TILLAGE EFFECTS ON SURFACE AND GROUNDWATER QUALITY IN LOESSIAL UPLAND SOYBEAN WATERSHEDS

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ABSTRACT. *Evaluation of tillage practices on surface and subsurface water quality is essential for conserving and protecting the nation's soil and water resources. The objective of this research was to evaluate the water quality of perched groundwater (0.15 to 3.04 m) and surface runoff from a 2.13 ha no-till and a 2.10 ha conventional-till soybean watershed for plant nutrients during the 1990-1993 water years. Mean nitrate-N concentrations for all groundwater depths and sites of the no-till and conventional-till watersheds were 4.81 and 5.98* $mg \cdot L^{-1}$*, respectively. Shallow groundwater* NO_3*-N concentrations for some storms exceeded U.S. Drinking Water Standards. However, in a forested riparian zone, only 61 m down slope from the conventional-till watershed, the mean* NO_3*-N concentration in groundwater was only 0.29* $mg \cdot L^{-1}$*. Higher nutrient concentrations in surface runoff from the no-till watershed reflect the lack of sediment to sorb soluble* PO_4*-P as well as the leaching of crop and weed residues. Despite greater runoff from the conventional-till watershed, soluble nutrient losses were generally similar from the no-till watershed due to the higher nutrient concentrations. Nutrient concentrations in surface runoff from both watersheds peaked a few days after a broadcast application of 0-20-20 and decreased during subsequent storms. Alternative methods of fertilizer application are needed to reduce nutrient concentrations in surface runoff.*

Keywords. *Tillage, Agricultural practices, Chemical application, Surface runoff, Groundwater pollution.*

Groundwater contamination by chemical fertilizers has been documented by various federal and state agencies in the United States and Canada (Goss and Goorahoo, 1995; Hamilton and Helsel, 1995; Kanwar, 1990; National Research Council, 1989; Hall et al., 1989; Kanwar et al., 1988; Brinsfield et al., 1987; Canter, 1987; Oakes et al., 1981; Gast et al., 1978). In Mississippi, groundwater constitutes 54% of all the freshwater and is the water supply of 93% of the population (Mississippi Groundwater Quality, 1986). In Mississippi's sparsely populated agricultural areas, groundwater contamination has not been considered a major problem. However, Mississippi's groundwater is susceptible to contamination due to the very permeable soils, shallow depth to groundwater, and large annual rainfall. Water quality information for most of the state is limited to a very few organic and inorganic compounds and is considered inadequate for the principal aquifers. Data is lacking on any potential agrichemical contamination of groundwater underlying the agricultural areas of Mississippi (Mississippi Groundwater Quality, 1986). Evaluation of farm management (tillage practices) on surface and subsurface agrichemical transport and on water quality is essential to conserving and protecting the state's and the nation's soil and water resources.

The three basic nutrients applied to crops are nitrogen, phosphate, and potassium. The only fertilizer nutrient believed to create significant groundwater contamination problems is N fertilizer as K and P are not highly soluble and are easily adsorbed to soil particles which prevents leaching. Nitrogen fertilizer accounts for half of the U.S. fertilizer usage. Fertilizer use in the U.S. has grown rapidly, increasing by 300% between 1960 and 1980, with the use of nitrogen increasing most rapidly at over 400%. Across the U.S., average fertilizer N rates to corn increased from 73 $kg \cdot ha^{-1}$ in 1967 to 151 $kg \cdot ha^{-1}$ in 1982 (Council for Agricultural Science and Technology, 1985). In the past, crops removed more N than was applied as commercial fertilizer; however, because of increased N fertilization rates in recent times, this trend has reversed. Now only about 60% or less of the N fertilizer applied is used by the crop in the year of application (Hallberg, 1987). The remainder is lost through leaching, washoff, volatilization, or stays in the soil profile (Tindall et al., 1995). The best known health problem caused by nitrates is methemoglobinemia, or blue baby disease. The current U.S. Drinking Water Standard for nitrates of 10 mg nitrate-N per liter is based on protecting against this disease. The type of tillage, as well as fertilizer N rates, application methods, and usage, may influence the movement of agrichemicals through the soil profile.

A major shift has occurred during the last decade by U.S. farmers away from conventional tillage, such as moldboard plowing, toward systems with reduced tillage, various versions of which are collectively termed conservation tillage. This tillage has been defined by the Natural Resources Conservation Service as providing 30% or more crop residue cover on the land surface at the time of planting, and the most recent statistics indicated that

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about 30% of cropland in the continental United States was planted with some form of conservation tillage.

