PLANT NUTRIENTS IN SHALLOW GROUND WATER AND SURFACE RUNOFF OF A NORTH MISSISSIPPI SOYBEAN WATERSHED

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Introduction

Maintaining and/or improving crop production efficiency without adversely affecting environmental quality is a major challenge for U. S. Agriculture. Pesticide and nitrate-N contamination of ground water is a national problem that needs timely and rational solutions. Research worldwide has shown that the most extensive source of pesticides and nutrients delivered to ground and surface waters is agriculture. There is a great public concern about ground water quality since it is the source of drinking water for half of the U. S. In rural communities, nearly 95% of the population depend upon wells for drinking water. The emphasis during the 1960's and 1970's was on point source pollution and surface water; at this time, there is a great public concern about ground water quality which will probably be a primary water quality issue of the 1990's.

In Mississippi, ground water constitutes 54% of all freshwater and is the water supply for 93% of the population (10). Ground water contamination is not yet considered to be a major problem. However the State's ground water is very susceptible to contamination because of the permeable soils, shallow depth to ground water, and high average annual rainfall (10). 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 are lacking on any potential agrichemical contamination of ground water underlying agricultural areas of the State, particularly the Delta along the Mississippi River and the uplands to the north. Evaluation of farm management (tillage practices, pesticide and fertilizer application technology) 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 ground water 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 65 lbs. per acre in 1967 to 135 lbs. per acre in 1982 (2). 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 (5). The remainder is lost through leaching, washoff, volatilization, or stays in the soil profile. The highly soluble nitrate form of nitrogen is easily transported through the soil by percolating water to ground water. The best known health problem caused by nitrates is methemoglobinemia, or blue baby disease. The current U. S. Drinking Water Standard for nitrates is based on protecting against this disease, and that standard is 10 mg nitrate-N per liter. Other health effects that may be associated with nitrates, but not well documented, include impairments of the nervous system, cancer (conversion of nitrates to nitrosamines), and birth defects. The type of land tillage, as well as fertilizer N usage, may also influence the movement of agrichemicals through the soil profile.

By the year 2,000, it has been estimated that 60 - 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 by 1990 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 pesticides and fertilizers. The objective of this research is to determine the effect of no-tillage soybeans on plant nutrient concentrations in shallow (perched) ground water and surface runoff during the 1990 water year.

Materials and Methods

Research directed toward the development of cost-effective methods of row crop production in DEC (Demonstration Erosion Control) watersheds was initiated during the fall of 1987 on the Nelson farm in Tate County, Mississippi. Included in the study area are three small watersheds about 2.09 to 3.17 ha in size. Soils belong to the Loring-Grenada series and are loessial. There is a genetic fragipan 0.3 to 1.0 m below the soil surface depending upon location within the watershed.

This study concerns watershed number one (Fig. 1) which is 2.14 ha in size. During the 1988/90 cropping years, the watershed was in minimum-till soybeans; for the 1990 cropping year, it was planted to no-till soybeans. In the fall of 1987, the three watersheds received a one time N fertilizer application of 44.8 $kg \cdot ha^{-1}$ as NH_4-NO_3 and were planted to winter wheat. No N fertilizers have been applied since that time. For the 1988-90 cropping years, 0-20-20 fertilizer was broadcast applied each spring before planting at a rate of 224 $kg \cdot ha^{-1}$.

Runoff from the watershed was measured with a 0.61 m Parshall flume equipped with a FW-1 recorder. Potentiometer output from the FW-1 was converted to discharge and the resultant discharge logged in an Omnidata Easy Logger (Version 3.0) every N minutes. The Omnidata Easy Logger was also used to activate an ISCO composite sampler. Sampling times were specified increments of runoff, resulting in one discharge-weighted sample per storm event. Samples were collected in a stainless steel container and stored at 4C until analysis. During the 1990 water year (WY), sample collection of runoff for plant nutrients was not begun until February 10, 1990.

For ground water sampling, 3 sites (Fig. 1) were established along the northern edge of the watershed. Sites 1, 2, and 3 were located 12.5, 40.7, and 83.3 m, respectively, from the uppermost edge (eastern boundary) of the watershed. The elevation above sea level of sites 1, 2, and 3 are 98.8, 97.6, and 94.8 m respectively. Instrumentation for ground water sampling at each site consisted of observation wells (sampling piezometers) and soil water suction tubes at 0.15, 0.30, 0.46, 0.61, 0.91, 1.22, and 1.52 m depths into the soil profile. Observation wells and soil water suction tubes were located about 4.56 m from the edge of the watershed, within crop rows, with a 0.91 m spacing between each observation well or soil water suction tube. Within 24 hrs of each storm event, the depth of ground water in each observation well was measured and all ground water evacuated. Similarly, all water was removed from the soil water suction tubes and tension set at 0.03 megapascal. Approximately 24 hours later, the depth of ground water in each observation well was again measured and samples obtained from the observation wells and soil water suction tubes. Samples were placed in amber glass containers and transported to the laboratory where they were stored at 4C until chemical analysis. Unless otherwise indicated, all chemistry data reported in this manuscript are from ground water obtained from the observation wells. At planting time, those portions of a crop row containing instrumentation were hand planted. All ground water sampling instrumentation was covered during fertilizer or pesticide applications. The ground water sampling equipment was installed during October 1989 with the first ground water samples obtained in January 1990 after the soil profile had become saturated.

