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HERBICIDE AND NITRATE MOVEMENT IN A SANDY SOIL IN THE LOWER WISCONSIN RIVER VALLEY

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PROJECT TOPIC AND SCOPE

The purpose of this project was to investigate the fate and transport of pesticides and nitrate in a sandy soil-landscape along the Lower Wisconsin River Valley (LWRV). This project was a continuance of an investigation of soil type and management practice impacts on pesticide and nitrate fate, initiated in 1989 with core support provided by WDATCP and WDNR. Results from experiments on effects of soil type on herbicide fate (LWRV soil vs. Central Sand Plain soil), and results from 1990 and 1991 hydrologic characterization and agrichemical fate field experiments were summarized by Lowery and McSweeney (1992) in a report to the WDATCP.

This report specifically summarizes results of field investigations of the fate and transport of atrazine and two of its metabolites and nitrate through the unsaturated zone to groundwater under irrigated and nonirrigated conditions in the LWRV. The influence of different tillage practices were also investigated. Results and analyses from the 1991 season that were not included in the Lowery and McSweeney (1992) report are included herein, as well as results from the 1992 and 1993 (partial) seasons.

METHODS AND MATERIALS

Site Characteristics

A 2.8-ha field site, located one mile north of the village of Arena in northeast Iowa County, was established in June 1989. The site is representative of the intensively cropped and irrigated alluvial sands along the lower Wisconsin River. The soil at the site is a Sparta sand (mesic, uncoated Typic Quartzipsamments) that has a dark and thick surface (mollic-like) horizon, which is indicative of its development under prairie (grasses) vegetation. Selected physical and chemical properties of Sparta sand from the site are given in table 1. The soil is excessively well drained and has a very low water holding capacity. As a consequence of the very small organic carbon and clay content, this soil possesses a small capacity to sorb atrazine (Table 1).

Site Layout and Treatments

A schematic plan of the research site, showing 1992 experimental treatments and groundwater monitoring locations, is illustrated in Figure 1. The experimental design was a split-split unbalanced block design. The main-block treatments were three levels of irrigation. The three irrigation treatments were: no-irrigation (No-I), irrigation to meet calculated evapotranspiration (ET) according to the Wisconsin Irrigation Scheduling Program (WISP), and irrigation to equal 3.8 cm of rainfall plus irrigation per week (ET+). The No-I block was split to give a control block with no-nitrogen under rain-fed conditions. The ET treatment block was split to accommodate a nitrification inhibitor (N-Serve) variable for the 1991 through 1993 crop seasons. Tillage was the sub-plot treatment consisted of moldboard plow tillage (MB) and no-tillage (NT). Each tillage plot was split (1990 and 1991 growing seasons only) to accommodate a sub-sub-plot

Table 1. Selected properties of Sparta sand, Arena field site.

Horizon	Depth	Sand	Clay	OC §	Kd † atrazine	Ksat ¶	Water ‡ Content$_{FMC}$
	cm	%	%	%	L/kg	cm/hr	%
Ap	0-23	96	1.6	0.39	0.58	27	11.1
A	23-33	96	1.6	0.56	0.60		11.9
AB	33-43	96	1.5	0.34	0.35		10.3
Bw1	43-54	96	1.0	0.27	0.30	33	8.5
Bw2	54-66	97	1.2	0.15	0.12		7.2
Bw3	66-84	99	0.6	0.08	0.10	83	4.8
BC	84-135	99	0.2	0.04	0.08		4.9
C	135-160	99	0.2	0.01	0.025		3.7

† Atrazine batch adsorption coefficient.

‡ Volumetric soil water content at field moisture capacity.

§ OC = organic carbon content.

¶ Ksat = water saturated hydraulic conductivity.

of with and without Acrysol ASE 108 polyacrylate added to the herbicide tank mix. In 1993 the ET+ irrigation treatment was discontinued and plots 5 through 10 were irrigated according to WISP. Plots one through four were irrigated at the ET+ irrigation rate as part of a nitrogen placement study.

The basic irrigation blocks and tillage sub-plots were the same for both the 1990, 1991, and 1992 growing seasons. However, six new plots were established in 1991 as part of a USDA-administered initiative on water quality in the form of Management System Evaluation Area (MSEA) plots. There are five main MSEA projects throughout the Midwest (they are located in Iowa, Minnesota, Missouri, Nebraska, and Ohio); the Arena site is a satellite of Minnesota's Northern Corn Belt Sand-Plain MSEA. The primary focus of all MSEA projects is to evaluate herbicide and nitrate leaching under selected tillage practices (ridge-till for our site) for corn-soybean rotation. The herbicides (atrazine/alachlor and metribuzin/alachlor) were band applied over the row, resulting in one-third the normal broadcast area. The MSEA plots were irrigated the same as the regular ET block. Herbicide and nitrogen transport were monitored by analysis of soil cores and groundwater samples. All soil samples were analyzed at the USDA National Soil Tilth Laboratory in Iowa and water samples were analyzed at the Department of Soil Science, UW-Madison.

In 1991, field plots were tilled and planted to corn (Pioneer 3417) on 3 May (DY 123). Starter fertilizer was applied at a rate of 92 kg/ha 6-24-24 and insecticide [tefluthrin (Force)] at a rate of 0.168 kg ai/ha. Herbicides were broadcast applied on 8 May (DY 128), after soil-water monitoring equipment installation, at the rates given in table 2. Nitrogen fertilizer (24% UAN) was split applied on 7 June (DY 158) and 17 June (DY 168) at 96 kg N/ha per application (total N equaled 193 kg/ha). Nitrogen was injected between the rows to a depth of 10 to 15 cm.

In 1992, field plots were tilled and planted to corn (Pioneer 3417) on 30 April (DY 121). Starter fertilizer was applied at a rate of 140 kg/ha 6-24-24 and insecticide [tefluthrin (Force)] at a rate of 0.168 kg ai/ha. Roundup (glyphosate) herbicide was applied at a rate of 1.12 kg ai/ha to MB and ridge-till plots 5 May. Preemergence herbicides were broadcast applied on 6 May (DY 127) after monitoring equipment installation, at the rates given in Table 2. Accent (nicosulfuron) herbicide was applied on 3 June to all corn plots except MSEA and N-placement plots. Nitrogen fertilizer (24% UAN) was split applied on 4 June (DY 156) and 18 June (DY 170) at 100 kg N/ha per application (total N equaled 200 kg/ha).

In 1993, field plots were planted to corn (Pioneer 3417) on 5 May (DY 125). Starter fertilizer was applied at a rate of 159 kg/ha 6-24-24 and insecticide [tefluthrin (Force)] at a rate of 0.150 kg ai/ha. Roundup (glyphosate) herbicide was applied at a rate of 1.12 kg ai/ha to NT and ridge-till plots 5 May. Preemergence herbicides were broadcast applied to the ET block on 7 May (DY 127), after monitoring equipment installation, at the rates given in Table 2. Accent (nicosulfuron) herbicide was applied to the east end of plots four through 10 and to No-I plots on 3 June (154). Nitrogen fertilizer (24% UAN) was split applied on 8 June (DY 159) at 102 kg-N/ha and 22 June (DY 173) at 99 kg-N/ha (total N equaled 201 kg/ha).

Table 2. Herbicide application rates for main water input blocks in 1990, 1991, 1992, and 1993.

Herbicide	No-polymer plots				Polymer plots †	
	1990	1991	1992	1993 ‡	1990	1991
	kg ai/ha					
Atrazine (4L)	0.96	0.84	0.84	0.84	0.84 §	0.91
Alachlor (Lasso, 4EC)	1.43	1.68	1.68	1.68	1.23	1.82
Metolachlor (Dual II, 8E)	1.43	1.68	---	---	1.23	1.82
Nicosulfuron (Accent, 75DF)	---	---	0.014	0.014	---	---
Imazethapyr (Pursuit)	---	---	---	0.028	---	---

† Acrysol ASE 108 polymer added to herbicide tank-mix [1.23 (1990) and 1.82 (1991) kg of polymer solids per ha]. Buffered with $NaCO_3$ (1990) and NH_4OH (1991) to approximately pH 7.5.

‡ Atrazine and alachlor applied only to ET block and MSEA corn; nicosulfuron applied only to No-I and east end of ET+ blocks; imazethapyr applied only to soybean in west end of ET+ block and No-I soybean.

§ Rates for polymer treatment are less than regular treatment due to viscosity changes during application.

Plots were irrigated with a three-tower, two-span, 95.4-m-long linear irrigation system. Water was supplied to the irrigation system by a 18.3-m deep supply well constructed at the site in April 1990. The well is fitted with a 14.5 L/sec submersible pump. The system was equipped with drop tubes and low-pressure spray nozzles with rotating spray-pads.

Water and Solute Monitoring

In cooperation with UW-Extension, a remotely-assessable, automatically-recording weather station was established adjacent to the research site in 1989. This station recorded the amount and intensity of rainfall at the site, as well as hourly air and soil temperature, relative humidity, solar radiation, wind speed and wind direction. These data were input into WISP to calculate ET and irrigation requirements. Project personnel recorded the quantity of water applied to each block as irrigation.

A schematic diagram illustrating the array of instrumentation at the field site is shown in Figure 2. All instrumentation requiring soil excavation for installation was installed during the period between planting and herbicide application each season to minimize herbicide contamination of the subsoil and samplers. Following the 1990 growing season, monitoring equipment was located west of areas disturbed by monitoring equipment from previous years.

Steel neutron-moisture-meter access tubes (150 to 200 cm by 4.2 cm i.d.) were installed in MB and NT tillage plot (21 in 1991, 17 in 1992, and 6 1993). Soil-water content was determined weekly in 1991 and bi-weekly in 1992 and 1993, with a Campbell Pacific Nuclear Model 503 Hydroprobe. The moisture probe was calibrated for the soil at the Arena site.

Herbicide and nitrate movement were monitored by analyzing samples taken from porous-cup solution samplers (PCS), soil cores, and groundwater monitoring wells. Three replications of porous-cup samplers were installed at four depths below the soil surface, 25, 60, 140, and 250 cm in 1991. The 250-cm-deep porous-cup samplers were not installed in any of the NT, polymer or No-N plots. Water sampling for tillage comparisons was restricted to irrigated, no-polymer plots. Water sampling for polymer comparisons was restricted to irrigated, MB plots. All MB, no-polymer plots were monitored with porous-cup samplers in 1991.

Monitoring efforts using porous-cup samplers in 1992 were focused only on MB and NT treatments under the ET and No-I water regimes. PCSs were also placed in the MB N-Serve plots. To better measure the variability in soil-water solute concentrations, five replicates of PCSs were placed in each treatment. Porous-cup samplers were only installed at two depths: in the middle of the root zone and below the root zone, 60 and 140 cm, respectively. In 1993, only the ET-MB regular-N and N-serve plots were sampled with PCSs. Only nitrate analysis was performed on 1993 samples.

Vacuums were placed on all samplers individually. Samples of soil water were removed from samplers about once a week, more frequently during periods of greater water input by rainfall and/or irrigation. These soil-water samples were vacuum siphoned into 0.5-L glass bottles, packed in ice and taken to the laboratory. Solution samples were kept at 4°C until analysis.