By the year 2000, some 60 to 70% of all U.S. cropland will employ some type of conservation tillage. For much farm land, conservation tillage may be the only way to reduce soil erosion to acceptable limits as provided by the Food Security Act of 1985. Conservation tillage has proven to minimize nonpoint contamination of surface water by reductions in runoff and erosion, but it also increases infiltration, and hence the potential for increased leaching of nitrates. Research is needed to determine the extent of chemical leaching to groundwater as a function of tillage practices. Therefore, a field study was started to understand the relationships among agricultural practices (tillage and chemical application), surface runoff (soil erosion), and groundwater pollution. The primary objective of this article is to quantify the concentrations of nutrients found in shallow groundwater and in surface runoff for specified tillage conditions.

Materials and Methods

This research was conducted on the Nelson Research Farm near the town of Como in Tate County in the northern part of the state of Mississippi. The study area includes watersheds number one and two which are 2.13 and 2.10 ha in size, respectively (fig. 1). These watersheds consisted of loess soils within the Loring-Grenada series. A genetic fragipan existed 0.3 to 1.0 m below the soil surface, depending upon location within the watershed. Prior to 1987 the watersheds were idle land with only limited cattle grazing with no fertilizer applications. During the 1988 and 1989 cropping years, both watersheds were in minimum-till soybeans; for the 1990-1993 water years (WYs), watershed 1 was in no-till soybeans and watershed 2, conventional-till soybeans. In the fall of 1987, the watersheds received a one time N fertilizer application of 45 $kg \cdot ha^{-1}$ as NH_4-NO_3 and were planted to winter wheat. No N fertilizers have been applied since that time. Each spring before planting in 1988-1990, 0-20-20 fertilizer was broadcast applied to both watersheds at a rate of 224 $kg \cdot ha^{-1}$; and 280 $kg \cdot ha^{-1}$ during the 1991 cropping year. In the 1992 and 1993 cropping year, 0-26-26 fertilizer was broadcast applied to both watersheds at an application rate of 174 $kg \cdot ha^{-1}$.

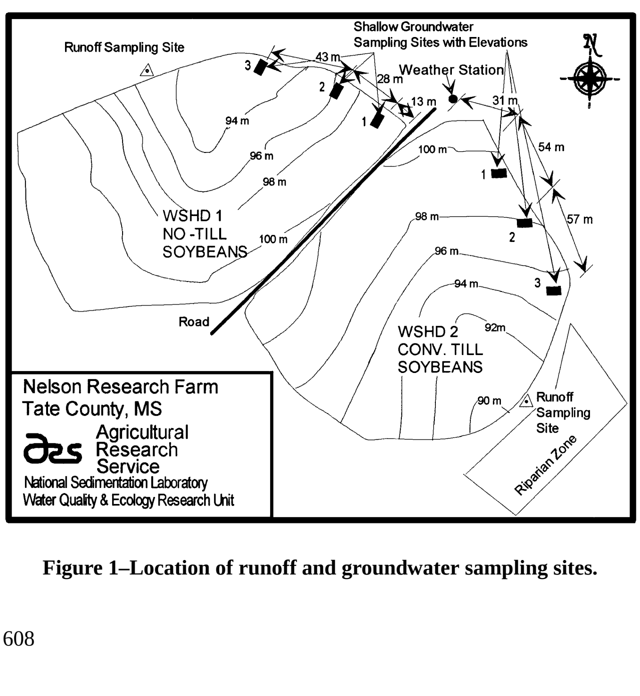

Figure 1–Location of runoff and groundwater sampling sites.

Each watershed outlet was instrumented for automatic data and discharge-weighted composite sample collection as described in detail by Grissinger and Murphree (1991) and Cullum et al. (1992). Three shallow groundwater sampling sites were located along one edge of each watershed to minimize disturbance to the watershed by foot traffic during sampling (fig. 1). Detailed descriptions of the groundwater sampling sites and of the runoff and groundwater sampling and handling procedures were reported previously (Schreiber, 1992). Runoff is reported for the 1990-1993 WYs. However, in the 1990 WY (1 Oct.-30 Sept.), runoff was sampled only from the no-till watershed.

Unless otherwise indicated, all chemistry data reported in this manuscript are from groundwater obtained from the observation wells at 0.15, 0.30, 0.46, 0.61, 0.91, 1.22, 1.52, and 3.04 m depths into the soil profile. At planting time, those portions of a crop row containing instrumentation were hand planted and cultivated as required. All groundwater sampling instrumentation was covered during fertilizer or pesticide applications. In this manuscript groundwater data are reported for the 1990-1993 WYs. However, in the 1990 WY, groundwater samples were collected only from the no-till watershed. During the 1990 WY just about all storm events were sampled for groundwater. In subsequent years storms were selectively sampled for groundwater, but concurrently for both watersheds.

Prior to chemical analysis, all samples were filtered using a 0.45 µm Millipore filter. Runoff and groundwater samples were analyzed for soluble PO_4-P and NO_3-N using a Dionex HPLC equipped with an AS4A anion column, an anion micromembrane suppressor, and a conductivity detector. Samples were analyzed for NH_4-N using the automated colorimetric phenate method (Technicon, 1973).