Prior to chemical analysis, all samples were filtered using a 0.45 µm Millipore filter. Runoff and ground water samples were analyzed for PO_4-P, NO_3-N, Cl, and SO_4-S 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 (13). As runoff sampling did not begin at the start of the 1990 WY, the discharge weighted nutrient concentration from February 10, 1990 through April 27, 1990, was used to estimate nutrient losses for the unsampled storms of October 16, 1989, through February 3, 1990. For this period, the storms showed seasonal similarities in plant nutrient concentrations. Sediment concentrations in runoff samples were determined gravimetrically.

Nutrient concentrations were usually not normally distributed in the runoff and ground water as determined by Lilliefor's test (1). Therefore, nonparametric Kolmogorov-Smirnov two-sample and two-sided test statistic, T_1, the greatest distance between two empirical cumulative distribution functions, was used to test the hypothesis that each nutrient concentration distribution was the same for all treatments. All statistical comparisons were conducted at the 0.05 probability level.

Names of commercial products are included for the benefit of the reader and do not imply endorsement or *preferential treatment by the U. S. Department of Agriculture.*

Results and Discussions

Nutrients in Surface Runoff: The mean discharge-weighted concentrations of PO_4-P, NH_4-N, NO_3-N, Cl, and SO_4-S in runoff for all measured storm events of the 1990 WY were 0.56, 0.15, 0.28, 2.33, and 0.92 $mg \cdot L^{-1}$, respectively (Table 1). Based upon the total runoff of 330 mm for the 1990 WY, total losses of PO_4-P, NH_4-N, NO_3-N, Cl, and SO_4-S were 1.21, 0.54, 1.06, 4.98, and 2.21 $kg \cdot ha^{-1}$, respectively. Total precipitation for the 1990 WY was 1,276 mm. Other water quality research in north Mississippi has shown total N and P losses (solution plus sediment) from no-till soybeans at 4.7 and 2.8 $kg \cdot ha^{-1}$, respectively (9).

Cumulative frequency distributions of runoff and PO_4-P, NH_4-N, and NO_3-N losses provided additional information on the losses of nutrients in runoff. For example, considering PO_4-P, NH_4-N, and NO_3-N for only the storms analyzed, 44, 36, and 22 percent of the runoff, respectively, had concentrations that exceeded the discharge-weighted mean concentration and produced about 81, 62, and 94 percent of the losses.

Single storm events can contribute a significant portion of the total (measured plus estimated) yearly losses. For example, a single storm event on May 21, 1990, (Table 1), contributed about 40% of the yearly PO_4-P losses. This high P loss was the result of both a relatively high P concentration (0.81 $mg \cdot L^{-1}$) and runoff (59.94 mm). Similarly, the largest NH_4-N and NO_3-N losses for a single storm event were 38 and 39 percent, respectively, of the total yearly losses.

The largest nutrient concentrations for PO_4-P, NO_3-N, Cl, and SO_4-S in runoff were 4.21, 2.30, 27.59, and 14.30 $mg \cdot L^{-1}$, respectively, which occurred on June 3, 1990 (Fig 2). These high nutrient concentrations are attributed to a broadcast application of 0-20-20 on May 26, 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. It should be noted that no NO_3-N was detected in surface runoff for the period March 9, 1990, through May 21, 1990. While the NH_4-N concentration in runoff increased relative to previous storms on June 3, 1990, the largest increase was not observed until one storm later on July 31, 1990, and may also reflect an increase in microbiological activity. Smaller increases in PO_4-P and Cl concentrations in runoff occurred on May 23, 1990, which may be the result of nutrients leached from desiccated vegetation due to a herbicide application on May 8, 1990.

Most likely, these solution losses of nutrients represent almost all of the total nutrient losses since sediment concentrations were low. For the 1990 WY, the mean discharge-weighted sediment concentration in runoff was only 319 $mg \cdot L^{-1}$; sediment yield was 1,050 $kg \cdot ha^{-1}$.