Soil cores were taken from each tillage sub-plot to a maximum depth of 2.3 m prior to herbicide application and three times after application. Cores were obtained with a truck- or tractor-mounted hydraulic probe except in July 1992 and 1993, where samples were collected by pounding core tubes into the ground by hand. Surface samples (0 to approximately 90 cm) were encased in 4.34 cm i.d. (1.71 inches) or 6.86 cm i.d. (2.7 inches) acetate sleeves, all subsurface (90 to 230 cm) cores were encased in 4.34 cm i.d. sleeves. All soil cores were taken in three steps: 0 to 90 cm (6.86 cm i.d.), 90 to 170 cm (4.34 cm i.d.), and 170 to 230 cm (4.34 cm i.d.). To reduce overall sample preparation and storage space, cores were sectioned, mixed, subsampled, labeled, and stored on ice in the field. Soil cores were divided into seven depth increments: 0 to 5, 5 to 20, 20 to 50, 50 to 90, 90 to 130, 130 to 170, 170 to 230 cm.

Four groundwater monitoring wells were installed at the site (Figure 1) in October 1989 by the Wisconsin Geological and Natural History Survey. Three shallow (approx. 4.6 m) wells were installed with 1.5 m screens at the water table. The other well was installed to a depth of 7.6 m.

In April 1991, a total of 28 piezometer-type wells were installed in 14 nests of two piezometers. Piezometer nests were placed immediately down gradient from each irrigation block and MSEA plot (Figure 1). In each nest, one piezometer is screened at the upper 0.91 m of the aquifer, based on the 1991 spring water table height. The second piezometer in each nest is screened at 1.5 to 1.8 m below the 1991 spring water table. Piezometers were constructed of 1.27 cm o.d. high density polyethylene (HDPE) semi-rigid tubing perforated at the bottom and screened with stainless-steel wire cloth (mesh = 150 x 150). Piezometers were installed in a manner similar to that described by Stites and Chambers (1991). Nine additional piezometers were installed in 1992 to improve areal and depth distribution measurements of solutes in groundwater. These new piezometers consisted of four piezometers screened at the water table (P29 to P32) and six deeper piezometers (P33 to P37), screened at 2.74 to 3.05 m below the 1991 spring water table (see Figure 1). A length of 0.64 cm o.d. HDPE semi-rigid tubing was placed at the bottom of each shallow piezometer to facilitate sample extraction when the water table dropped below the top of the screen. Samples were collected by applying a vacuum in a sample bottle that was sufficiently large enough to pull water from a connected piezometer into the bottle.

Herbicide and Nitrate Analysis

Concentrations of five solutes (atrazine, alachlor, metolachlor, bromide, and nitrate) were determined in soil and water from the research site. Herbicides concentrations were determined using a Hewlett-Packard 5890A gas chromatograph (GC) in the Nonpoint Source Pollution Project Laboratory in the Department of Soil Science. The GC was equipped with a megabore (10 m by 0.53 mm i.d.) capillary column of intermediate polarity (5/95 phenyl/ methyl liquid stationary phase). The characteristics of the mobile-phase were: support, H 3.5 mL/min-air 100 mL/min; carrier, He 10 mL/min; and makeup, He 20 mL/min. The analytes were measured with a nitrogen-phosphorus detector. Soil-solution subsamples analyzed for herbicides were placed into C-18 solid-phase extraction (SPE) tubes, extracted and concentrated with methanol before GC analysis. Herbicides were extracted from soils with 4:1 v/v methanol:water solutions, concentrated, and then isolated by SPE prior to GC analysis.

Quality assurance and quality control procedures included about 5% duplicates and matrix blanks. In addition, one laboratory-fortified spike was analyzed every 11 samples.

Prior to July 1991, all groundwater samples from standard monitoring wells were analyzed by the Univ. of Wisconsin-Madison, State Laboratory of Hygiene. Piezometer samples and monitoring well samples collected after July 1991, were analyzed in the Department of Soil Science.

Nitrate and bromide concentrations in soil-solution and piezometer subsamples were determined on a Dionex ion chromatograph at the UWEX Soil and Forage Analysis Laboratory, Marshfield, WI. Inorganic ions (bromide and nitrate) were extracted from 1990 soil samples with distilled water and determined by automated analysis and ion selective electrode in the Department of Soil Science. Nitrate concentrations in 1991 and 1992 soil samples were determined at the UWEX Soil and Plant Analysis Laboratory, Madison, WI. Soil samples collected from the ET block and MSEA plots during 1993 were sent to the National Soil Tilth Lab in Iowa for pesticide and nitrate analysis.

Yield Determination

Two, 9.1 m long yield rows in each sub-plot were mechanically harvested with a plot combine 7 October 1991 (DY 280), 27 October 1992 (DY 174), and 18 October 1993 (DY 164) for corn grain yield, moisture content, and percent N determination. Total dry matter accumulation was measured in early July and at maturity (late September/early October) each year. Total N uptake was determined on the end-of-growing-season total biomass samples.

RESULTS AND DISCUSSION

Rainfall, Irrigation, and Water Balance

Rainfall during the 1991 growing season was about five cm less than normal. In 1991, irrigation accounted for about one third of the total water input to irrigated plots. Several large rain events occurred near the time of nitrogen application. There were six, 2-day periods where the combined rainfall/irrigation was greater than 4.1 cm. The risk of receiving a substantial rainfall within a day of irrigation is high and can result in "hydrologic overload" for this soil and rapid percolation of water and dissolved solutes to the groundwater.

Total rainfall for the 1992 season was slightly above normal (Table 2); however, May and June were each about 5 cm below normal, and July and September were above normal. Several large (>2.5 cm) rainstorms occurred in July and September.

The Arena site received about 27 cm more rainfall than the 30 yr average between 1 May and 1 October in 1993. The July plus August precipitation was 21 cm above normal.

Field Water Balance and Drainage

Water drainage from the root zone (100-cm depth) was calculated for each irrigation block. Seasonal water balance components are given in Table 3. Seasonal evapotranspiration values are the sum of daily evapotranspiration values that were calculated by a modified Priestly-Taylor equation (Priestly and Taylor, 1972) based on temperature and solar-radiation values measured continuously at the field and canopy cover. No differentiation was made for evapotranspiration calculations between the two irrigation treatments. Daily root zone water depletion status was determined by subtracting daily evapotranspiration from field water capacity (profile water content after free drainage of a fully wetted profile). Daily rainfall and/or irrigation in excess of the root zone water depletion status resulted in drainage.

Drainage in the non-irrigated treatments could not be calculated by the procedures described above because the occasionally stressed condition of the No-I corn plants violated assumptions of the Priestly-Taylor evapotranspiration techniques. To estimate the drainage in the No-I block for 1991 we employed the comprehensive soil-plant-atmosphere model Cupid (Norman and Campbell, 1983). This model treats energy and mass exchange at the soil-plant-atmosphere interface rigorously and gives reasonable estimates of evapotranspiration for corn under most conditions. Cupid estimates of seasonal evapotranspiration and drainage for the No-I, as well as the irrigated treatments are also given in Table 3.

Drainage at the Arena site is primarily driven by large rainfall events and the often unavoidable situation where a moderate rainfall follows an irrigation. Cumulative growing season drainage was 32 to 39% of total rain plus irrigation in 1991, 48 to 54% during 1992, and 58 to 60% in 1993. Even during the slightly above normal rainfall year of 1992, nearly 50% of the applied water was lost to deep percolation under our 'best' irrigation management practice. Based on the WISP water balance technique, there was about 4 to 10 cm additional drainage from ET+ treatments compared to ET treatments. Comparing the Cupid and WISP water balance estimates, Cupid predicted less evapotranspiration and more drainage than the WISP approach. Drainage from the No-I treatment in 1991 was about 23% of the rainfall input, regardless of the fact that overall rainfall was below normal. This again demonstrates the "hydrologic overload" that occurs when large rainstorms are received at this site.

Table 3. Irrigation, precipitation, drainage, and evapotranspiration at the Arena field site, May through September for the 1991, 1992, and 1993 seasons.

Treatment ‡	Irrigation †			Rain + irrigation				Drainage ¶				Evapotranspiration #			
							30-yr §	Cupid	WISP			Cupid	WISP		
	1991	1992	1993	1991	1992	1993	average	1991	1991	1992	1993	1991	1991	1992	1993
	cm														
No-I	0	0	0	40.7	48.6	73.0	45.7	~~9.5~~ 4.9	---	---	---	~~30.7~~ 37.4	---	---	---
ET	23.1	21.0	10.3	63.8	69.6	83.3		~~24.7~~ 16.2	20.6	33.1	48.2	~~36.2~~ 47.0	41.9	36.8	34.3
ET+	30.5	30.6	13.0	71.2	78.9	86.0		~~29.1~~ 18.4	28.1	42.7	52.4	~~37.5~~ 48.3	41.9	36.8	34.3

† 1991: First irrigation 29 June (DY 180); last irrigation 29 August (DY 241).
1992: First irrigation 1 June (DY 153); last irrigation 5 Sept. (DY 249).
1993: First irrigation 28 June (DY 179); last irrigation 7 Sept. (DY 250).

‡ No-I = no irrigation; ET = irrigated to replace water lost by evapotranspiration according to WISP; ET+ = irrigated at 3.8 cm of rainfall + irrigation per week.

§ Average precipitation recorded at Lone Rock and Prairie du Sac National Weather Service observation sites. ck this wd

¶ Drainage estimated by the soil-plant-atmosphere model Cupid or by water balance using WISP evapotranspiration estimates.

Evapotranspiration calculated from Cupid model or by Priestly-Taylor approach in WISP. ET and ET+ treatments were assumed to have the same evapotranspiration in WISP water balance calculations. Priestly-Taylor approach can not be used to calculate evapotranspiration under moisture stress conditions in No-I treatment.

Soil-Water Atrazine Concentration

1991

Soil-water atrazine data for the 1991 season were summarized in the Lowery and McSweeney (1992) report; thus only a brief summary is given here. In general, peak concentrations of atrazine were measured between 30 and 60 days after application and corresponded closely to major rain events during mid-June. Peak concentrations at the 250-cm depth were less than 4 mg/L. Concentrations up to 3 mg/L were measured at 250 cm under the No-I treatment where we anticipated less leaching because of the relatively small water input. Differences in average atrazine concentrations between the three water management regimes were small, with overall seasonal mean concentrations at 140 cm ranging from 0.6 to 2.3 ppb (coefficient of variation about 110%). However, it is likely there was less overall drainage under the No-I treatment, resulting in less loading to groundwater relative to the irrigated treatments. Estimates of 1991 atrazine loss below the root zone are presented in a later section.

1992

Five replicates each of PCSs, were placed at 60- and 140-cm depths in the ET-MB and ET-NT regular N plots, ET-MB N-Serve plots,and No-I MB and No-I NT plots. These were sampled 18 times from late May to early November. All samples of sufficient volume were analyzed for parent atrazine, deethylatrazine (DEAT), and deisopropylatrazine (DEISOAT). Average concentrations of the three analytes with respect to time for the irrigated and No-I MB and NT plots are shown in Figures 3 and 4, respectively. DEAT was the predominant form of atrazine residue measured at both depths for all treatments and all times. Very few detections of DEISOAT were observed from any treatments.