Nonparametric tests were used because, in general, sediment and nutrient concentrations and losses were not normally distributed as determined by Lillifor's test (Conover, 1971). The Kolmogorov-Smirnov two sample test statistic, T_1 (Conover, 1971), was used to test the null hypotheses: there was no significant difference in sediment or nutrient concentration or loss distribution functions for the no-till or conventional-till methods. T_1 is the greatest distance between the two empirical distribution functions. Tests of significance were made at the 0.05 probability level (Conover, 1971; Sanders et al., 1983).

Results and Discussion

Hydrologic Attributes of the Study Watersheds

Total precipitation for the 1991 WY was 1783 mm, 34% greater than the 30-year mean. This compares with precipitation of only 1281 for the 1990 WY and 1384 for the 1992 WY. In the final study year, 1993 WY, precipitation was 1126 mm, just about equal to the 30-year mean (table 1).

In the 1990 WY, runoff from the no-till watershed was only 330 mm compared to 690 mm in the 1991 WY. Runoff from the conventional-till watershed was much greater at 900 mm in the 1991 WY. Similarly, for the 1992

Table 1. Some hydrologic attributes for two soybean watersheds

Tillage Practice	Rainfall (mm)	Runoff (mm)	Groundwater Samples (no.)
No-till			
1990	1281	330	236
1991	1783	690	169
1992	1384	357	122
1993	1126	189	183
Conventional-till			
1991	1783	900	86
1992	1384	460	48
1993	1126	236	100

WY runoff from the no-till watershed was only 357 mm compared to 460 mm for the conventional watershed. In the final year of study, the 1993 WY, runoff from the no-till watershed was 189 mm compared with 236 mm for the conventional-till watershed (table 1).

Once the soil profile became saturated, groundwater samples were easily obtained, particularly from observation wells > 0.61 m. For the 1990 WY, profile saturation occurred in the no-till watershed about mid-January, after a total of 220 mm of rainfall from the start of the WY compared to the beginning of December after a total of 191 mm of rain during the 1991 WY. In contrast, an additional 197 mm of rainfall was required before shallow groundwater was detected in the observation wells of the conventional-till watershed, about mid-December (1991WY). In addition, during the 1991 WY, 169 samples were obtained from observation wells of the no-till watershed compared with only 86 samples for the conventional-till watershed (table 1). For the 1992 WY, the first groundwater samples were obtained from both watersheds on 4 December 1991 after a total of 240 mm of rainfall from the start of the water year. As during the previous WY, 122 samples were obtained from the observation wells of the no-till watershed compared with only 48 samples for the conventional-till watershed (table 1). During the 1993 WY the first groundwater samples were obtained on 2 November from the no-till watershed after 79 mm of total rainfall had occurred. In contrast, another 81 mm of rainfall was needed before groundwater was obtained from the conventional-till watershed. As in the other WYs, almost twice as many groundwater samples were obtained from the no-till watershed (table 1). Increased infiltration is thought to be one factor for the greater abundance of shallow groundwater in the soil profile of the no-till watershed. Soil surface seal on the conventional-till watershed may be another. The distribution of water in the observation wells for both watersheds after a typical storm event is shown in figure 2. These data show the tendency of groundwater to pond above and within the fragipan located 0.61 to 0.91 m below the soil surface.

The overall contribution that macropore flow has on groundwater contamination is probably insignificant due to the fragipan layer found in many soils of north Mississippi, even though these macropores provide pathways for water to penetrate vertically deeper into the soil profile by gravity than the wetting front established by Darcian principles or mass transport at field capacity. The fragipan layer, characterized by high bulk densities, very low hydraulic

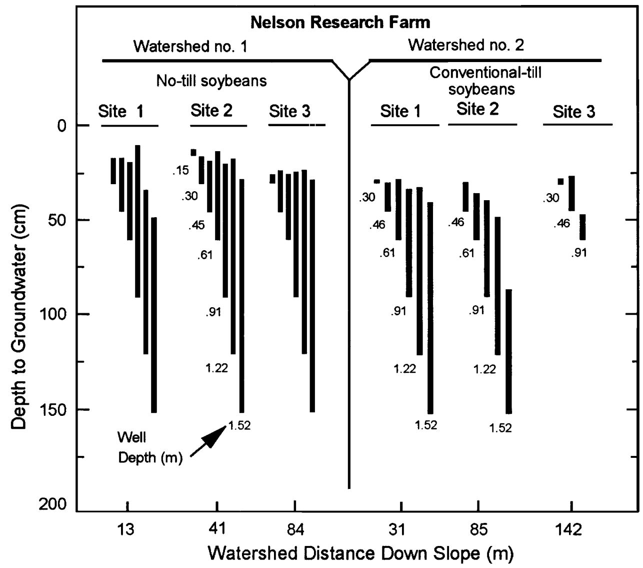

Figure 2–Groundwater in observation wells after a typical storm event.