Nutrients in Shallow Ground Water: Once the soil profile became saturated about mid-January, 1990, ground water samples were easily obtained, particularly at observation well depths greater than 0.61 m. A typical distribution of water in the observation wells after a storm event is shown in Figure 3. These data show the tendency of ground water to pond above the fragipan located 0.61 to 0.91 m below the soil surface. Nearly equal amounts (level) of water in all observation wells at site 3 may be an indication of water movement down slope across the fragipan surface. Finally, the data indicate an abundance of ground water within the fragipan itself. Research has indicated that a common characteristic of fragipan soils is that the material above the fragipan is usually quite porous whereas the fragipans have a much lower saturated hydraulic conductivity than the materials above, hence, low tension water accumulates at the top of the fragipan and moves laterally (4, 11).

The annual mean PO_4-P, NH_4-N, NO_3-N, Cl, and SO_4-S concentrations for all ground water sites and depths were 0.05, 0.08, 11.56, 14.70, and 1.56 $mg \cdot L^{-1}$, respectively. With the exception of PO_4-P and NH_4-N, nutrient concentrations in ground water were higher than those in runoff. Shallow ground water NO_3-N concentrations for some storms exceeded the U. S. Drinking Water Standard by as much as a factor of 2.7 (Fig. 4) and are of interest since no N fertilizers were applied after 1987. In fact, for all sites and depths, 59% of all NO_3-N concentrations exceeded the U. S. Drinking Water Standard of 10 $mg \cdot L^{-1}$. Three coastal plain studies indicate that even when recommended nutrient management practices were followed, NO_3-N concentrations in shallow ground water were significantly higher than the standard for public drinking water. In one study of conventional-till soybeans, thirty-nine out of forty-four samples exceeded the nitrate-N standard of 10 $mg \cdot L^{-1}$ (7). Groundwater at 1.5 m with corn that received N fertilization showed NO_3-N concentrations to be about 18 $mg \cdot L^{-1}$ (14). Tile drainage from Ohio alfalfa over a two year period average 1.5 $mg \cdot L^{-1}$ NO_3-N, compared with 4.9 to 32.8 $mg \cdot L^{-1}$ measured under soybeans (6). In this present study, soybean residues, tops and roots, are suspected as the NO_3-N source. As in other research, it would appear 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 the soybean harvest (12). 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 (3). 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 (8).

In general (sites 2 and 3), NO_3-N concentrations during the winter at depths <0.46 m were greater than those deeper in the soil profile (Fig. 4 and Fig. 5). However, these higher ground water NO_3-N concentrations at the shallow depths in the soil profile decreased dramatically (Fig. 5) during the spring 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. For much of this same time period, no NO_3-N was detected in runoff.

In contrast to sites 2 and 3, winter NO_3-N concentrations at site 1 were greater at the 1.52 m depth than at shallower depths in the soil profile. These higher NO_3-N concentrations may be attributed to a combination of biological and hydrological factors. For example, site 1 has less slope than sites 2 and 3 that may result in a greater accumulation of surface residues and hence a larger earthworm population to incorporate residues into the soil profile. Furthermore, the flatter slope would promote a greater amount of downward water movement (leaching) and perching above the fragipan. Additional research is needed to verify this hypothesis. The initially high NO_3-N concentrations at the 1.52 m depth decreased continuously during the winter/spring months, such that by late spring NO_3-N concentrations were similar to those at the shallower depths (Fig. 4).

In general, with only a few exceptions, distribution functions of NO_3-N concentrations in ground water for individual storm events differed significantly (5 percent level) at observation well depths 0.61 m or greater, but were similar (5 percent level) at well depths 0.46 m or less. Distribution functions of PO_4-P and NH_4-N concentrations were the same (5 percent level) across study sites at all well depths. No trends in PO_4-P or NH_4-N concentrations were observed with season or well depth.

Ground water samples were collected and analyzed from both observation wells and soil water suction tubes, all at the same sites and depths. The annual mean PO_4-P, NH_4-N, NO_3-N, Cl, and SO_4-S concentrations in ground water collected by soil water suction tubes (for all sites and depths) were 0.05, 0.08, 9.94, 10.16, and 12.43 $mg \cdot L^{-1}$, respectively. At all sites, for individual storm events, distribution functions of Cl and NO_3-N concentrations, collected by these two techniques, generally differed significantly (5 percent level) at depths greater than 0.46 to 0.61 m. The SO_4-S concentrations differed significantly (5 percent level) at all depths. In contrast (except for a few depths and sites), PO_4-P and NH_4-N concentration distribution functions did not differ between the two sampling methods.