From the middle of July (DY 200) to the end of September (DY 270) very few samples of sufficient volume were collected from the 60-cm depth samplers. This is presumably a result of high water uptake by plant roots that are concentrated at this depth and the relatively small amount of rainfall during this period. The lack of samples during this period resulted in poorly defined peak solute concentrations at the 60-cm depth. Samples from the No-I block had smaller concentrations of solutes, particularly DEAT. Late season DEAT concentrations at the 60-cm depth under irrigated conditions were 2 to 4 µg/L, suggesting a significant source of DEAT remained in the topsoil.

Atrazine residue concentrations at the 140 cm depth were generally greater under irrigated conditions compared with nonirrigated conditions Figures 3 and 4. Average parent atrazine concentrations were usually less than 1 µg/L and DEAT concentrations were less than 3 µg/L. In contrast, average peak concentrations were in the range of 3 to 4 µg/L for the irrigated treatments. Peak concentrations at 140 cm, occurred shortly after the second week of July (DY 189-195) during which 10 cm of rain followed a 1.5-cm irrigation (Figure 3). Note, this occurred 62 days after herbicide application. The large rain that occurred near DY 325 may have caused a residual pulse of parent atrazine to be leached out of the topsoil as is evidenced by a slight increase in atrazine concentrations during the last sampling for many of the treatments (Figures 3 and 4).

Similar to previous years with respect to tillage comparisons, there were only small differences observed in soil-water atrazine concentrations. Under irrigated conditions there was a trend toward greater DEAT concentrations under MB as compared to NT. This is evident by the peak concentration being more than double in the MB compared with NT (Figure 3).

Atrazine Residue Flux Estimations

For both the 1991 and 1992 seasons, the flux of atrazine or atrazine and metabolites was estimated by combining daily drainage estimates described earlier, with estimates of daily solute concentration. The daily atrazine or metabolite concentrations were calculated by performing a piece-wise linear fit to observed average solute concentrations from the 140-cm depth. Ninety-five percent confidence intervals of the mean concentrations were also obtained.

1991

For the 1991 flux estimates, the model Cupid was used to predict drainage. The drainage estimates were combined with daily atrazine concentrations (averaged across tillage and polymer) for the three irrigation regimes. A short summary is presented here, a more complete description of 1991 solute flux estimations, including graphs was presented by Fermanich et al. (1993), and is included as Appendix A to this report. Seasonal atrazine flux below the root zone ranged from 0.22% (0.002 kg/ha) of the applied for nonirrigated plots to 0.75% (0.007 kg/ha) for the greatest irrigation regime. Taking into consideration variability in leachate solute concentrations, the upper bound of atrazine flux estimates were more than double the average estimates. Overall estimated loss to groundwater is small. However, we calculated that it would take only 1.5% of the applied atrazine (given a 0.84 kg/ha application) to contaminate the top 1 m of the aquifer to a level equal to or greater than the Wisconsin groundwater enforcement standard (ES; 3.0 μg/L) given uniform distribution and an estimated aquifer porosity of 45%.

1992

Preliminary flux estimations for atrazine and the two metabolites from the ET (WISP) irrigated treatments are given in Table 4. Drainage estimates from the WISP water balance approach were used to make solute flux calculations since the Cupid simulations have not been completed. Note that the WISP drainage calculations in 1991 were smaller than the Cupid simulations (Table 3). The mean flux estimated for atrazine averaged across tillage in 1992 was 0.58% of the applied, which is very close to the amount estimated in 1991 (0.55% of applied). These flux estimates are very similar regardless of the fact that 9 to 13 cm more drainage occurred in 1992, suggesting that atrazine concentrations were smaller in 1992, particularly during large drainage periods.

Table 4. Growing season atrazine and metabolite flux at 140 cm for the treatment block that was irrigated according to WISP, Arena, WI, 1992. Flux values were calculated from average soil-water solute concentration measurements and drainage estimates based on WISP.

Treatment †	Deisopropylatrazine			Deethylatrazine			Atrazine		
	Lower ‡	Mean	Upper	Lower	Mean	Upper	Lower	Mean	Upper
	kg/ha (% of applied atrazine §)								
ET NT	0	0.0003	0.0009	0.0013	0.0058	0.0118	0.0013	0.0031	0.0076
		(0.04)	(0.13)	(0.18)	(0.78)	(1.62)	(0.15)	(0.37)	(0.90)
ET MB	0	0.0006	0.0017	0.0010	0.0105	0.0246	0.0002	0.0053	0.0164
		(0.09)	(0.25)	(0.14)	(1.44)	(3.38)	(0.02)	(0.63)	(1.95)
ET Avg.	0	0.0005	0.0015	0.0001	0.0091	0.229	0.0	0.0049	0.0165
		(0.07)	(0.22)	(0.01)	(1.25)	(3.15)		(0.58)	(1.96)

† ET = irrigated to replace water lost by evapotranspiration according to WISP; NT = no-tillage; MB = moldboard plow tillage; ET Avg. = solute concentrations were averaged across tillage treatments prior to flux calculations.

‡ Piece-wise linear model fit to the mean soil-water solute concentrations for each sampling date and to the lower and upper 95% confidence intervals of the mean concentrations.

§ Percent of applied for each compound based on molar equivalents of a 0.841 kg ai/ha (3.8989 moles/ ha) atrazine application.

Atrazine and DEAT fluxes from MB plots were about twice those of NT (Table 4). We use the same drainage estimates to calculate the solute flux for both tillage treatments, therefore, differences are a result of overall soil-water concentrations and/or the timing of peak concentrations with respect to major drainage events. For both tillage treatments, DEAT flux at a depth of 140 cm for the season was more than twice that of parent atrazine. Total residue flux (DEISOAT+DEAT+Atrazine) for the season was 1.2% of applied for NT and 2.2% of applied for MB. The upper bound on the flux estimates are more than twice the mean estimates based on variability in measured solute concentrations.

Groundwater Monitoring Results

Piezometers were sampled a total of seven times in 1991, eleven times in 1992 and nine times in 1993. Results from 1991 samplings were summarized in the Lowery and McSweeney (1992) report. Figures 5 and 6 show representative concentration vs. time profiles for paired piezometers (shallow and deeper) during 1992. DEAT was greater than atrazine in nearly all samples. Atrazine concentrations were consistently less than 1 μg/L, except for piezometer 13, and there was little evidence of a "slug" input to the groundwater resulting from the early May atrazine application.

Piezometer data for the period 1 May 1991 through 12 July 1993 are shown for several piezometers in Figure 7. Piezometers 3 and 4 are located down gradient from the ET+ irrigation treatment which received atrazine in 1990, 1991 and 1992, but not in 1993. There is a trend of decreasing atrazine concentrations throughout 1991 and in to late summer 1992. The relatively high concentrations in early 1991 were presumably from atrazine that leached as a result of the above normal precipitation that occurred in the 1990 growing season. Atrazine and DEAT concentrations appear to increase in September and October 1992. This increase was likely from the 1992 atrazine application. We expect the concentrations to continue to decrease in samples from the remainder of 1993 since no atrazine was applied up-gradient of these wells since May 1992. To help discern treatment impacts on groundwater atrazine residue concentrations we plan to map spatial concentration contours across the site for several time periods.

Nitrate-nitrogen concentrations in 1992 piezometer samples ranged from 0.2 mg/L in wells up-gradient of the site to 55 mg/L for samples collected directly beneath treated areas. The mean and median NO_3-N concentration for all piezometer samples were 11.7 and 10.9 mg/L, respectively. Sixty-one percent of the wells had NO_3-N concentrations greater than 10 mg/L. Figure 8 shows nitrate-N concentrations during 1992 for two nests of piezometers located at three depths. Multi-year trends in NO_3-N data for piezometers 3, 4, and 23 are presented in Figure 9. For the time period shown in Figure 9, NO_3-N concentrations fluctuate from about 8 to >25 mg/L. Similar to atrazine, there was an increase in nitrate concentrations in the fall of 1992. Piezometer 23 in Figure 9 shows that NO_3-N concentrations have remained below 10 mg/L directly down-gradient from plots that received only a small amount of N fertilizer at planting.

Nitrogen Leaching Assessment

The nitrate content at the 60-cm depth rapidly increased immediately following nitrogen fertilization in 1991 and 1992 (Figures 10 and 11). Porous-cup samplers at the 60-cm depth were positioned at an angle so that the sampling point was directly beneath the zone of application. This configuration is the reason for the very large NO_3-N concentrations in the 60 cm samplers. In both years, at least one large (>2.5 cm) rainfall occurred shortly after N application and carried a portion of the N fertilizer down to the middle of the root zone. The concentration of NO_3-N at a depth of 140 cm directly beneath the row was generally <20 mg/L for both years and all treatments. There was a noticeable increase in nitrate concentration at the 140 cm depth for ET NT plots in 1991 within 20 days after application (Figure 10). From mid-August (DY 225) to the end of the growing season (DY 275), very little nitrate was collected at 140 cm. Plant growth and N-uptake are rapid during that time of the season and likely limited the amount of N available to be leached.

Soil core data for 1991 show an increase in NO_3-N below the root zone of about 20 kg N/ha in ET between late April (DY 115) and mid-October (Figure 12). The increase was about the same for the ET+ treatment, but only about half as large in the No-I plots. Nitrate flux below the root zone, based on PCS nitrate-N concentrations and drainage estimates, were calculated to be 12, 20 and 58 kg N/ha for the No-I, ET and ET+ treatments, respectively (see Appendix A for details). If we assume that the soil cores taken in mid-October "captured" all of the nitrate lost to deep percolation during the growing season, then these two different techniques of estimating leaching losses agree very well. Nitrate soil and leachate flux data for 1992 have not been completely analyzed at this time.

SUMMARY

This report presented results primarily from the 1992 growing season in which overall rainfall was slightly (6%) above normal. However, precipitation in May and June was 50% below normal and July through September precipitation was 42% above normal. Drainage below the root zone, based on a simple water balance approach utilizing WISP, ranged from 32% of the total rain plus irrigation for the dry 1991 season to 60% of the total water input for the very wet 1993 growing season. Drainage was primarily driven by large (>2.5 cm) rainstorms, particularly when they occurred immediately after irrigation.

Deethylatrazine was the dominant form of atrazine residue in soil-water and groundwater collected from irrigated and non-irrigated treatments. Parent atrazine was found at concentrations about one-half of that measured for deethylatrazine, and deisopropylatrazine was only detected infrequently. As expected, atrazine residue concentrations in soil-water collected beneath non-irrigated plots were substantially lower (two to four times) than those measured beneath irrigated plots.

The mean atrazine flux below the root zone, calculated from 1991 soil-water concentration measurements and drainage estimates, were less than 1% of that applied for all three water input treatments. Parent atrazine flux from the ET irrigated plots in 1992 was very similar to that estimated for the 1991 growing season (about 0.55% of applied). For 1992, we estimated that total atrazine residue flux below root zone of irrigated MB plots was about twice that of NT plots. We estimated that total average atrazine residue flux to groundwater during the growing season was 1 to 2% of the applied atrazine. This quantity (1 to 2% of applied) is enough to cause the Wisconsin groundwater enforcement standard (3 μg/L) to be exceeded in the top one meter of the aquifer. Groundwater monitoring results confirm that total residue concentrations beneath treated plots have exceeded 3 μg/L on several occasions and at several locations.