conductivities, brittleness, compactness, and absence of fine feeder roots in the brittle portion (Soil Survey Staff, 1975), impedes the vertical movement of water into the soil profile. Rhoton and Tyler (1990) and Römkens et al. (1986) showed higher bulk densities of the fragipan layer when compared to the layer above the pan. As bulk density increased, the number and size of pores decreased which reduced the saturated hydraulic conductivity. Römkens also noted a decrease in silt content and an increase in clay content in the deeper parts of the soil profile which would further retard Darcian flow. Lateral water movement along the surface of the fragipan is suspected (Römkens and Grissinger, personal communication, 1993). The excess water (difference of Darcian flow in layer above fragipan to that within the fragipan) either enters large cracks in the fragipan to continue its downward movement or exits down slope onto the soil surface to enter streams as surface runoff. If these cracks are not continuous through the fragipan, the water in the cracks enters into the soil matrix of the unsaturated soil layer above the pan to be used by the growing crop or into the slower moving Darcian flow in the fragipan layer.

Fragipan horizons that retard the downward movement of water are found in the Loring-Grenada soil series at the interface between the relatively friable Peoria upper loess layer and the more dense, brittle Roxana loess layer of the uplands of northern Mississippi (Schreiber et al., 1993). These horizons are believed to have formed at uniform depths, perhaps due to a relic of pre-Peorian weathering of the Roxana paleosurface (Buntley et al., 1977; Grissinger et al., 1982). Surface drainage normally occurs westerly to the Mississippi alluvial valley. Bulk densities tended to increase from 1.3 to 1.5 Mg/m^3 with soil depth, being more pronounced at the fragipan location. Saturated hydraulic conductivity values for the Loring soil layer above the fragipan were generally of the order of magnitude of 1 mm/h and at the fragipan of 0.1 mm/h. Schreiber et al. (1993) found these soils were moderately permeable in layers above the fragipan and slowly permeable in the fragipan due to the differences in the hydraulic characteristics between the two soil horizons. Römkens et al. (1986) found that the free water above the fragipan, that is above the Roxana, seemed to move laterally rather than vertically. Low tension water was shown to accumulate at the top of the fragipan and field studies at Holly Springs (Schreiber et al., 1993) concur with Römkens et al. (1986) in that excess waters tend to flow laterally across the fragipan surface (Grossman and Carlisle, 1969).

Soil properties such as texture, porosity, organic matter content, clay mineral content, and moisture content influences the fate and transport of water (Römkens et al., 1986) and subsequently, pesticides in the subsurface environment. Sandy soils with low clay content provide a higher potential for pesticides leaching than silt soils (Baver, 1966). However, silts and clays, which have a number of macropores and fissures, enhance the potential for preferential flow (short-circuiting Darcian flow) of water and dissolved pesticides to groundwater.

Nutrients in Shallow Groundwater

The mean nutrient concentrations in the groundwater by watershed for all sites/depths for the 1991-1993 WYs are presented in table 2. Data for the no-till watershed are also presented for the 1990 WY, but are not used in the calculation of mean values. As expected, with the exception of NO_3-N, nutrient concentrations in groundwater were lower than those in runoff for the study periods (tables 2 and 3). Although mean nutrient concentrations (table 2) in groundwater for the no- and conventional-till watersheds appeared to be similar in the 1991-1993 WYs, only the distribution functions of NH_4-N concentrations for all sites and depths were the same (5% level). Nitrate-N concentrations in groundwater for the conventional-till watershed were higher than those observed for the no-till watershed during the 1991-1992 WYs and differed significantly each WY. During the 1993 WY, the distribution functions of NO_3-N concentrations were also significantly different, but with NO_3-N concentrations higher for the no-till watershed. In this present study, soybean residues, tops and roots, are suspected as the NO_3-N source. No N fertilizers have been applied to the watersheds since 1987. Other research (Staver and Brinsfield, 1989) has shown that one of the primary factors that determines the magnitude of N leaching losses to groundwater is the availability of soluble N forms, especially nitrate, in the upper soil profile after soybean harvest. In addition, legumes may cause a greater availability of NO_3-N in the root zone and hence can promote significant nitrification and NO_3-N leaching (Groffman et al., 1987). Furthermore, the use of conservation tillage may result in increased infiltration rates due primarily to the formation of macropores in the soil, and thus increasing the likelihood of chemicals leaching beyond the root zone (McCormick and Algozin, 1989).