Summary and Conclusions

While the results presented within this manuscript represent only one year of research, and should be considered preliminary, they do provide the following insights regarding the quality of ground and surface water of a no-till soybean watershed:

1. Most plant nutrient concentrations, except NO_3-N, in shallow ground water are relatively low and present no environmental problems.

2. Even though no nitrogen was applied to the no-till soybeans, NO_3-N concentrations in shallow ground water, at times, exceeded U. S. Drinking Water Standards. Crop residues are the suspected N source.

3. Plant nutrient concentrations and yields in surface runoff from a no-till soybean watershed are relatively low and should pose no environmental problem.

4. Once the soil profile becomes saturated, free water is easily perched above the fragipan and is suspected to move down-slope laterally across the fragipan surface.

The results of this one year study have also helped to define additional research areas which include:

1. Research is needed to define ground and surface water quality under conventional-till soybeans as compared with the no-till soybeans of this present

study (This research was initiated at the start of 1991 WY).

2. Additional research is needed to define and quantify the movement of shallow ground water that may contain high NO_3-N concentrations.

3. A more detailed sampling and chemical analysis of soil and crop residues is needed to better define N cycling. The role of soybean residues as a N source needs to be determined and related to environmental factors such as rainfall intensity and duration.

4. Deeper observation wells are needed to determine if plant nutrients, specifically NO_3-N, are moving below the fragipan.

5. Research is needed to define the role of cover crops and application of fertilizers below ground as a means of reducing plant nutrient concentrations in ground water and surface runoff, respectively.

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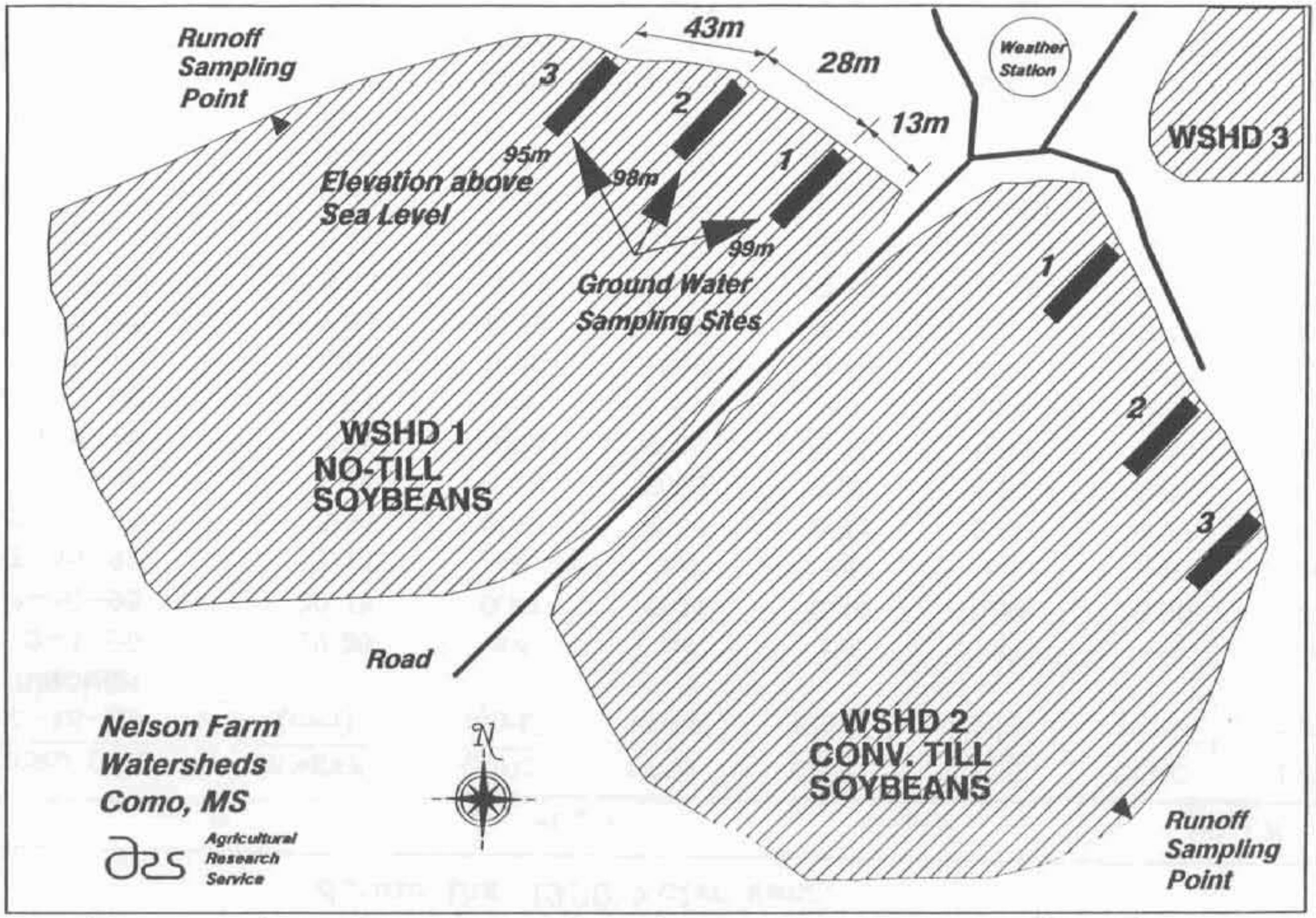