Parent alachlor was not detected in any soil-water or groundwater samples with the analytical procedures we employed in this study.

Nitrate concentrations in the root zone often exceeded 60 mg NO_3-N/L following N fertilization. Large rainstorms shortly after N application caused NO_3-N concentrations >10 mg/L in soil water collected below the root zone. For the "best" irrigation management strategy (ET) in 1991, we estimated that only 20 kg N/ha were lost to groundwater during the growing season. This suggests that timing of nitrogen applications coincided with plant demand in 1991. Seasonal fluctuations of NO_3-N concentrations in groundwater range from about 8 to 30 mg/L.

Future work on 1991 through 1993 data include: spatial analysis of groundwater data to determine treatment effects; calculate atrazine residue and nitrate flux below the root zone using Cupid drainage estimates; and perform nitrogen budget analysis with respect to plant uptake, soil N content and estimated leachate losses.

CONCLUSIONS

We know that from previous studies (Lowery and McSweeney, 1992) the soil-landscape setting at the Arena site in the LWRV has a very low water holding capacity and conducts excess precipitation or irrigation water quickly (1 to 2 days) through the unsaturated zone to groundwater. Furthermore, we know that because of the physical and chemical characteristics (small organic matter and clay content, type of organic matter, etc.) of Sparta sand, this soil-landscape setting possesses relatively little capacity to sorb atrazine and retard its movement with percolating water. It is this combination of characteristics that enables a small percentage (albeit significant) of the atrazine applied to the land surface to migrate to groundwater during the growing season of application in this soil-landscape setting. Specific conclusions are as follows:

1. Deethylatrazine was the primary form of atrazine residue that leached from the root zone of Sparta sand. Parent atrazine also leached from the root zone of this soil to groundwater during the year of application, but at less than half the levels found for deethylatrazine.

2. Irrigation increased the amount of atrazine residues and nitrate that leached below the root zone, but large rainstorms (>2.5 cm) were the driving force for leaching. Even under the rainfed (nonirrigated) conditions, substantial quantities of rainfall (>20%) can percolate to groundwater during the growing season and carry with it significant amounts of atrazine residue and/or nitrate.

3. The relationship, with respect to timing between occurrence of deep percolation causing rainstorms and agrichemical concentration in the upper root zone, controls the amount of agrichemical lost to groundwater.

4. There was a trend toward less atrazine residue leaching under NT compared with MB treatments, especially during the 1992 growing season.

REFERENCES

Fermanich, K.J., B. Lowery, W.L. Bland, and K. McSweeney. 1993. Water, atrazine, and nitrate flux below the root zone of a sandy soil. p. 92-99. In Proc. Agricultural Research to Protect Water Quality Conf. Minneapolis, MN. 21-24 Feb. 1993. Soil and Water Conserv. Soc., Ankeny, IA.

Lowery, B., and K. McSweeney. 1992. Effect of soil type, selected best management practices, and tillage on atrazine and alachlor movement through the unsaturated zone. Final Report to the Wisconsin Department Agriculture, Trade and Consumer Protection, Pesticide Research Program. 30 July 1992. Dep. of Soil Science, Univ. of Wisconsin-Madison.

Norman, J.M., and G.S. Campbell. 1983. Application of a plant-environment model to problems in irrigation. p. 158-188. In D. Hillel (ed.) Advances in irrigation. Academic Press, New York.

Priestly, C.H.B., and R.J. Taylor. 1972. On the assessment of surface heat flux and evapotranspiration using large-scale parameters. Mon. Weather Rev. 100:81-92.

Stites, W., and L.W. Chambers. 1991. A method for installing miniature multilevel sampling wells. Ground Water 29:430-432.

LIST OF FIGURES

Figure 8. Nitrate-N concentrations in two nests of piezometers located at the west side of the Arena site, 1992. Piezometers 7, 8, and 34 were located immediately down- gradient of MSEA corn plots and sampled water from about 0 to 45, 75 to 120, and 175 to 220 cm below the water table, respectively. Piezometers 11, 12, and 35 were located immediately down-gradient from WISP (ET) irrigated plots and sampled similar depths of the aquifer to piezometers 7, 8, and 34, respectively.

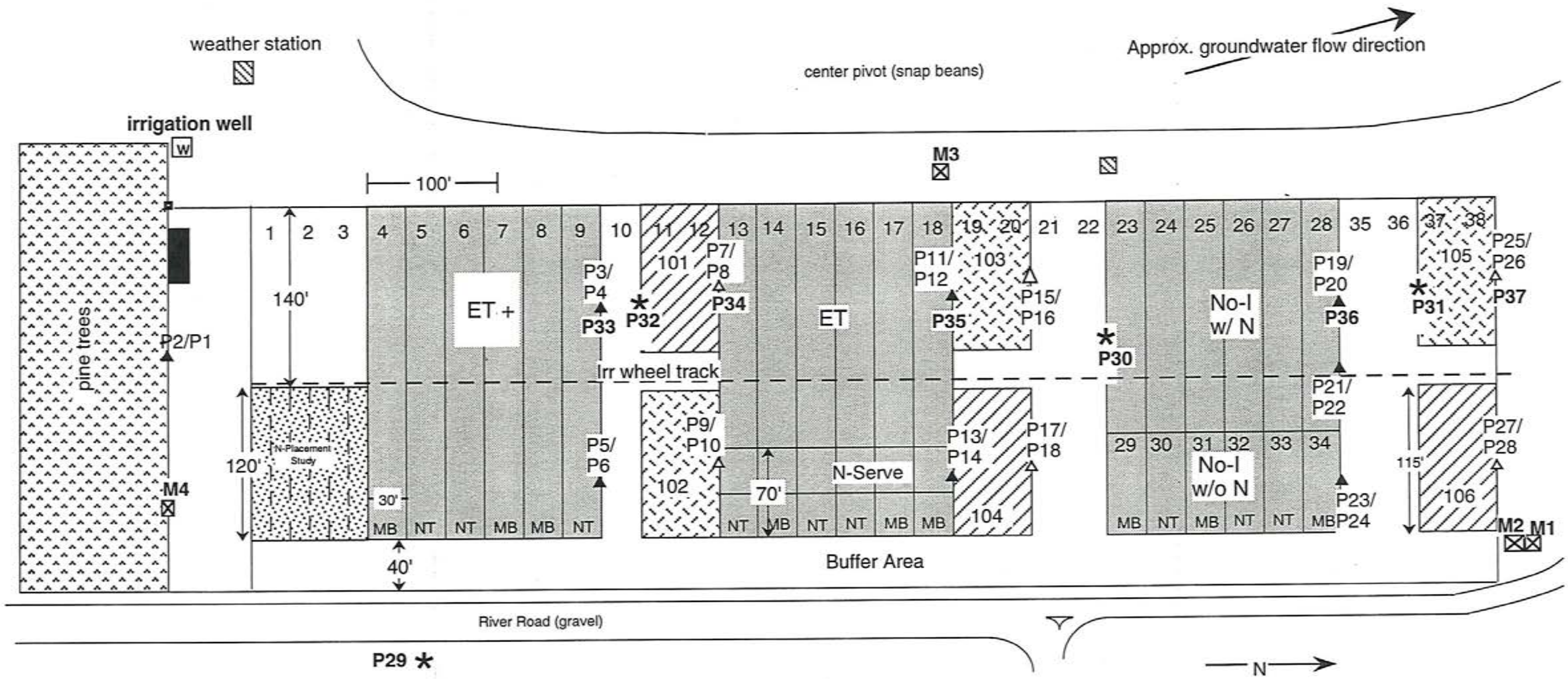
Figure 9. Nitrate-N concentrations in piezometers 3 and 4 located immediately down-gradient from corn plots in 1991 and 1992 and soybean plots in 1993. The plots were irrigated at ET+ in 1990, 1991, and 1992 and irrigated according to WISP in 1993. Piezometer 23 is screened at the water table and is located immediately down-gradient from plots that have been under nonirrigated, no-nitrogen treatments from 1990 through 1993.

Figure 10. Nitrate-N concentration in soil water collected from 60 and 140 cm beneath the soil surface at Arena, 1991. ET = irrigated according to WISP, MB = moldboard plow tillage, and NT = no-tillage. Arrows denote when N fertilizer was applied.

Figure 11. Nitrate-N concentrations in soil water collected at 60 and 140 cm below the soil surface at Arena, 1992. ET = irrigated according to WISP, MB = moldboard plow tillage, and NT = no-tillage. Nitrogen fertilizer was split applied on 4 June (DY=156) and 18 June (DY=170). The numbers above the symbols are the number of samples averaged for that sampling date.

Figure 12. Soil nitrate content under ET irrigated (irrigated according to WISP) moldboard plow tillage (MB) and no-tillage (NT) plots, Arena, 1991. Nitrogen fertilizer was split applied on 7 June (DY=158) and 17 June (DY=168).

Figure 1. Schematic map of Arena research site,1992 .



Treatments

No-I	no supplemental irrigation
ET	irrigated to meet evapotranspiration water losses
ET +	irrigated to obtain 1.5" total water per week
MB	moldboard plow (conventional tillage)
NT	no-till (conservation tillage)

Legend:

- Buffer Areas and headrows
- IRRIGATION RESEARCH PLOTS
- CORN--MSEA
- SOYBEANS--MSEA
- △ **Piezometer well--MSEA**
- ▲ **Piezometer well--Irr. treatments**
- ⊠ **monitoring well**
- * **new piezometer April 1992 (3' screen)**