In general, both watersheds produced higher NO_3-N concentrations at all depths during the winter months which decreased during the spring most probably due to (1) continual leaching of the soil profile, (2) nutrient uptake by a prolific late winter-early spring growth of native vegetation, and (3) denitrification (fig. 3). For most sites on both watersheds, NO_3-N concentrations were higher at the 1.52 m depth compared with shallower depths which may

Table 2. Nutrient concentrations in shallow (< 3.04 m) groundwater from soybean watersheds and a riparian zone

Tillage Practice	Nutrients PO_4-P (mg L^{-1})	NH_4N (mg L^{-1})	NO_3-N (mg L^{-1})
No-till			
Groundwater 1990	0.05	0.08	11.56
Groundwater 1991	0.06	0.10	4.50
Groundwater 1992	0.05	0.11	4.09
Groundwater 1993	0.05	0.11	5.56
$\bar{x}$*	0.06	0.11	4.81
Conventional-till			
Groundwater 1991	0.04	0.11	5.83
Groundwater 1992	0.04	0.10	8.06
Groundwater 1993	0.04	0.09	5.11
$\bar{x}$*	0.04	0.10	5.98
Riparian zone			
Groundwater 1991	0.03	0.08	0.38
Groundwater 1992	0.03	0.06	0.29
Groundwater 1993	0.03	0.17	0.20
$\bar{x}$*	0.03	0.10	0.29

* Mean nutrient concentrations only for the 1991-1993 WY time period of all sites and depths.

Table 3. Solution nutrient concentrations and losses in surface runoff from soybean watersheds

Tillage Practice	Concentration PO_4-P (mg·L^{-1})	NH_4-N (mg·L^{-1})	NO_3-N (mg·L^{-1})	Losses PO_4-P (kg·ha^{-1})	NH_4-N (kg·ha^{-1})	NO_3-N (kg·ha^{-1})
No-till						
Runoff 1990	0.56	0.15	0.28	1.21	0.54	1.06
Runoff 1991	0.55	0.24	0.64	3.80	1.63	4.39
Runoff 1992	0.57	0.34	0.64	2.02	1.21	2.27
Runoff 1993	0.63	0.29	0.89	1.19	0.54	1.69
$\bar{x}$*	0.57	0.26	0.63	2.06	0.98	2.35
Conventional-till						
Runoff 1991	0.09	0.12	0.53	0.80	1.11	4.72
Runoff 1992	0.07	0.23	0.28	0.33	1.01	1.25
Runoff 1993	0.13	0.20	0.79	0.31	0.47	1.86
$\bar{x}$*	0.09	0.16	0.50	0.48	0.86	2.61

* Discharge-weighted mean nutrient concentrations from all surface runoff samples.

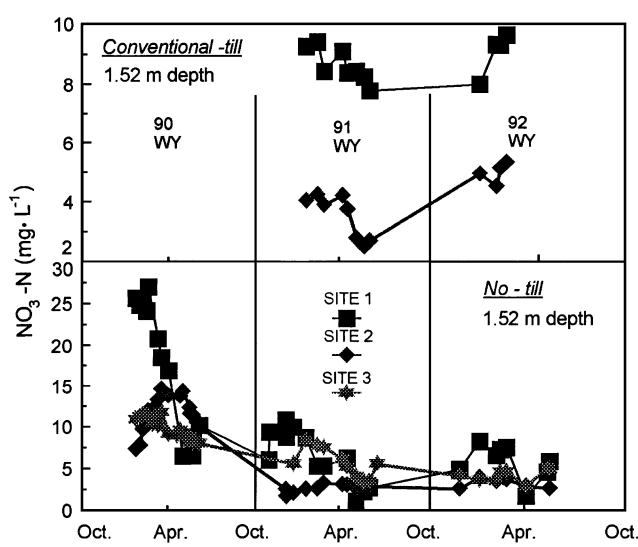

Figure 3–Seasonal nitrate-N concentrations in groundwater from soybean watersheds. No additional groundwater was observed after April at 1.52 m depth in conventional-till.

be an indication of NO_3-N accumulation with time. In general for both watersheds for the study period, distribution functions of NO_3-N concentrations were similar at well depths of 1.52 m or greater.

During the 1990 WY, no-till shallow groundwater NO_3-N concentrations for some storms exceeded the U.S. Drinking Water Standard (10 $mg \cdot L^{-1}$ NO_3-N) by as much as a factor of 2.7 (fig. 3). In fact, for all sites and depths, 59% of all NO_3-N concentrations exceeded the nitrate-N standard. As the watersheds were in idle pasture prior to 1987, microbial degradation of accumulated organic matter, along with the one time NH_4-NO_3 application, are the suspected sources of nitrate nitrogen. In contrast, for the 1991 WY, only 3 and 2% of all NO_3-N concentrations from the no-till and conventional-till watersheds, respectively, exceeded the standard, compared with 1 and 23%, respectively, during the 1992 WY. Furthermore, compared with the 1990 WY, the mean NO_3-N concentration in groundwater for the no-till watershed decreased by 61% during the 1991 WY (fig. 4). Continued NO_3-N leaching from the soil profile by a higher than normal rainfall during the 1991 WY is probably the main reason for decreased NO_3-N concentrations in groundwater. In the final study year, 1993 WY, 10 and 5% of all NO_3-N concentrations from the no-till and conventional-till watersheds, respectively, exceeded the standard, compared with 23 and 8%, respectively, for the entire study period, 1990-1993 WYs.

