

**WATER-COLUMN SEDIMENT NUTRIENT
INTERACTIONS AS A FUNCTION OF HYDROLOGY
(HOPKINS PRAIRIE)**

FINAL REPORT, 1991-92

by

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EXECUTIVE SUMMARY

The St. Johns River Water Management District has undertaken a research project to investigate the effects of fluctuating water levels on the ecological functions of wetlands. Hopkins Prairie, a relatively pristine, herbaceous wetland, located in the Ocala National Forest, Florida, has been chosen as a long-term ecological research site for this purpose. In 1989, the University of Florida, Department of Soil Science, was contracted by the District to evaluate the effects of hydrology, particularly water table levels, on the biogeochemistry of nutrients in Hopkins Prairie soils. The research reported herein is a continuation of this project.

This study included three tasks:

- Task 1 - to relate water table level to changes in concentrations of water-extractable nutrients.
- Task 2 - to relate the effects of alternating flooding and draining of an organic wetland soil on the distribution and availability of major plant nutrients.
- Task 3 - to quantify the effects of sulfate reduction on organic matter decomposition.

Two sampling sites were selected within the prairie to correspond with ongoing research by the District and other contractors. One site was located in an open water marsh area, dominated by the macrophytes, Rhynchospora inundata, Eriocaulon compressum, Eleocharis elongata and Nymphaea

odorata. A second site was selected within the nearby sawgrass community (dominated by C. ladium jamaicens and Cephalathus occidentalis). Three sampling replications were used at each location.

The effect of water table fluctuation on soil redox potential and concentrations of water extractable nutrients in the soil was determined by field sampling during a period from May 1991 through January 1992. Redox measurements and soil cores to a depth of 60 cm were taken at approximately monthly intervals. Intact soil cores were also taken from the two sampling locations at one sampling time to evaluate the effect of water table depth on nutrient transformations under controlled laboratory conditions.

There was no overlying water on the prairie during the entire study period but the water table within the soil fluctuated due to rainfall. The redox potential of the soil, which is a measure of aeration, reflected the water table depth within the soil profile for both field and laboratory studies. Measurements made under laboratory conditions were more sensitive to water table fluctuation than those made in the field because measurements were made more frequently and without the interference of rainfall events between sampling periods.

Water table depth affected nutrient transformations within the soil profile, as indicated by both field and laboratory studies. Ammonium was converted to nitrate in the

aerobic zone above the water table and was subsequently lost from the system through denitrification (conversion of nitrate to nitrogen gas) as the water table moved upward toward the soil surface. Soluble reactive phosphorus concentration was low in the entire profile for both soils. This indicates the P may be the limiting factor for plant growth in this ecosystem. Soluble reactive phosphorus did not show any relationship to water table fluctuation in the field study although subsequent laboratory studies suggested that phosphorus concentrations were lower above than below the water table.

Sulfate reduction, which is a driving force for organic matter decomposition in anaerobic soils, occurred in Hopkins Prairie soil, but at unexpectedly slow rates. It appears that the organic matter in these soils is only slowly available to microbes. Thus, it takes relatively long periods of anaerobic conditions to develop the redox potential necessary for sulfate reduction to occur. Laboratory studies indicated a two-month period of anaerobic conditions was required before sulfate reduction occurred. These conditions would certainly be met when overlying water is present on the prairie. In the absence of overlying water, sulfate reduction would likely occur only well below the water table in a zone where the soil remains anaerobic for long periods.

This research provides baseline information with regard to how a pristine wetland such as Hopkins Prairie transforms

and retains nutrients under varying hydrologic conditions. The information contained herein, combined with information provided by the District and its contractors will be useful in evaluating management programs for wetland prairies under natural and nutrient amended (i.e., from agricultural drainage water or sewage effluent) situations.

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1.0 INTRODUCTION

Wetlands are an important component of our environment. They provide many ecological functions including habitats for wildlife and waterfowl, groundwater recharge, flood control and prevention, and natural water purifiers. Hydrology has been identified as "probably the single most important determinant for the establishment and maintenance of specific types of wetlands and wetland processes" (Mitch and Gosselink, 1986). Hydrologic factors of importance include water depth, duration and timing of flooded and unflooded periods, and depth of water table during unflooded periods.