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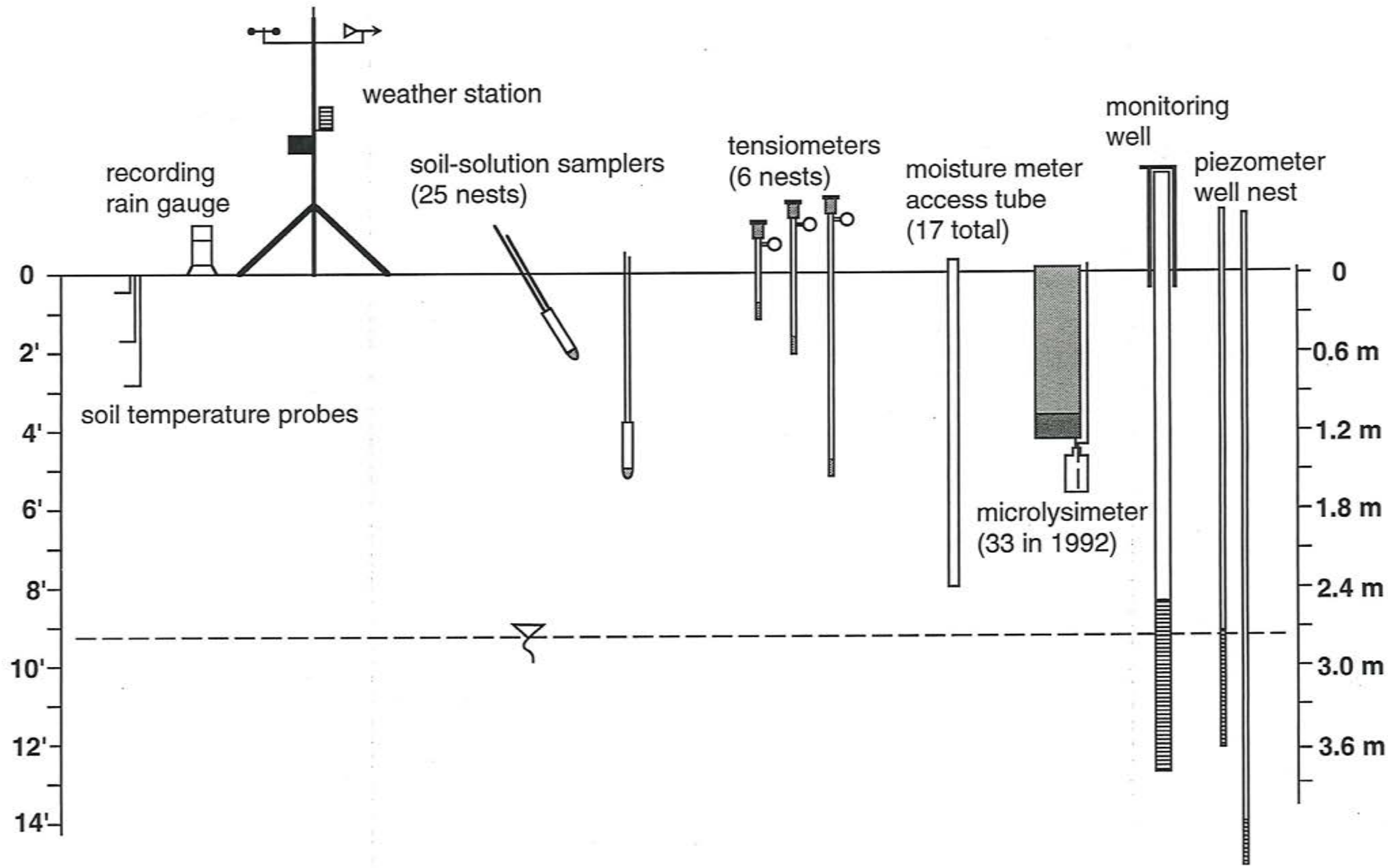
Figure 2. Instrumentation at Arena Research Site, 1992



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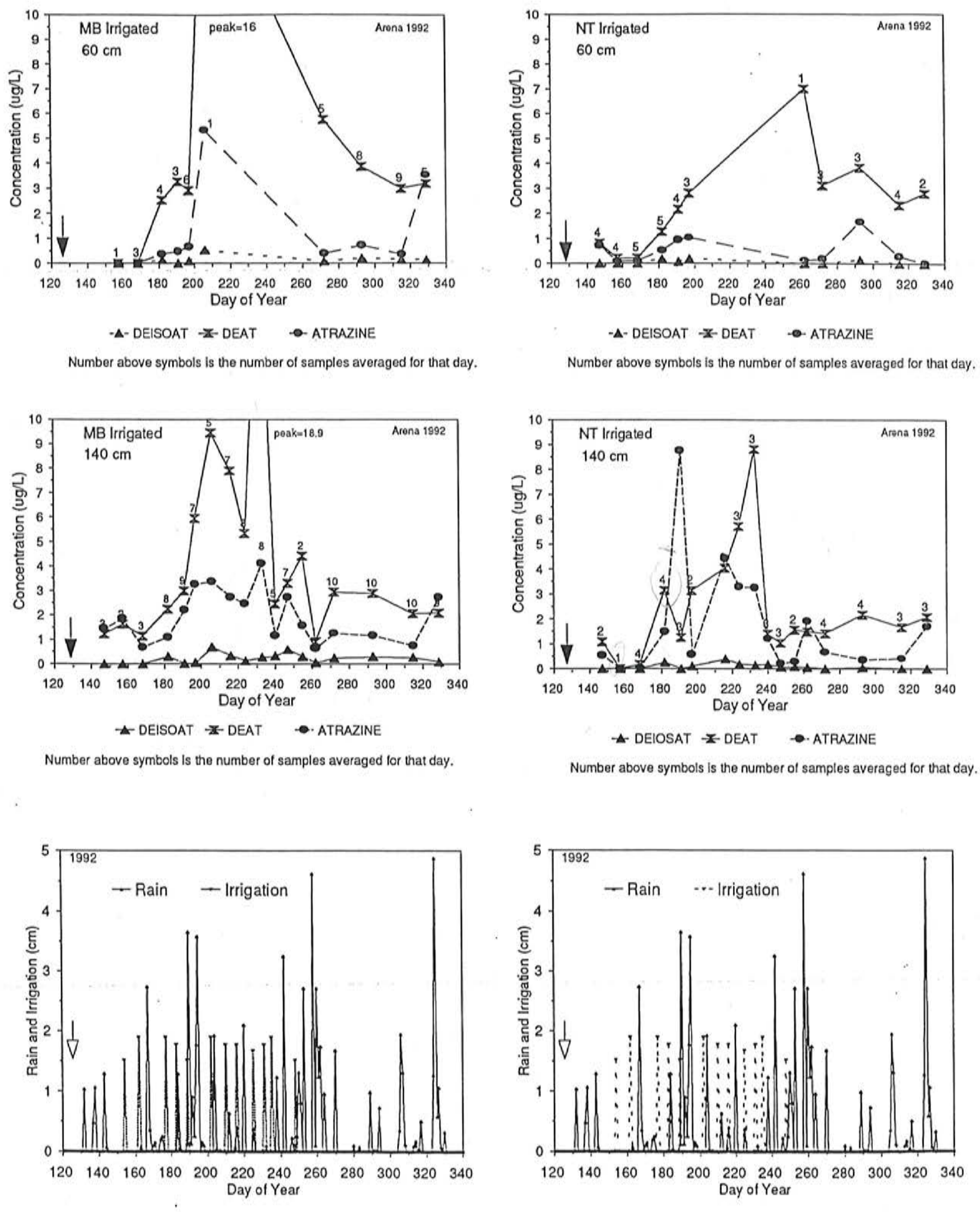


Fig. 3. Mean atrazine, deethylatrazine (DEAT) and deisopropylatrazine (DEISOAT) concentration in soil-water collected at 60 and 140 cm beneath irrigated moldboard plow tillage (MB) and no-tillage (NT) plots, Arena, WI., 1992. MB data are averaged across with- and with-out N-Serve nitrogen, fertilizer treatments. Bottom graphs show daily rainfall and irrigation. Arrows denote atrazine application date of 6 May (DY=127).

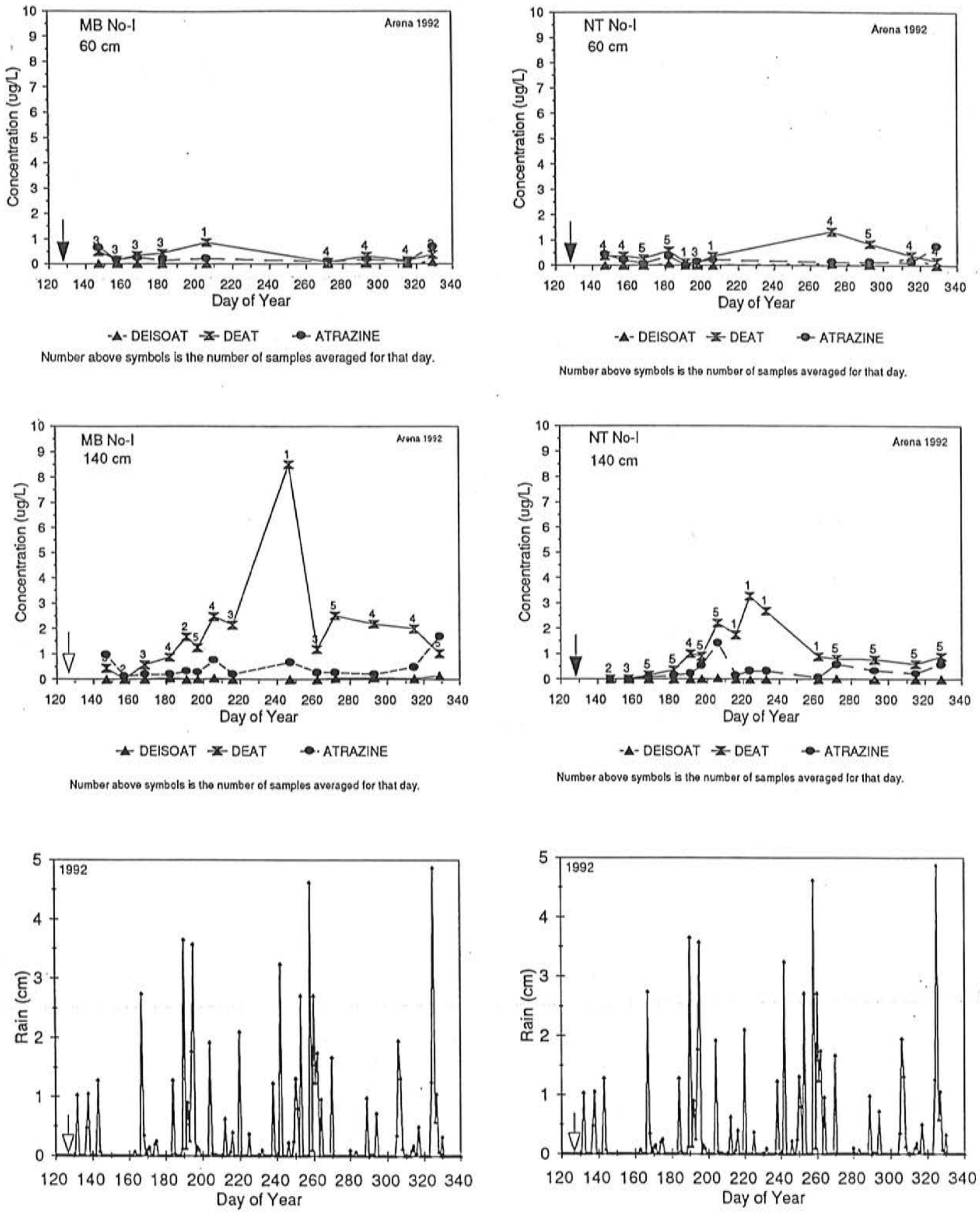


Fig. 4. As for Fig. 3 except under nonirrigated (No-I) treatments. Also, there are no N-Serve nitrogen fertilizer treatments.