In one study of conventional-till soybeans, 39 out of 44 groundwater samples exceeded the nitrate-N standard of 10 $mg \cdot L^{-1}$ (Magette et al., 1989). Groundwater at a 1.5 m depth under corn that received N fertilization showed NO_3-N concentrations to be about 18 $mg \cdot L^{-1}$ (Weil et al., 1990). Drainage from Ohio alfalfa over a two-year period averaged 1.5 $mg \cdot L^{-1}$ NO_3-N compared with 4.9 to 32.8 $mg \cdot L^{-1}$ measured under soybeans (Logan et al., 1980). The water quality conditions in surficial unconsolidated aquifers were assessed in five agricultural areas in the United States. Nitrate-N exceeded the water quality standard in 12 to 46% of the wells. In general, nitrate concentrations were elevated in the upper 100 to 200 feet (Hamilton and Helsel, 1995). In Ontario, Canada, about 14% of the wells exceeded the water quality standard (Goss and Goorahoo, 1995). In contrast to the watersheds of this present study, NO_3-N concentrations in groundwater of a forested riparian zone, only 61 m downslope from the conventional-till watershed, were much lower (table 2).

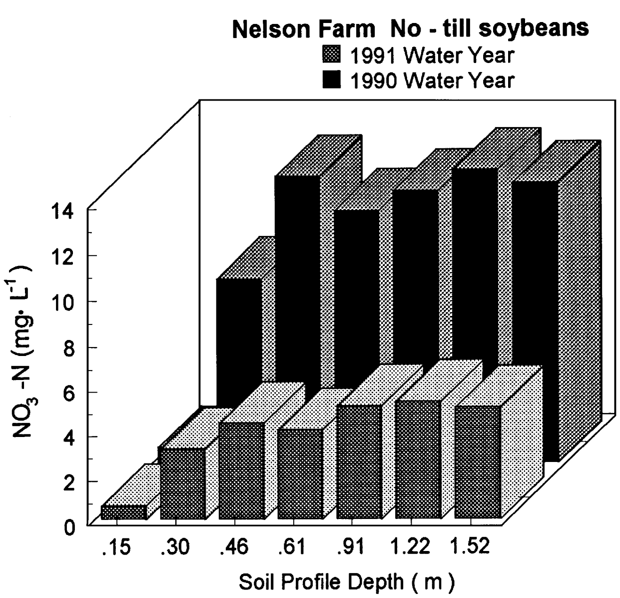

Figure 4–Nitrate-N in shallow groundwater under no-till soybeans (WY mean concentrations for all sites).

For all sites and depths, the 1991-1992 WY mean NO_3-N concentration in shallow riparian groundwater was only 0.29 $mg \cdot L^{-1}$ (table 2). Other nutrient concentrations in the riparian zone groundwater are also presented (table 2). The riparian zone is located downslope and adjacent to the conventional-till watershed (fig. 1). These much lower NO_3-N concentrations can be attributed to vegetative uptake, denitrification, and dilution by shallow groundwater within the riparian zone. Other research has shown riparian zones to be very effective areas by which to reduce high NO_3-N concentrations in agricultural runoff and groundwater flow (Jacobs and Gilliam, 1985). In the Southeast, natural remediation plays a dominant role. Groundwater is generally not contaminated with NO_3-N due to vegetative uptake and denitrification as a result of a wet, warm, and C rich environment (Spalding and Exner, 1993). Riparian zone research in New Zealand indicates that runoff returned to streams was depleted in sediment nutrients and dissolved N, but was enriched in dissolved P (Cooper et al., 1995).

Soluble Nutrients in Surface Runoff

The mean discharge-weighted plant nutrient (soluble) concentrations in surface runoff for the study period are presented in table 3. In general, for each WY of the study period, nutrient concentrations were similar in surface runoff for each respective tillage system. The higher nutrient concentrations in runoff from the no-till compared with the conventional-till watershed during the 1991-1993 WYs are most likely due to the leaching of accumulated soybean and weed residues. The distribution functions of PO_4-P concentrations in runoff differed significantly between the tillage systems for all WYs. In addition, the distribution functions of NH_4-N differed significantly during the 1991 WY, and those of NO_3-N for the 1992 WY. Soluble PO_4-P concentrations in runoff from the no-till soybean watershed exceeded those from the conventional-till by a factor of five to eight (table 3). The much higher suspended sediment in runoff from the conventional-till watershed would sorb soluble phosphorus, thereby reducing soluble PO_4-P concentrations in runoff. For example, during the 1991 WY, the mean discharge-weighted suspended sediment concentrations in runoff from the no- and conventional-till watersheds were 67 and 3569 $mg \cdot L^{-1}$, respectively. In addition, the application of fertilizer to no-till surface organic residues, relatively low in aluminum and iron compounds which tend to tie-up phosphorous, could also contribute to higher soluble phosphorous concentrations.