The St. Johns River Water Management District (District) has undertaken a research project to investigate the influence of hydrology on the ecological functions of wetlands. Hopkins Prairie has been chosen as a long term ecological research site for this study. In 1989 through 1990, the University of Florida, Department of Soil Science, was contracted by the District to evaluate the effects of hydrology, particularly the water table levels, on the biogeochemistry of nutrients in Hopkins Prairie soils. The research reported herein is a continuation of this project. The objectives of this study were to: (1) relate water table level to changes in concentrations of water-extractable nutrients (Task 1), (2) relate the effects of alternating flooding and draining of organic wetland soil on the distribution and availability of major plant nutrients in controlled laboratory column studies

(Task 2), and (3) quantify the effects of sulfate reduction on the organic matter decomposition (Task 3).

2.0 MATERIALS AND METHODS

2.1 Study Site

Hopkins Prairie is located in the Ocala National Forest in central Florida. The District operated a research platform in the prairie which was equipped to collect weather data (rainfall, temperature, relative humidity, solar radiation, and wind speed direction) and continuous water level recordings. Sediment cores and porewater samples were collected in the general vicinity of this platform.

Two study sites were selected within the prairie to correspond with ongoing research by the District and other contractors. One site was located in an open water marsh area, dominated by the macrophytes, Rhynchospora inundata, Eriocaulon compressum, Eleocharis elongata and Nymphaea odorata. A second site was selected within the nearby sawgrass community (dominated by C. ladium jamaicensis and Cephalathus occidentalis). Three sampling replications were used at each location.

2.2 Task 1: Monitoring of Water-Extractable Nutrients

2.2.1 Soil sampling

Three sampling stations were chosen within each of the two study sites. Two soil cores were taken with a stainless steel probe to a depth of 60 cm at each of the six stations at

approximately monthly intervals from May 1991 to January 1992. Each core was sectioned at 5 cm intervals in the field. Samples were stored in plastic sample bags which were kept in a cooler and transported back to the laboratory. Samples were stored at 4°C until analyzed.

2.2.2 Redox Potential

Soil redox potential was measured at 2 cm intervals when soil samples were collected. Redox electrodes were constructed according to Faulkner et al. (1989). The platinum electrode was pressed into the soil at 2 cm intervals and a reference electrode was inserted into the soil surface and wetted with deionized water to ensure good contact. Both electrodes were connected to a millivolt meter. Readings were recorded after meter stabilization, usually within 3-5 minutes. The meter readings were corrected by adding 244 mV to express the values in reference to a standard hydrogen electrode. Duplicate readings were taken at each sampling station.

2.2.3 Laboratory procedures

Soil moisture content was determined by drying subsamples at 105°C for 48 hours (Gardner, 1986). Bulk density was calculated by relating the dry weight of the entire increment to the volume of the increment. Soil pH was measured in a water saturated soil with a combination glass electrode. Water extractable elements were obtained by weighing a known amount of wet soil (1.0 g dry weight equivalent) into a 50 ml

centrifuge tube, and adding distilled water to obtain a soil:liquid ratio of 1:20 on a dry weight basis. After shaking for 1 hour, the soil suspensions were centrifuged at 8,000 rpm for 15 minutes and then filtered through Gelman 0.45 μm membrane filters. The water extracts were analyzed for ammonium, nitrate, and soluble reactive phosphorus with autoanalyzer methodologies (EPA method 515.2, 353.2, and 365.2, respectively) and sulfate with ion chromatography method 4110 (APHS, 1989).

Finely ground oven-dried soil samples were analyzed for total nitrogen, sulfur and carbon with a Carlo-Erba NA-1500 CNS analyzer (Haak-Buchler Instruments, Saddlebrook, New Jersey).

2.3 Task 2: Effects of Water Table Manipulation in Laboratory Soil Columns on Nutrient Transformation

Four soil columns were collected from both sites by driving a plexiglass tube (6.5 cm i.d.) into the soil to a depth of 45 cm. The columns were set-up in the laboratory. Ceramic porewater samplers were embedded in the columns at 5, 10, 15, 20, 30, and 40 cm intervals from the soil surface. Each porewater sampler was connected via Tygon tubing to sample containers.