Figure 1. Location of runoff and ground water sampling sites.

Table 1. Nutrient concentration in runoff of individual storm events from a no-till soybean watershed during the 1990 water year.

STORM DATE	RUNOFF	PO_4–P		NH_4–N		NO_3–N	
		CONC	LOSS	CONC	LOSS	CONC	LOSS
10–16–89 THROUGH	(mm)	$mg \cdot L^{-1}$	$kg \cdot ha^{-1}$	$mg \cdot L^{-1}$	$kg \cdot ha^{-1}$	$mg \cdot L^{-1}$	$kg \cdot ha^{-1}$
2–3–90	159.36	nd	nd	nd	nd	nd	nd
2–10–90	30.73	0.27	0.08	0.14	0.04	0.95	0.29
2–15–90	7.11	nd	nd	nd	nd	nd	nd
2–22–90	3.81	0.12	0.01	0.01	0.00	0.77	0.03
3–2–90	5.16	0.59	0.03	0.30	0.02	0.02	0.00
3–9–90	2.79	0.09	0.00	0.19	0.01	0.00	0.00
3–10–90	0.58	nd	nd	nd	nd	nd	nd
3–15–90	11.66	0.00	0.00	0.20	0.02	0.00	0.00
3–20–90	2.44	0.03	0.00	0.22	0.01	0.00	0.00
4–5–90	5.61	0.11	0.01	0.23	0.01	0.00	0.00
4–21–90	18.62	0.09	0.02	0.21	0.04	0.00	0.00
4–27–90	8.79	0.15	0.01	0.22	0.02	0.00	0.00
5–2–90	0.86	0.14	0.00	0.34	0.00	0.00	0.00
5–12–90	5.41	1.06	0.06	0.08	0.01	0.00	0.00
5–21–90	59.94	0.81	0.48	0.06	0.04	0.00	0.00
6–3–90	4.22	4.21	0.18	0.22	0.01	2.30	0.10
7–31–90	2.46	1.12	0.03	0.99	0.02	1.50	0.04