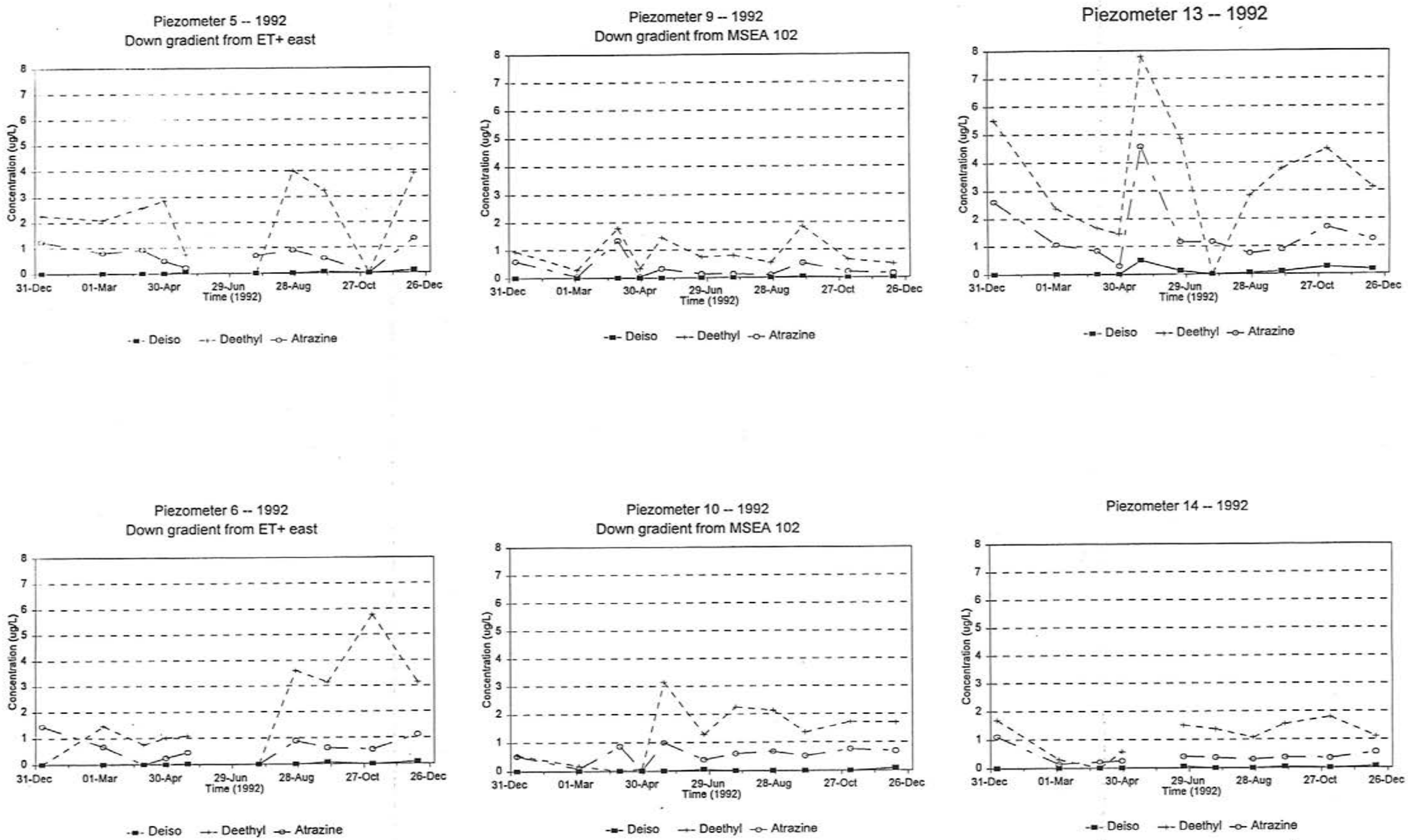


Fig. 5. Atrazine, deethylatrazine (Deethyl) and deisopropylatrazine (Deiso) concentration in groundwater collected from the east side of the Arena site, 1992. Piezometers 5, 9, and 13 have 90 cm screened intervals located at the water table and collected water from the top 30 to 60 cm of the aquifer in 1992. Piezometers 6, 10, and 14 are nested with piezometers 5, 9, and 13, respectively, and have 30 cm screened intervals that collected water from about 120 to 150 cm below the water table. Piezometers 5 and 6 were immediately down gradient of the highest irrigation treatment, piezometers 9 and 10 were immediately down gradient from MSEA soybean plots that did not receive atrazine in 1992, and piezometers 13 and 14 were immediately down gradient of WISP (ET) irrigated plots.

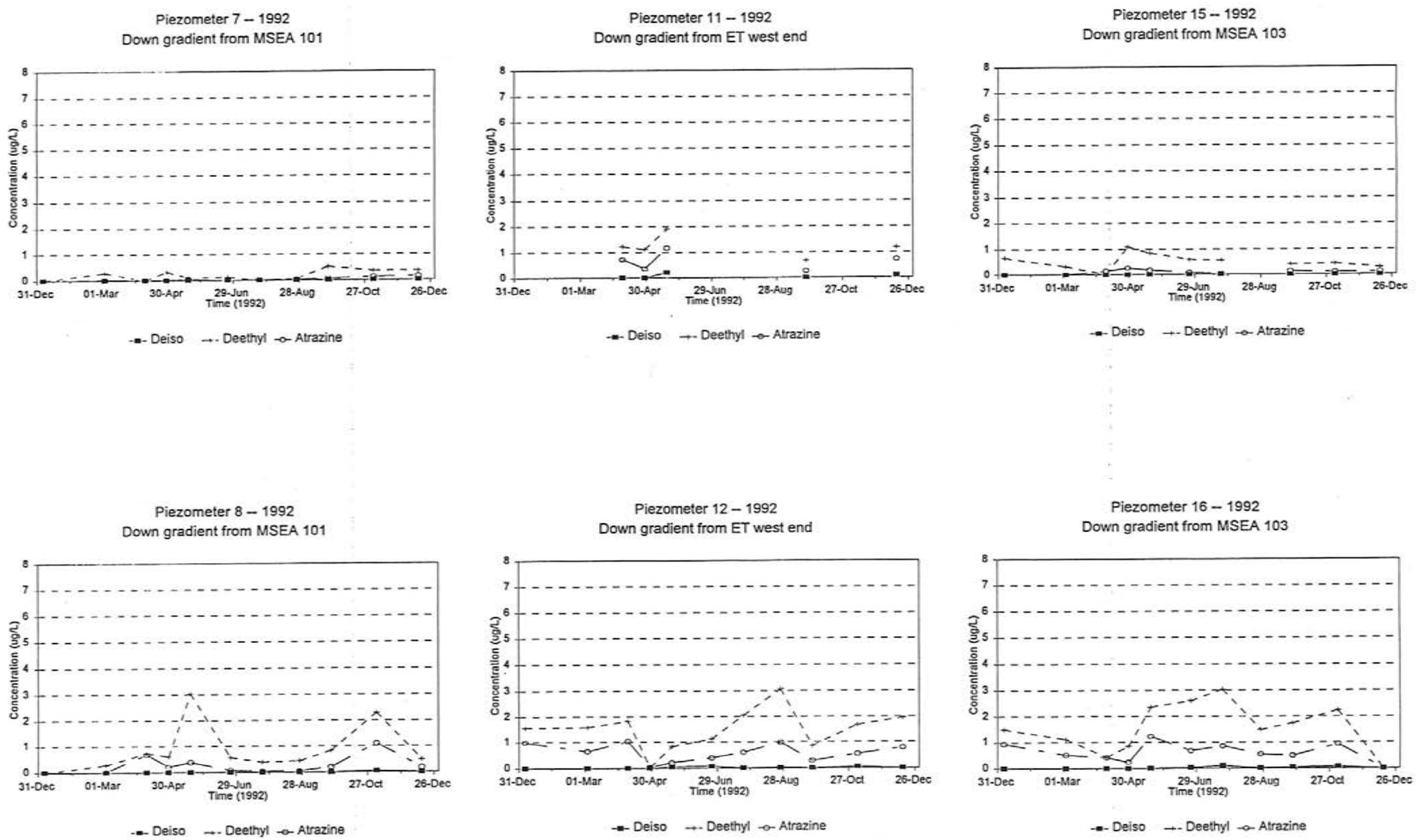
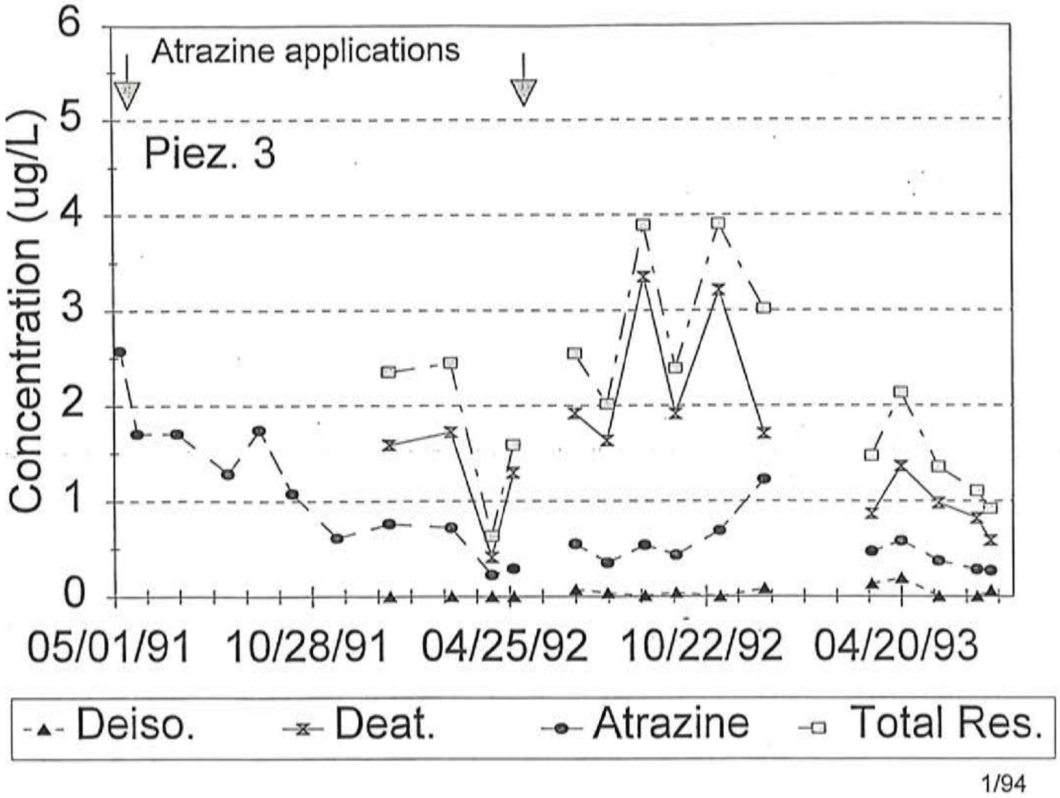


Fig. 6. Atrazine, deethylatrazine (Deethyl) and deisopropylatrazine (Deiso) concentration in groundwater collected from the west side of the Arena site, 1992. Piezometers 7, 11, and 15 have 90 cm screened intervals located at the water table and collected water from the top 0 to 45 cm of the aquifer in 1992. Piezometers 8, 12, and 16 are nested with piezometers 7, 11, and 15, respectively, and have 30 cm screened intervals that collected water from about 75 to 120 cm below the water table. Piezometers 7 and 8 were located immediately down gradient from MSEA band-applied atrazine plots, piezometers 11 and 12 were located immediately down gradient from WISP (ET) irrigated plots, and piezometers 15 and 16 were located immediately down-gradient from MSEA soybean plots that did not receive atrazine in 1992.