Platinum electrodes were also installed at 2, 5, 10, 15, 20, 30 and 40 cm below the soil surface in duplicate columns. The redox potential at different depths was measured with a voltmeter and a reference electrode (see Section 2.2.2).

All columns were flooded initially for four weeks, followed by two weeks of draining, four weeks of flooding, and four weeks of draining. Porewater samples were collected weekly. Redox potentials were measured every two days. The porewater samples were analyzed for ammonium, nitrate, soluble reactive phosphorus and sulfate using the methods described in Section 2.2.3.

2.4 Task 3: Sulfate Reduction and Organic Matter Decomposition.

A bulk soil sample was collected from the top 10 cm of soil in the open water area of the Hopkins Prairie sampling site. The sample was mixed thoroughly and all large roots were removed. Equal amounts of wet soil (1 gm dry basis) were weighed into a series of 50 ml centrifuge tubes. Three replicates of each treatment were used. The soils were treated with glucose and/or sulfate as follows:

- (1) Soil only.
- (2) Soil + 300 μg of carbon (glucose) per gm of dry soil.
- (3) Soil + 300 μg of carbon and 100 μg of sulfur per gm dry soil.
- (4) Soil + 300 μg carbon and 200 μg sulfur per gm dry soil.
- (5) Soil + 300 μg carbon and 400 μg Sulfur per gm dry soil.

The soil was brought to saturation with deionized water and the centrifuge tubes were sealed with airtight septum caps. The tubes were purged of air with purified nitrogen gas

at the beginning of the experiment and periodically during the incubation at room temperature. The soils of each treatment were extracted with oxygen-free deionized water at 0, 3, 7, 14, 21, 28, 42 and 63 days of incubation using a 1:20 soil to water ratio.

Another set of samples subjected to the same treatments were incubated at room temperature and head space gas samples were collected after 0, 3, 7, 14, 21, 28, 42 and 63 days of incubation. Head space was purged with purified nitrogen gas after each sampling. The gas samples were analyzed for carbon dioxide concentrations with a Hewlett Packard 5840A Gas Chromatograph using a 2 m PROPAC-N column and a thermal conductivity detector.

2.5 Statistical Analysis

All statistics were performed using the Statistical Analysis System (SAS 1990). Analysis of variance was carried out with PROC GLM procedure. The Least Significant Difference Test was used for the comparisons of total carbon, nitrogen, sulfur, redox potentials and nutrients among different depths within a soil profile. The comparisons between the two soils were carried out with the Bonferroni corrected T Test using the LSMEANS/PDIFF statement. The Duncan's Multiple Range Test was used for the comparisons among different treatments in Task 3.

3.0 RESULTS AND DISCUSSION

3.1 Task 1. Pore Water Monitoring

3.1.1 Hydrology

The hydrologic cycle plays a very important role in nutrient transformations in Hopkins Prairie soils (Graetz, 1991). There was no overlying water during this study, therefore, the effect of hydrology was mainly through the water table depth fluctuation in the soil profile. The monthly rainfall during the study period ranged from 0 to 155 mm with most of the rainfall occurring during the period from March to September 1991. There was essentially no rainfall from October 1991 through January 1992 (Fig. 1). The rainfall changes were also reflected in corresponding water table fluctuations. The water table in the open water site peaked in June and then decreased with time with the lowest level appearing in December 1991 (Fig. 1). The water table was generally lower, relative to ground surface elevation, in the sawgrass area than in the open water area although the same general trend in water table fluctuation was observed as noted for the open water area.

The water table never reached the soil surface during this study, providing oxidized conditions in the upper layer of soil. This affected the nutrient distribution and transformation within the profile.