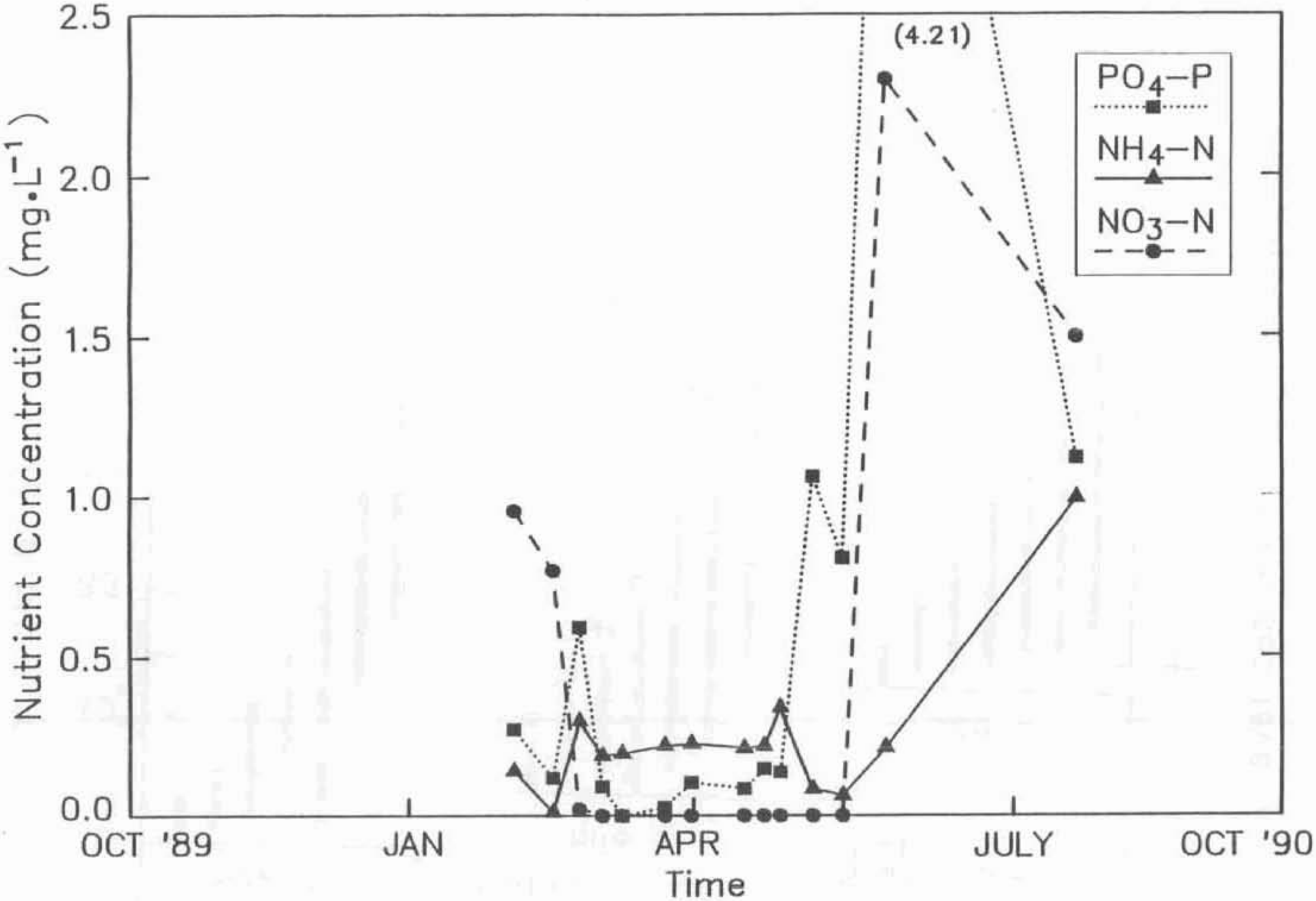

Figure 2. Nutrient concentrations in runoff from a no–till soybean watershed.

