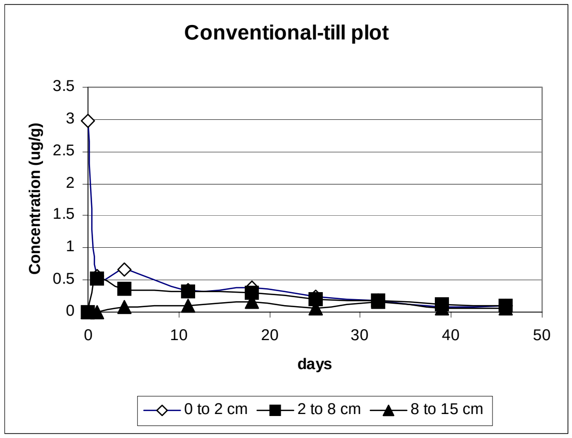
Overall, results showed that differences in the amount of defoliants lost in runoff may be strongly influenced by properties of the active ingredients. Much more of tribufos and thidiazuron (>3 X) was detected in the runoff than the dimethipin. The study also showed that the mass lost in runoff of the later two compounds can be as high as 15% of that applied under a worst-case scenario where an intense storm occurs soon after application.

Results from the spring rainfall simulation studies indicate that cover-crop residue intercepted up to 80% of the herbicide sprays. Herbicide runoff from conventional-till plots was 3 to 10X greater than on strip-till plots. Pendimethalin runoff losses were 0.1% (strip) to 1.2 % (conventional) of the amount applied while fluometuron losses were 0.05 % (strip) and 0.2 % (conventional). Data showed a strong positive impact of the tillage treatment on loss of these compounds.

Herbicide and Defoliant Dissipation in Soil. Degradation and dissipation of the fluometuron in the soil is relatively rapid ($t_{1/2}$ = 10 to 15 days) at the site. Although some leaching of the fluometuron was observed, it is a relatively minor process in terms of the mass of the chemical applied to the plots. The concentration of the fluometuron detected at the bottom of plow layer was much lower than in the surface soil (Fig. 3). In addition, the compound was detected only at trace levels in tile drain samples and was not detected in samples pulled from the monitoring wells. Results support the conclusion that the low leaching rate was directly attributable to rapid soil degradation.

Similar results were obtained with the defoliant tribufos. Field dissipation half-lives were even less, 1 to 3 days. Its' relatively rapid degradation and or volatilization provided likely explanations. Both processes remove tribufos from the surface soil and therefore reduce its' potential for runoff. Nevertheless, as indicated in table 4, the compound was detected in runoff samples. The levels detected were above toxic thresholds for aquatic invertebrates. Thus ecological impacts may result if runoff enters streams and rivers directly. These findings motivated a study on the efficacy of grass -filter strips in removing tribufos from runoff. Preliminary results were positive. Concentrations of edge of filter strip samples were 5 to 36 times lower then edge of filed samples (Potter et al, 2001). An update on this work is provided in separate chapter in this report.

Crop-performance. Yields for 2001 are summarized in Table 5. Lint yields averaged 1260 lbs/ac. for the conventional-till plots and 1345 lbs/ac. for the strip-till plots. Yields from plot 6 have been consistently lower than the other plots. If this plot is removed from the average for the strip-till plots, the average is then approximately 1460 lbs/ac.



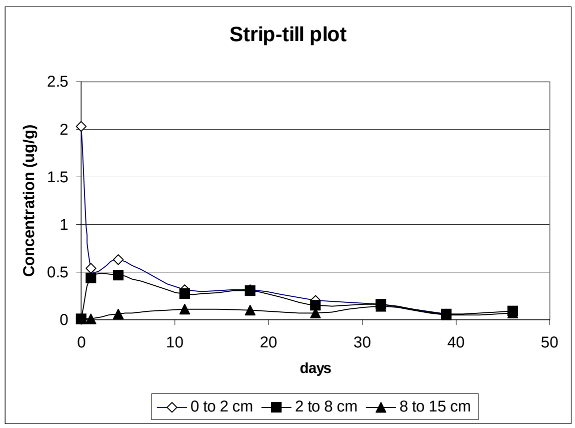


Figure 3. Concentration of fluometuron in soil as a function of time and depth in the plow layer.

Table 5. 2001 Cotton yields.

plot #	tillage	seed cotton lbs/ac	lint yield, 38% turnout lbs/ac
1	conventional	3609	1371
2	strip	3803	1445
3	conventional	3379	1284
4	strip	3939	1497
5	conventional	2709	1030
6	strip	2632	1000
7	strip	3782	1437
7	conventional	3568	1356

SUMMARY AND CONCLUSIONS

Significant differences in water quantity, water quality, and crop yield have been observed between conventional- and strip-till treatments. Infiltration in the strip-till plots has been greater. As a consequence, runoff and sediment loss from these plots was lower than that observed in the conventional-till plots. Herbicide losses from the conventional-till plots was also greater. Additional findings include:

1. Greater runoff was observed from conventional-till plots.
2. Total sediment and maximum sediment delivery rates in runoff were greater from conventional-till plots.
3. Greater infiltration rates were observed on the strip-till plots.
4. Greater soil-water contents were observed in the top 12 inches of the soil profile of the conventional-till plots.
5. Peak surface runoff due to natural rainfall was up to five times greater on conventional-till plots.
6. More fluometuron, the active ingredient in the pre-emergence herbicide Cotoran, reached the soil surface during application on conventional-till plots; however, higher rates of evaporative loss rapidly reduced levels to those found on strip-till plots.
7. Fluometuron leached at higher rates on the strip-till plots but, leaching accounted for only a small fraction of that applied.
8. The highest rate of fluometuron loss from the plots was in surface runoff. It accounted for 1 to 2 % of the active ingredient applied.
9. In soil, fluometuron is rapidly converted to DMF. Its' stability appears to be similar to that of fluometuron. Formation of TFA appears to be a relatively minor process.
10. Fluometuron was more mobile than the other pre-emergence herbicide used at the site, pendimethalin.
11. Up to 15 % of the defoliants, tribufos and thidiazuron, applied was detected in runoff from small plots when simulated rainfall was applied 1 hour after defoliant application. In the same study only 4 % of another defoliant, dimethipin, was carried from the plots in runoff.
12. No differences in the rate of defoliant loss was observed between the two tillage treatments.
13. While overall yields from the plots have been relatively low, yields from the strip-till plots have been equal to or greater than those observed from the conventional-till plots.

In summary, findings indicated that strip-till led to increased infiltration and reduced sediment transport and runoff when compared to conventional-till. Some potentially negative observations associated with strip-till included enhanced herbicide leaching and lower soil water contents in the upper root zone. As subsequent crops are produced on the plots and environmental monitoring continued, more definitive data will be available to evaluate positive and negative aspects of strip-till versus conventional-till. These results should be of interest to growers and water managers who are concerned with optimizing water use to lower production costs and at the same time protect water quality.

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