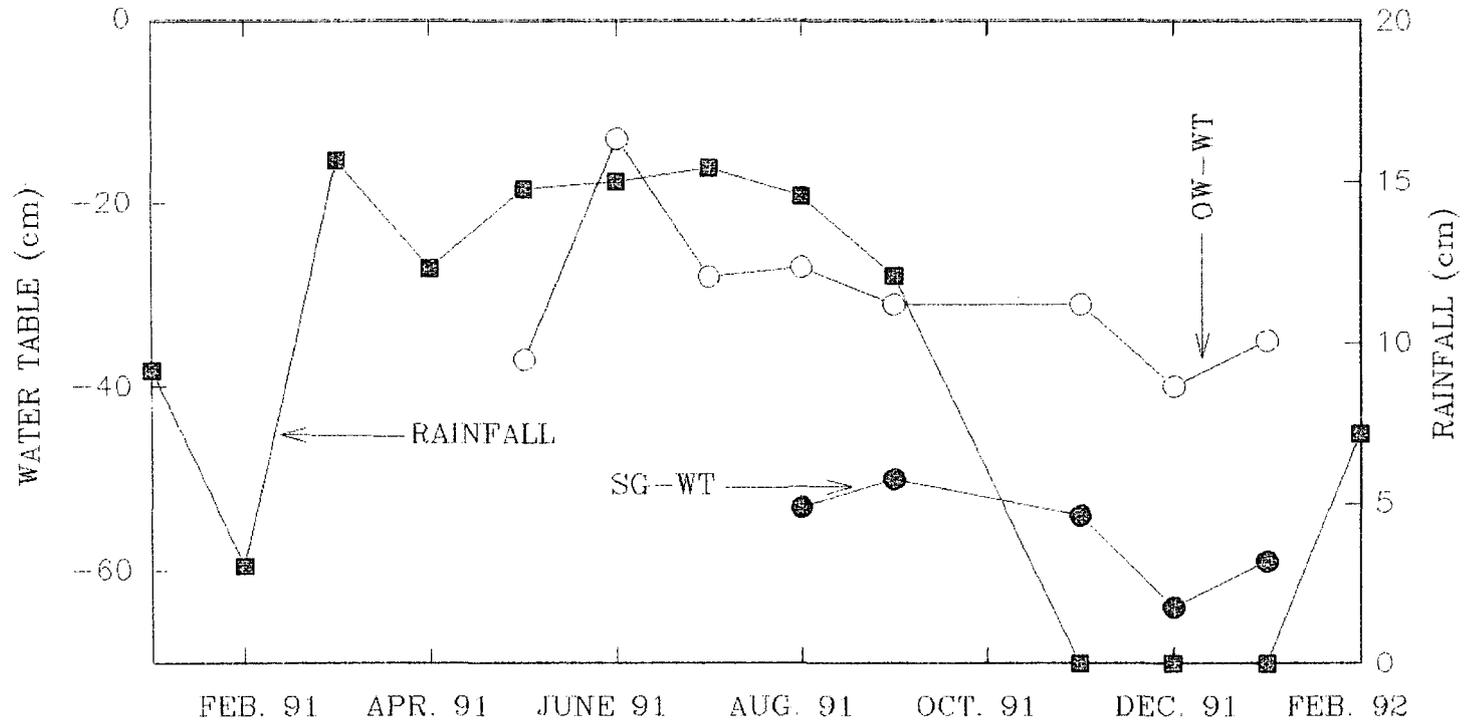


Figure 1. Rainfall and water table changes in Hopkins Prairie. OW-WT= water table for open water and SG-WT=water table for sawgrass site.

3.1.2 Soil Characterization

Major Nutrient Elements

Characterization of soil profiles showed that the soil in Hopkins Prairie sampling site is a typical organic wetland soil with high organic matter content and little mineral matter (Graetz, 1991). The soil for this year's characterization was collected when no overlying water was present. During the previous study (Graetz, 1991) the soil was characterized when overlying water was present. The basic physical and chemical parameters did not show much change even though the hydrologic conditions under which the samples were collected were markedly different.

Data obtained by 5 cm intervals (Appendix Table 1) were combined into 0-30 and 30-60 cm increments for summary purposes. Total carbon content was generally lower in the 0-30 cm layer of both soils than in the 30-60 cm layer (Table 1). Nitrogen content was greater in the 0-30 cm layer than in the 30-60 cm layer (Table 1). However, nitrogen content was relatively uniform with depth in the sawgrass site. Carbon/nitrogen ratio of the open water soil was lower in the surface soil (0-30 cm). Differences in C/N ratio between the two soil depths and the two soils were not significant.