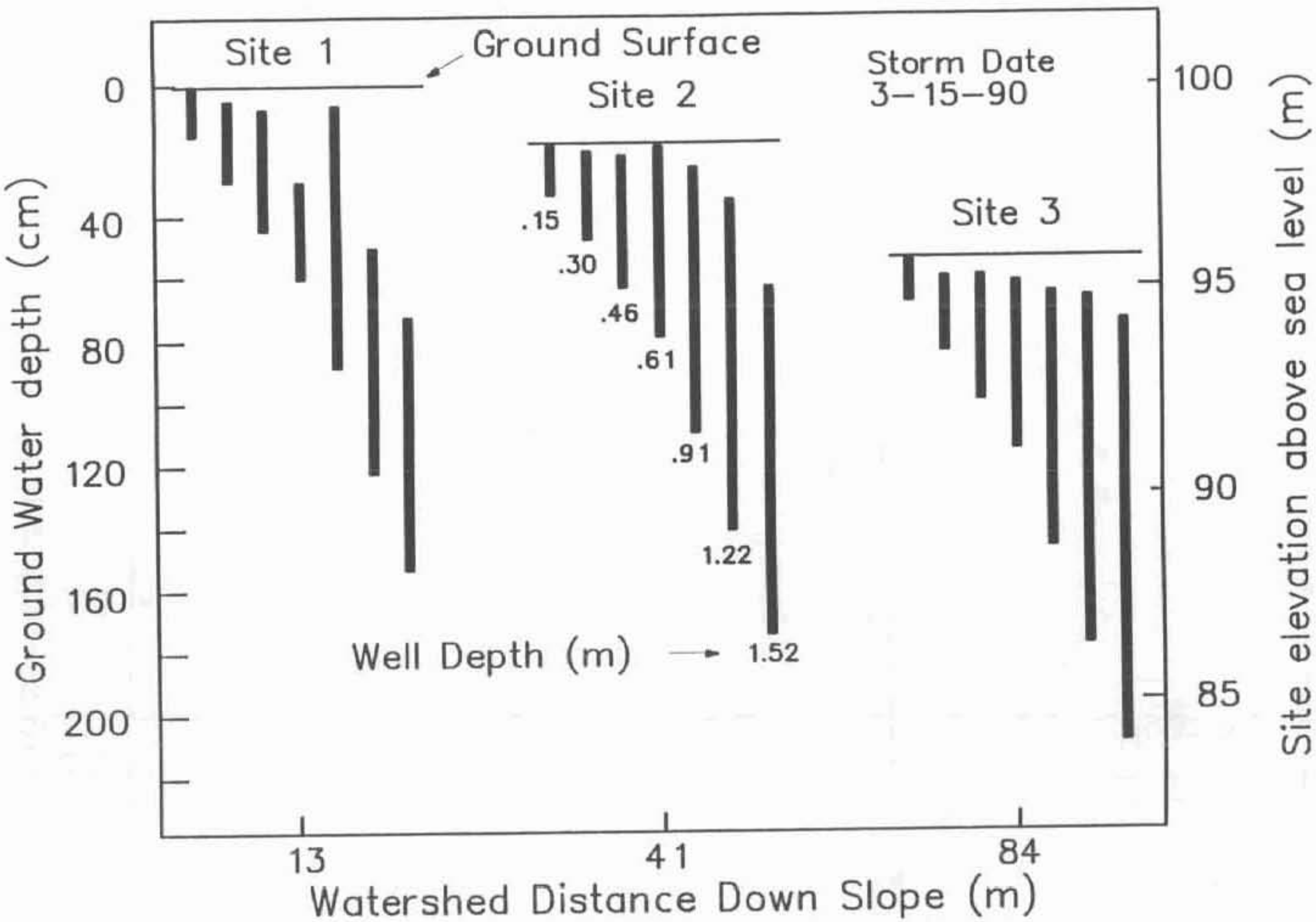

Figure 3. Ground water in observation wells after a typical storm event.

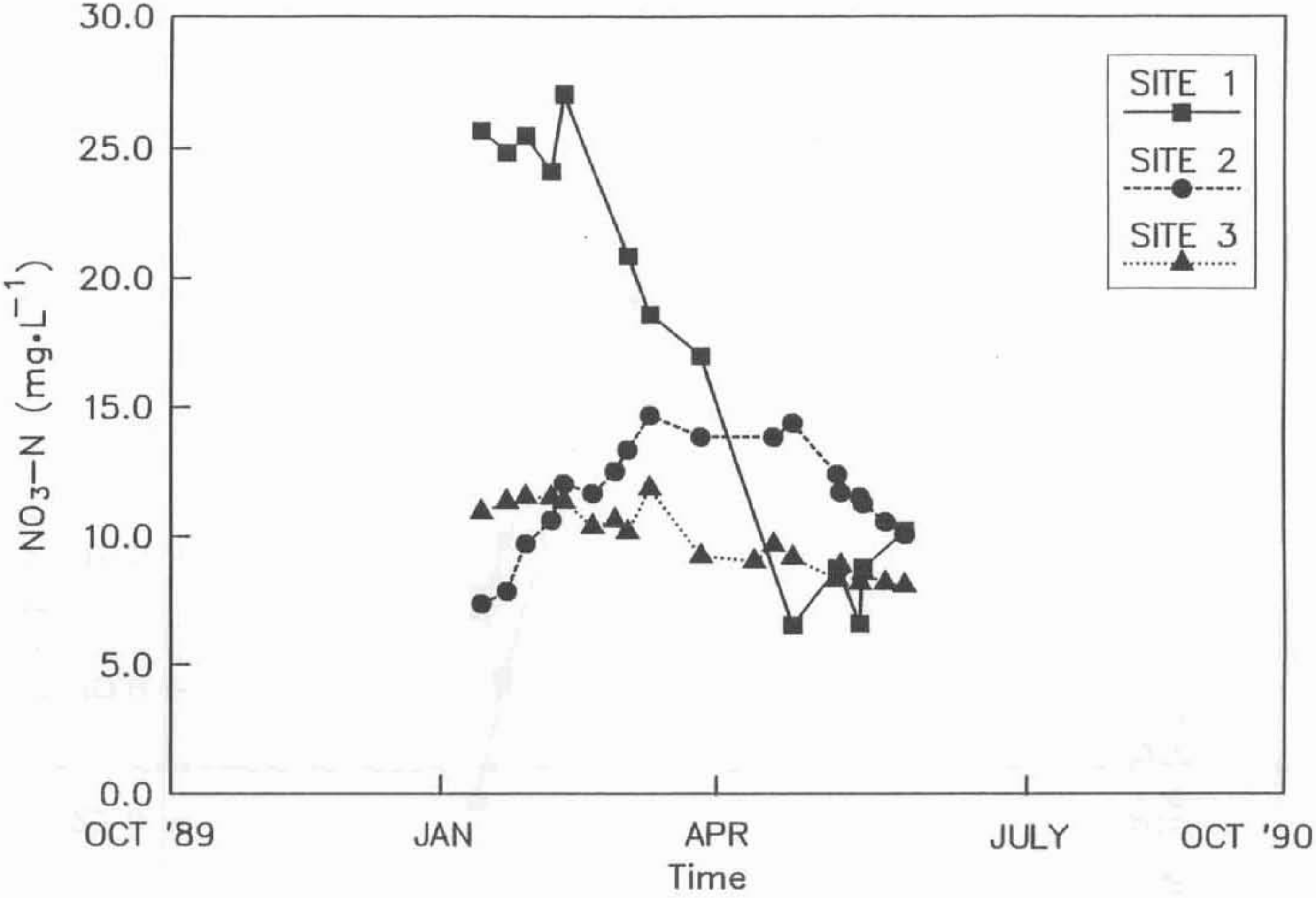

Figure 4. Nitrate–N concentrations in ground water of a no–till soybean watershed at the 1.52 m depth.