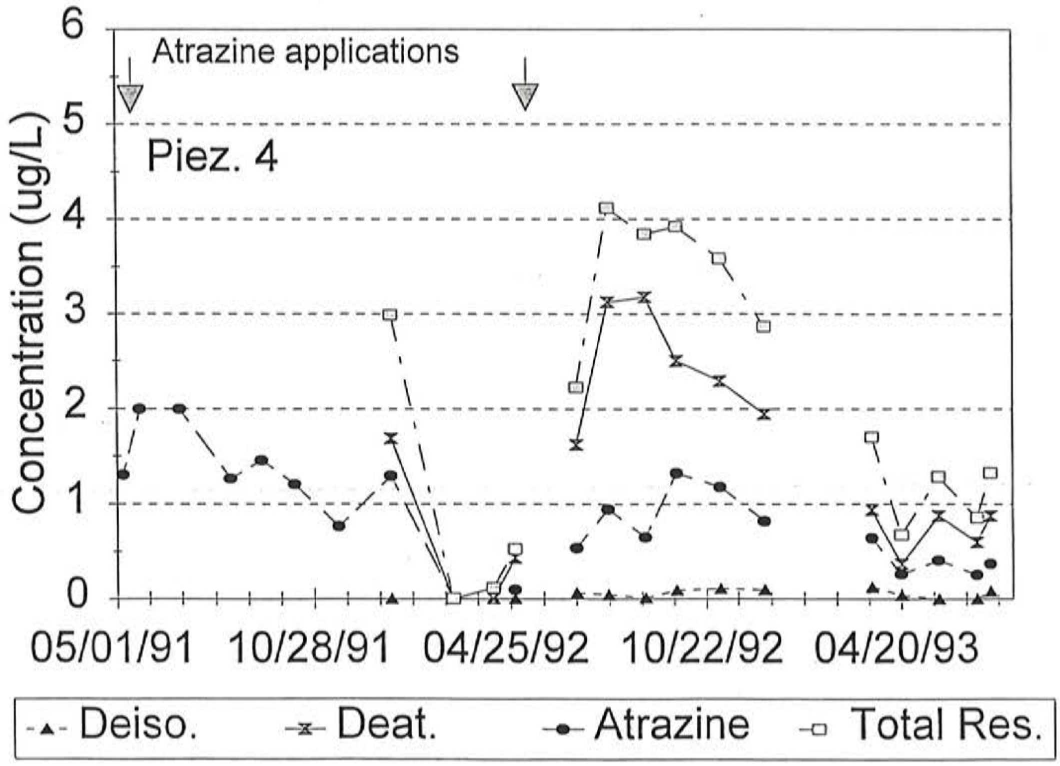
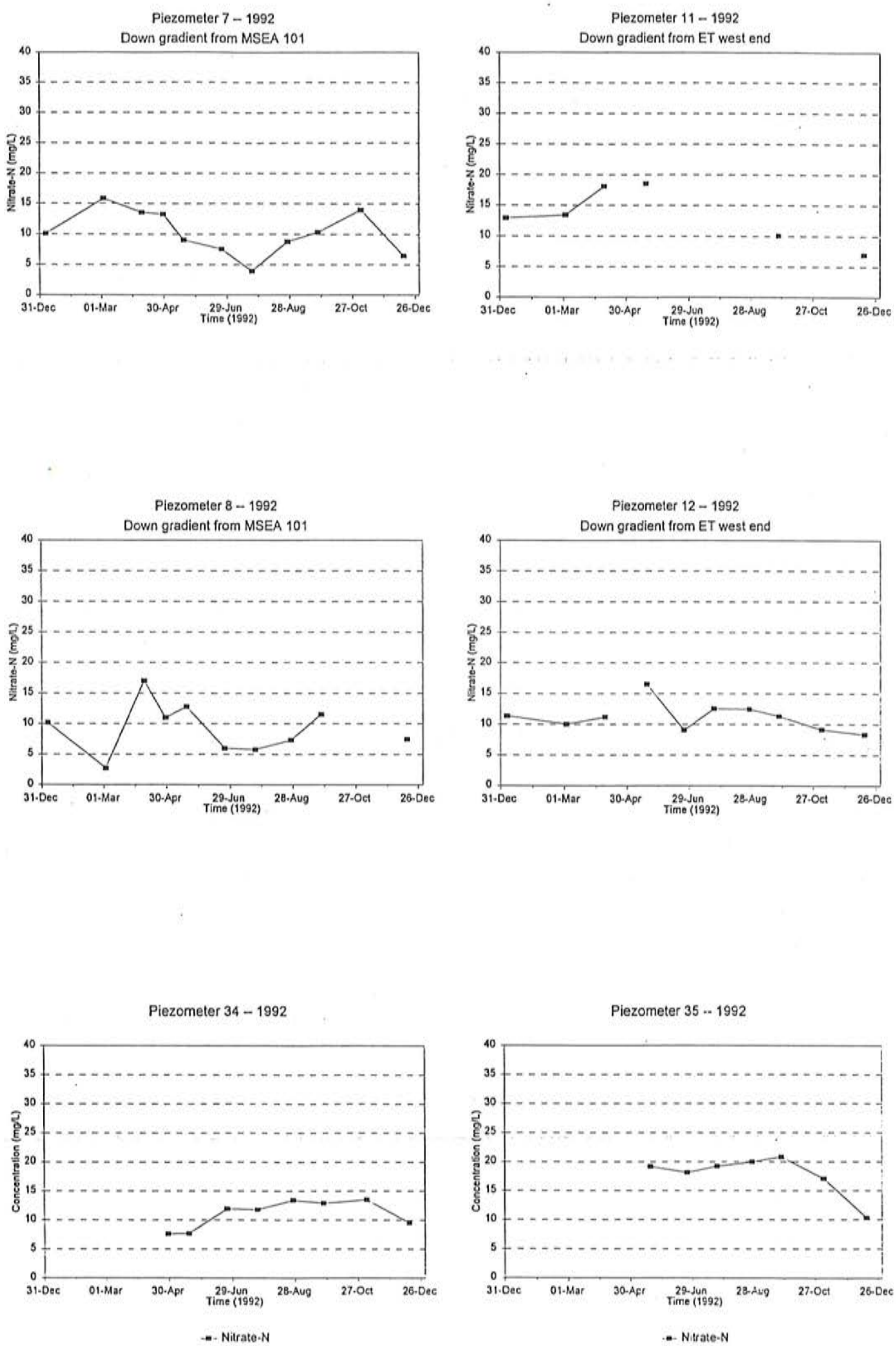


Fig. 7. Atrazine, deethylatrazine (Deat), deisopropylatrazine (Deiso) and sum of atrazine+Deat+Deiso (Total Res.) concentrations in nested piezometers located immediately down gradient from ET+ irrigation treatments (3.8 cm of total water per week). The ET+ treatment received atrazine applications in early May of 1990, 1991, and 1992. Piezometer 3 collected water from the top 0 to 90 cm and piezometer 4 sampled water from about 120 to 180 cm below the water table.



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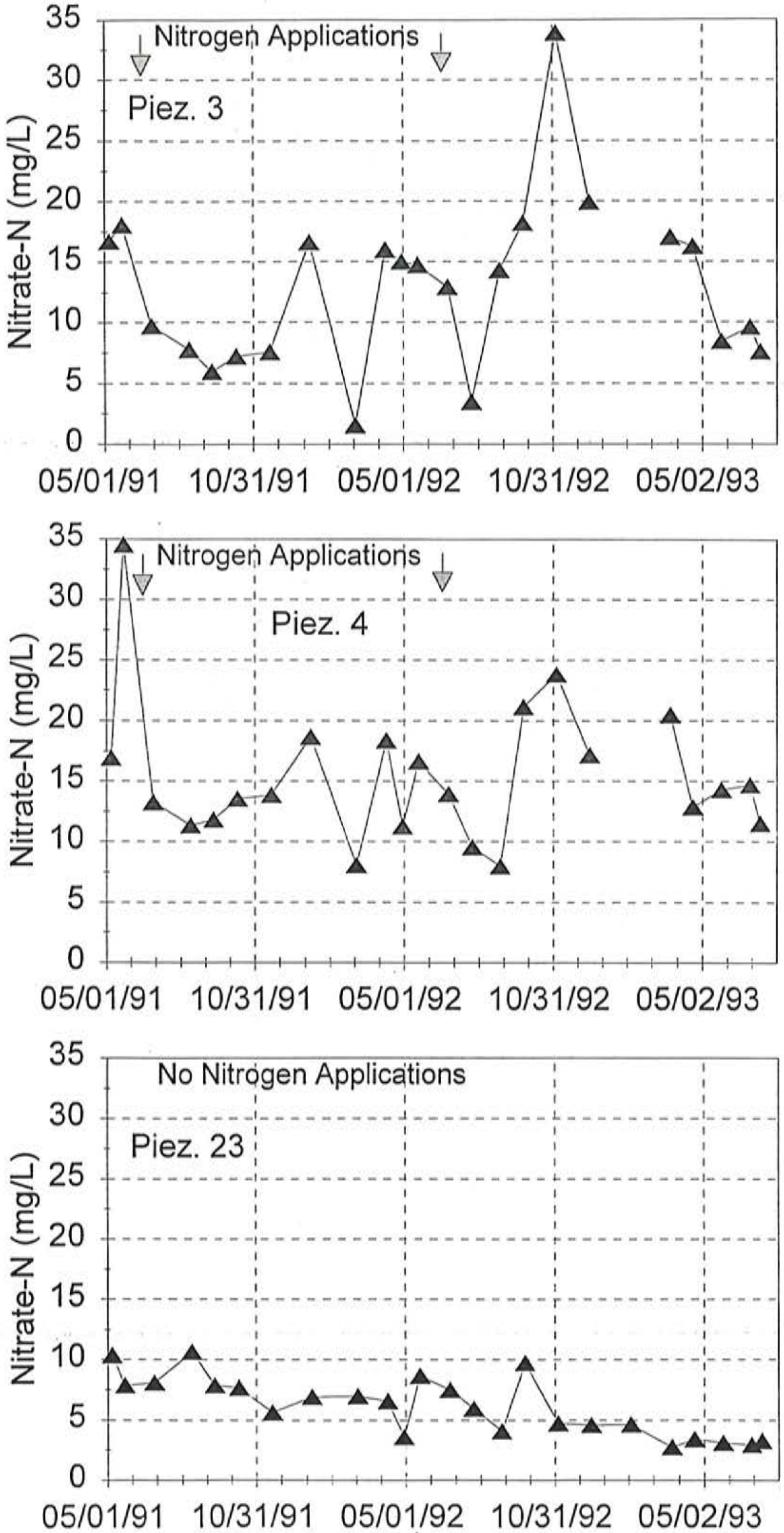
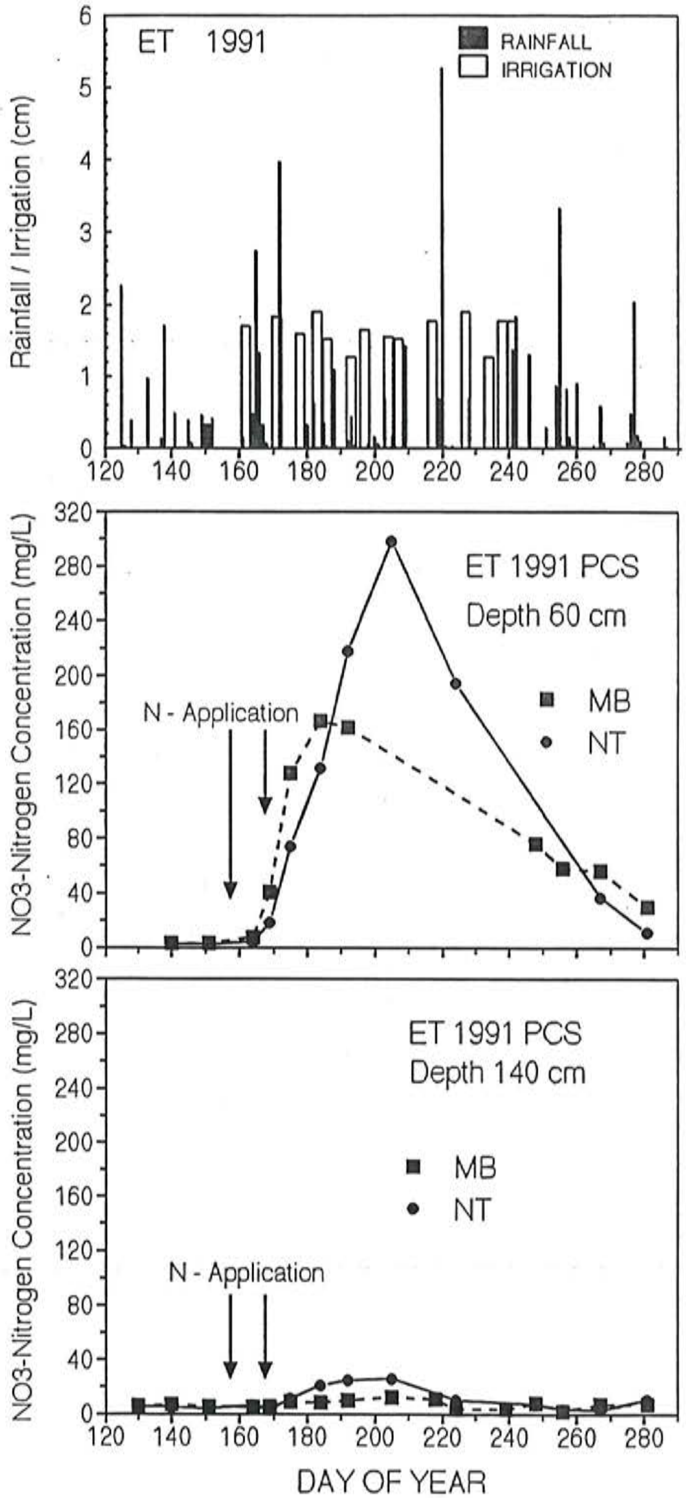