In general, plant nutrient concentrations in runoff showed similar seasonal trends for both tillage systems (fig. 5). Lowest nutrient concentrations in runoff were observed during the winter and early spring months, a time period of minimal microbiological activity. During the 1990 WY, the largest nutrient concentrations for PO_4-P and

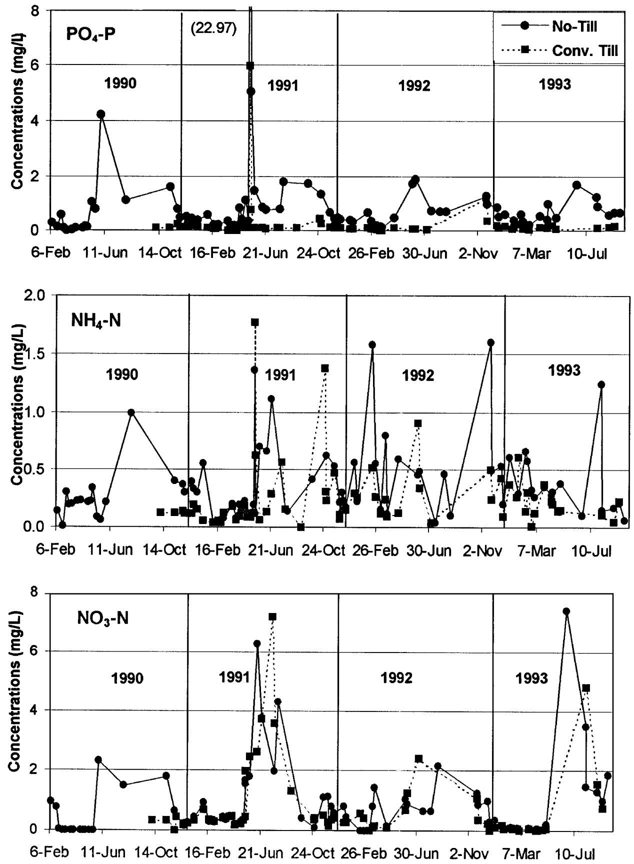

Figure 5–Seasonal nutrient concentrations in surface runoff from soybean watersheds.

NO_3-N in runoff from the no-till watershed were 4.21 and 2.30 mg·L^{-1}, respectively, which occurred on 3 June 1990 (fig. 5). These high nutrient concentrations are attributed to a broadcast application of 0-20-20 on 26 May 1990. As the fertilizer should not have contained any nitrogen compounds, the increase in NO_3-N may have resulted from a stimulation of microbiological activity. Nitrate-N was not detected in surface runoff for the period 9 March 1990, through 21 May 1990. While the NH_4-N concentration in runoff increased relative to a previous storm on 3 June 1990, the largest increase was not observed until one storm later on 31 July 1990, and may also reflect an increase in microbiological activity. Increases in PO_4-P concentrations in runoff occurred on 23 May 1990, which may be the result of nutrients leached from desiccated vegetation due to a burndown herbicide application on 8 May 1990.

Similar to the 1990 WY, the highest nutrient concentrations in runoff during the 1991 WY also occurred immediately following a broadcast application of 0-20-20 on 14 May 1991 (fig. 5). The highest PO_4-P, NH_4-N, and NO_3-N concentrations in runoff from the no-till watershed were 22.97, 1.36, and 6.25 mg·L^{-1} compared with 5.97, 1.77, and 7.21 mg·L^{-1} for the conventional-till watershed. The high PO_4-P and NH_4-N concentrations were observed in runoff within two days after fertilizer application, whereas the higher NO_3-N concentrations were not observed until about one month later in runoff from the no-till watershed, and two months later in runoff from the conventional-till watershed. During the late spring and summer months PO_4-P concentrations rapidly decreased to near pre-fertilization levels. Nitrate-N and NH_4-N concentrations also decreased during the summer months, but at a slower rate. Nutrient concentrations in runoff, particularly from the no till watershed, increased slightly during the fall which probably represents leaching of crop residues and other desiccated vegetation (fig. 5). Similarly, during the 1992 WY, most nutrient concentrations increased in surface runoff for storms following a broadcast application of 0-26-26 on 23 April 1992 (fig. 5). The increase in nutrient concentrations was most noticeable for the soluble P in runoff from the no-till watershed and NO_3-N in runoff from the conventional-till watershed. Soluble P concentrations in runoff from the conventional-till watershed did not increase, probably due to the greater concentrations of suspended sediment. Somewhat similar seasonal trends in soluble nutrient concentrations were observed during the 1993 WY (fig. 5). Fertilizer as 0-26-26 was broadcast applied on 5 May 1993.