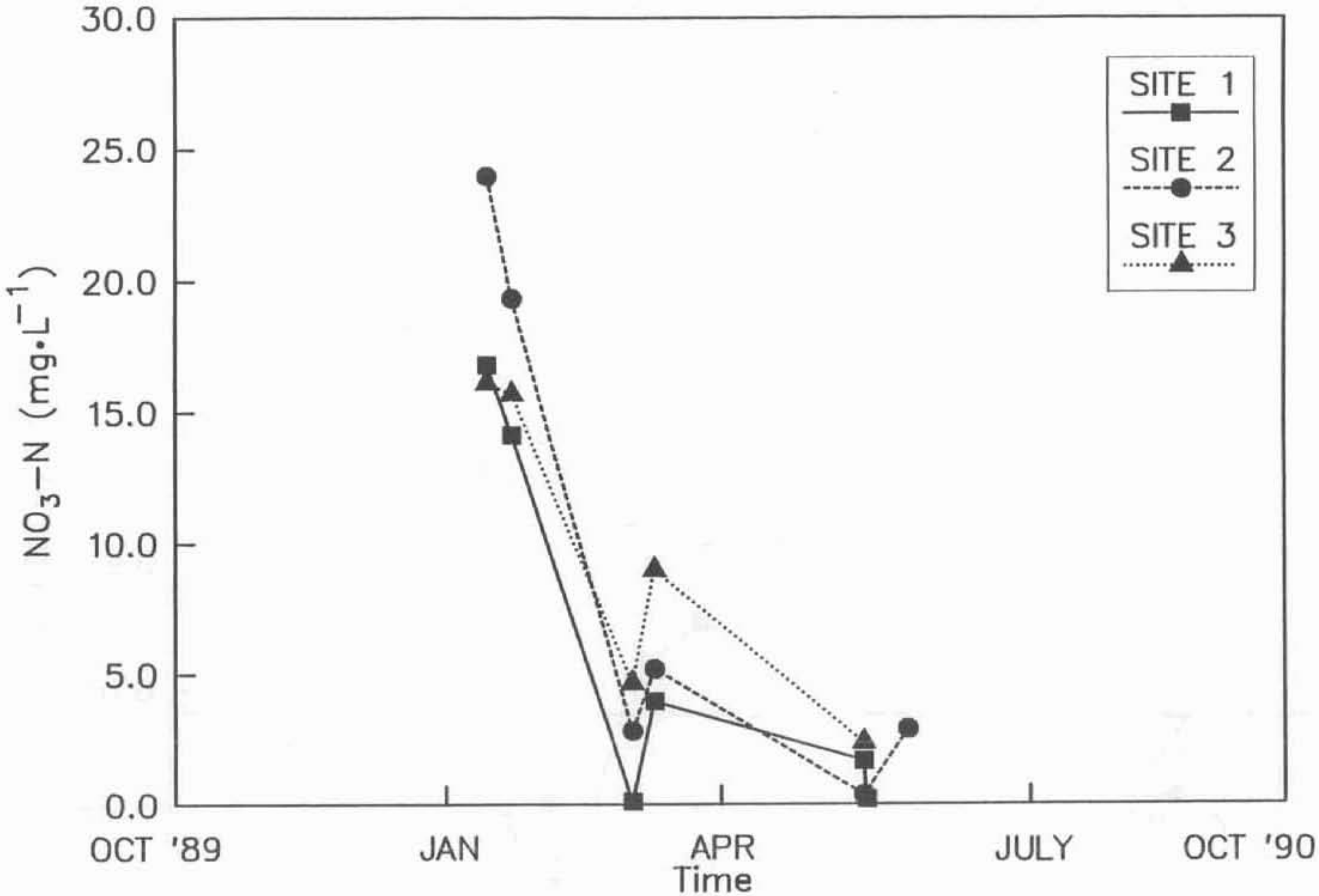

Figure 5. Nitrate–N concentrations in ground water of a no–till soybean watershed at the 0.30 m depth.