Fig. 9. Nitrate-N concentrations in piezometers 3 and 4 located immediately down gradient from corn plots in 1991 and 1992 and soybean plots in 1993. The plots were irrigated at ET+ in 1990, 1991, and 1992; and irrigated according to WISP in 1993. Piezometer 23 is screened at the water table and is located immediately down gradient from plots that have been under nonirrigated, no-nitrogen treatments from 1990 through 1993.



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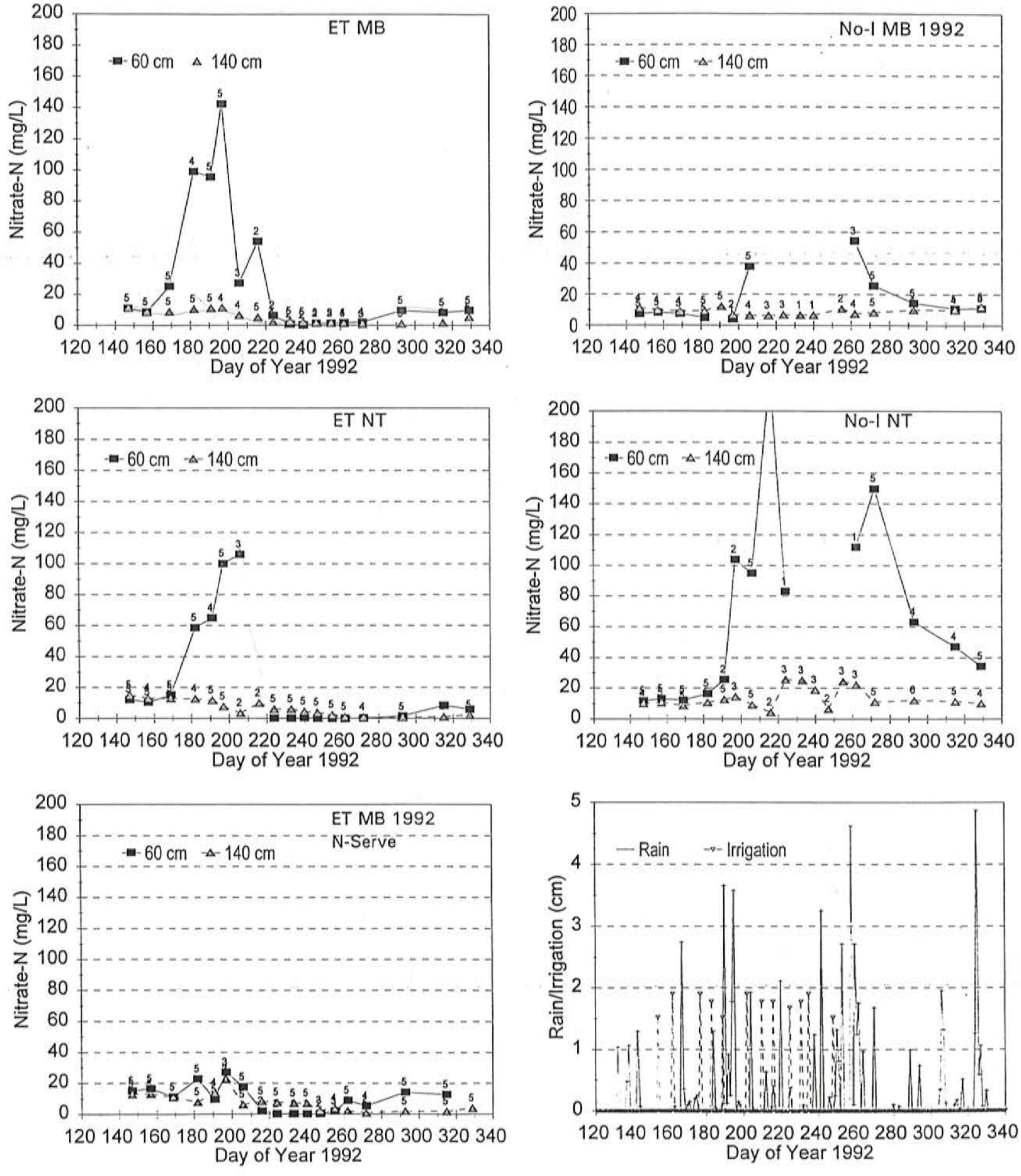

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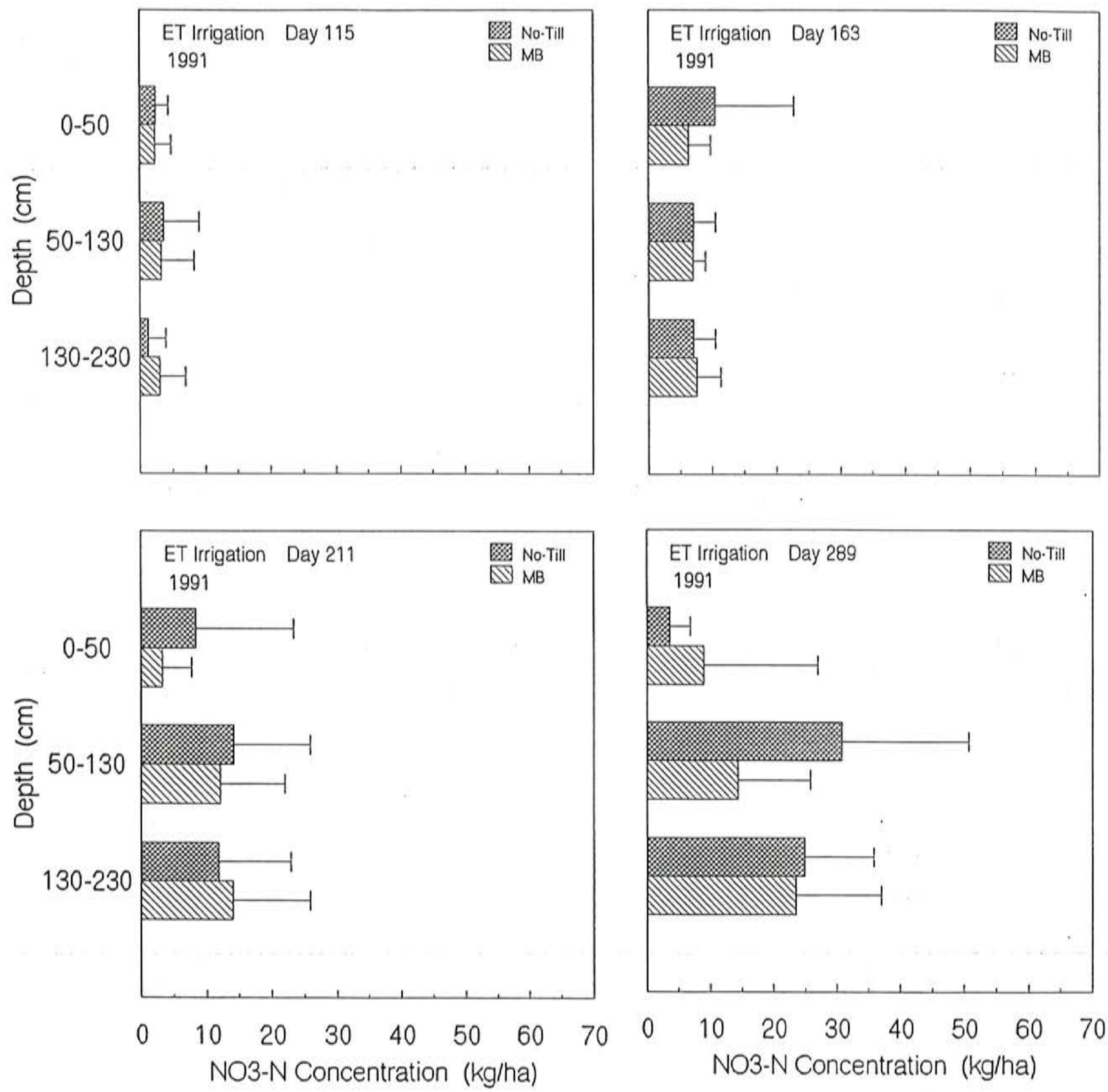

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APPENDIX A.

Water, atrazine, and nitrate flux below the root zone of a sandy soil.

K.J. Fermanich, B. Lowery, W.L. Bland, and K. McSweeney.

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