In Hopkins Prairie, the water level drops below the soil surface on a cyclic basis (Clough, 1992) resulting in the

Table 1. Comparisons of total carbon, nitrogen, and sulfur contents and C/N and C/S ratios between open water (OW) and sawgrass (SG) soils in Hopkins Prairie(n=3).

	Depth -cm-	Soil		P>T
		OW	SG	
C, gm kg ⁻¹	0-30	488	459	0.0032*
	30-60	521	495	0.0057*
	P>T	0.0016*	0.001*	
N, gm kg ⁻¹	0-30	28.7	26.9	0.4596
	30-60	22.4	28.3	0.0332
	P>T	0.0255	0.5607	
S, gm kg ⁻¹	0-30	17.0	8.4	0.0015*
	30-60	30.9	12.5	0.0001*
	P>T	0.0001*	0.0521	
C/N, gm kg ⁻¹	0-30	18.1	17.2	0.6111
	30-60	23.7	18.4	0.0182
	P>T	0.0141	0.505	
C/S, gm kg ⁻¹	0-30	30.7	55.9	0.0032*
	30-60	17.5	45.6	0.0017*
	P>T	0.0609	0.1247	

* Significant at 1.25% level based on Bonferroni T Test.

surface soil becoming aerobic during drawdown periods. Organic matter undergoes more rapid decomposition under these aerobic conditions resulting in lower soil carbon content in the surface soil. The soil below 30 cm remains saturated and anaerobic during much longer time periods than the surface soil and probably becomes aerobic only under very severe drought conditions. Under anaerobic conditions, organic matter decomposition is much slower than under aerobic and therefore the organic matter tends to accumulate more at deeper depths.

Total sulfur content was lower in the 0-30 cm layer than in the 30-60 cm layer of the open water soil (Table 1). The biogeochemical cycling of sulfur behaves similar to that of carbon. Thus, over the life of the prairie, more organic sulfur was likely oxidized to sulfate and in the 0-30 cm layer than in the 30-60 cm layer. This sulfate would be subject to loss through sulfate reduction under anaerobic conditions.

Total carbon and sulfur contents were higher in the open water soil than in the sawgrass soil. The nitrogen contents of the two soils were not different. Since both open water and sawgrass sites have the same geology, the difference was likely caused by the existing plant communities in the two areas. However, the role of plants in nutrient cycling in these study sites is not clear at present.

Moisture Content and Bulk Density

The moisture contents were measured at 5 cm intervals (Appendix Table 2) in both open water and sawgrass areas

throughout the study period and summarized by 0-30 and 30-60 cm increments (Table 2). Although the water table depth fluctuated during this period, this was not reflected by soil moisture content. The water-holding capacity of these soils is sufficiently high that even under non-saturated conditions the moisture content remains high. At saturation, these soils contain approximately 89-90% water.

Soil bulk density in the open water location was relatively uniform throughout the 60-cm soil profile (Table 3). There was no apparent compaction of the soil with depth. Problems obtaining intact soil cores in the sawgrass location due to root mass interference during coring did not allow us to determine bulk density in the sawgrass location.

Soil reaction (pH)

Soils in both open water and sawgrass communities showed an acid reaction. Soil pH increased consistently with depth at both sites with none showing more than a one unit increase (Appendix Table 3 and Table 4). The pH of the sawgrass soil was generally lower than that of the open water soil. The lower pH near the soil surface results from accumulation of organic acids during aerobic decomposition of organic matter. The sawgrass soil is also generally more aerobic than the open water soil which would account for the differences in pH.

Table 2. Comparisons of moisture contents (%) between open water (OW) and sawgrass (SG) soils in Hopkins Prairie (n=3).