Solution plant nutrient losses for each tillage system are presented in table 3. For both the no-till and conventional-till watersheds, soluble plant nutrient losses were largest during the 1991 WY, primarily due to greater amounts of runoff. For each of the 1991-1993 WYs, only the distribution functions of solution PO_4-P losses differed significantly between the two tillage systems. Despite lower runoff from the no-till watershed for all WYs, the soluble PO_4-P losses for the 1991, 1992, and 1993 WY were nearly five, six, and four times that of the conventional-till watershed, due to the higher concentrations of soluble PO_4-P. Other water quality research in north Mississippi has shown total (solution plus sediment) N and P losses from no-till soybeans to be 4.7 and 2.8 kg·ha^{-1}, respectively (McDowell and McGregor, 1980).

Sediment Nutrients in Surface Runoff

Solution losses of nutrients from the no-till watershed represented almost all of the N and P nutrient losses since sediment concentrations and yields were low (tables 3 and 4). For the 1990, 1991, 1992, and 1993 WY, the mean discharge-weighted sediment concentrations in the no-till runoff were only 319, 67, 105, and 80 mg·L^{-1}, respectively; sediment yields were 1050, 455, 375, and 136 kg·ha^{-1}, respectively. In contrast, the 1991, 1992 and 1993 WY mean discharge-weighted sediment concentrations in runoff from the conventional-till watershed were 3569,

Table 4. Sediment nutrient concentrations and losses in surface runoff from soybean watersheds

	Concentration		Losses	
Tillage Practice	P (mg·kg^{-1})	N (mg·kg^{-1})	P (kg·ha^{-1})	N (kg·ha^{-1})
No-till				
Sediment 1990	1692	1249	1.78	1.32
Sediment 1991	1876	6000	0.86	2.75
Sediment 1992	2090	3294	0.79	1.24
Sediment 1993	1681	6319	0.23	0.86
$\bar{x}$*	1905	4552	0.92	1.54
Conventional-till				
Sediment 1991	641	271	20.38	8.61
Sediment 1992	611	910	14.01	20.87
Sediment 1993	1833	770	2.23	5.31
$\bar{x}$*	636	617	12.21	11.60

* Sediment-weighted mean nutrient concentration.

5241, and 1270 mg·L^{-1}, respectively, and sediment yields of 31 928, 22 994, and 2898 kg·ha^{-1}. Compared to the no-till watershed, sediment associated nutrient losses from the conventional-till watershed are a substantial portion of the soluble plus sediment nutrient yield (table 4). A portion of the P associated with the sediment can be bio-available to aquatic organisms (Sharpley, 1993; Hegemann et al., 1983).

For both N and P, nutrient (soluble plus sediment) losses were reduced by as much as a factor of five with the no-till system for soybeans. In addition, another important pollutant to aquatic ecosystems, sediment, was reduced (sediment loss) by as much as 98%. However, under no-till soybeans, soluble P yields increased four to six fold compared to the conventional-till soybeans. As mentioned earlier, this increase in soluble P transport is related directly to the lack of sediment present to sorb the soluble P. The soluble losses of N (NO_3-N + NH_4-N) were about the same for both tillage systems.

Summary and Conclusions

The results presented within this manuscript represent a four year research project that provides some insights regarding the quality of shallow ground and surface water of a no-till and conventional-till soybean watershed in northern Mississippi. Once the soil profile becomes saturated, free water is easily perched above the fragipan, and is suspected to move laterally down-slope across the fragipan surface. The data for the study period indicate that tillage differences for soybeans, no- or conventional-till, do not greatly affect the mean concentration of plant nutrients in shallow (< 3.04 m) groundwater. In fact, shallow groundwater NO_3-N concentrations under conventional-till soybeans for comparable years were slightly greater than those under no-till soybeans. However, no-tillage may increase the potential for nutrient movement in groundwater. Even though no nitrogen was applied to the soybeans, NO_3-N concentrations in shallow groundwater from either conventional or no-till soybeans at times exceeded the U.S. Drinking Water N standard. Crop residues are the suspected N source. The quantity and distribution of rainfall is thought to play an important role in NO_3-N leaching from the soil profile, and hence, NO_3-N concentrations in shallow groundwater. Finally, no-till soybeans reduced N and P losses (sediment plus solution) by as much as a factor of five which was largely a result of a 95 to 98% reduction in sediment losses. However, no-till soybeans did increase both soluble P concentrations and losses in surface runoff.

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