DATE	Depth -cm-	Moisture content, %		
		OW	SG	P>T
MAY 91	0-30	88.8	87.5	0.1185
	30-60	88.5	88.7	0.7998
	P>T	0.7356	0.1353	
JUNE 91	0-30	88.4	87.8	0.4989
	30-60	89.0	90.0	0.2614
	P>T	0.4747	0.0285	
JUL. 91	0-30	87.8	87.2	0.5564
	30-60	88.8	89.4	0.5352
	P>T	0.3362	0.0517	
AUG. 91	0-30	88.4	87.6	0.2257
	30-60	88.7	89.6	0.1487
	P>T	0.5839	0.0083*	
SEPT. 91	0-30	87.4	87.1	0.791
	30-60	88.8	89.0	0.9154
	P>T	0.2831	0.1635	
NOV. 91	0-30	87.3	87.6	0.7498
	30-60	86.9	89.6	0.0096*
	P>T	0.6063	0.036	
DEC. 91	0-30	88.3	86.6	0.1342
	30-60	88.9	89.4	0.6306
	P>T	0.5443	0.0232	
JAN. 92	0-30	86.3	87.5	0.3882
	30-60	88.7	89.4	0.4039
	P>T	0.1005	0.082	

* Significant at 1.25% level based on Bonferroni T Test.

Table 3. Bulk density of soil samples collected from the open water area of Hopkins Prairie (n=3).

DEPTH	BULK DENSITY						MEAN	
	5/1	6/5	7/9	8/30	9/27	11/5		
cm	-----g cm ⁻³ -----							
0-5	0.08	0.12	0.12	0.11	0.12	0.09	0.10	CDE*
5-10	0.10	0.11	0.11	0.11	0.12	0.09	0.11	CD
10-15	0.12	0.12	0.13	0.12	0.13	0.12	0.12	B
15-20	0.10	0.11	0.10	0.10	0.11	0.10	0.10	DE
20-25	0.10	0.11	0.13	0.12	0.14	0.15	0.12	AB
25-30	0.13	0.14	0.16	0.14	0.13	0.15	0.14	A
30-35	0.07	0.13	0.10	0.10	0.08	0.10	0.10	E
35-40	0.11	0.14	0.10	0.10	0.09	0.11	0.10	CDE
40-45	0.15	0.11	0.11	0.11	0.13	0.11	0.12	CDE
45-50	0.11	0.11	0.13	0.12	0.11	0.15	0.12	BC
50-55	0.11	0.12	0.11	0.12	0.10	0.15	0.12	BCD
55-60	0.12	0.13	0.12	0.11	0.10	0.11	0.11	BCD

* Means within a column followed by the same letter do not differ significantly, Alpha=0.05, based on Least Significant Difference Test.

Table 4. Comparisons of pH between open water (OW) and sawgrass (SG) soils in Hopkins Prairie (n=3).

DATE	DEPTH	pH		P>T
		OW	SG	
MAY 91	0-30	4.3	4.1	0.0109*
	30-60	5.0	4.6	0.0005*
	P>T	0.0001*	0.0001*	
JUNE 91	0-30	4.4	4.0	0.0875
	30-60	5.0	4.6	0.239
	P>T	0.1096	0.0144	
JUL. 91	0-30	4.3	3.7	0.0011*
	30-60	4.9	4.2	0.0008*
	P>T	0.0015*	0.0022*	
SEPT. 91	0-30	4.3	3.7	0.0024*
	30-60	5.2	4.4	0.0005*
	P>T	0.0002*	0.0007*	
NOV. 91	0-30	4.3	3.7	0.0054*
	30-60	5.1	4.4	0.0041*
	P>T	0.0025*	0.0032*	
DEC. 91	0-30	4.1	3.5	0.0001*
	30-60	4.9	4.4	0.0003*
	P>T	0.0001*	0.0001*	
JAN. 92	0-30	4.2	3.5	0.0032*
	30-60	5.0	4.3	0.0024*
	P>T	0.0006*	0.0008*	

* Significant at 1.25% level based on Bonferroni T Test.

3.1.3. Redox Potential

Soil redox potential (Eh) is a good indicator of soil oxidation-reduction conditions. By measuring the Eh at narrow intervals in the soil profile, very clear redox profiles were observed (Fig. 2).

Although the water table depth fluctuated during the study period, the redox potentials in the upper 10 cm of open water soil were always greater than +300 mV, indicating that an oxidizing condition existed in this soil layer throughout the study period (Fig. 2; Table 5). For May 1991 and September 1991 through January 1992, there was a distinct transition of the redox profile at the water table. Soil above the water table was uniformly oxidized as evidenced by the high redox potentials and small variations in this zone (Fig. 2). Redox potential began to decrease near the water table and continued to decrease until it stabilized below the water table. Therefore, a transition zone, within which the redox potentials underwent a drastic change, was developed. The redox potential below the transition zone was significantly lower than that above the transition zone for all sampling dates (Table 5). In spite of the great change in redox potential around the water table, the redox potentials in the lower depths remained anaerobic with only a small variation with time (Fig 2).

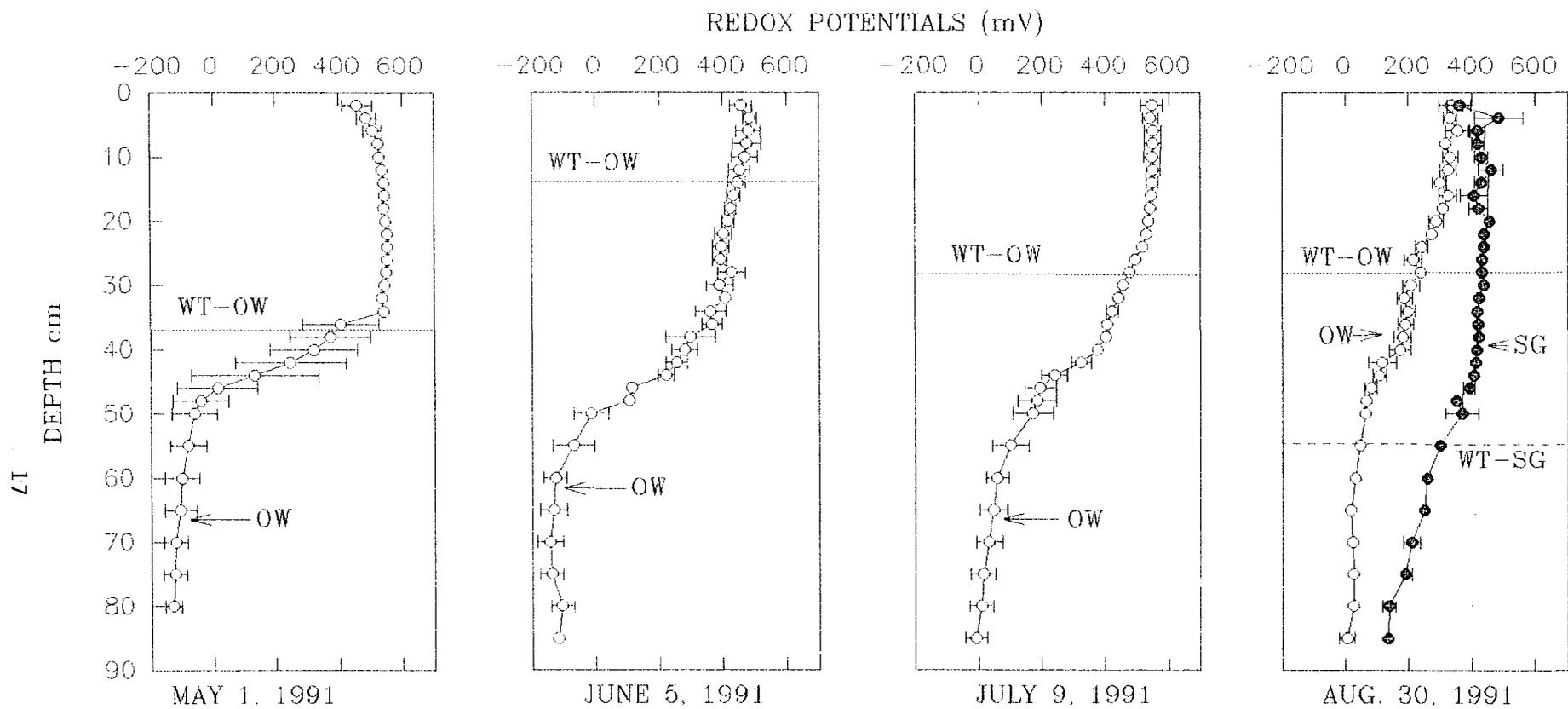


Figure 2. Soil redox potential profiles for open water (OW) and sawgrass (SG) communities of Hopkins Prairie (Error bars = ± 1 std. error) (WT-OW = Water table for open water and WT-SG = water table for sawgrass)

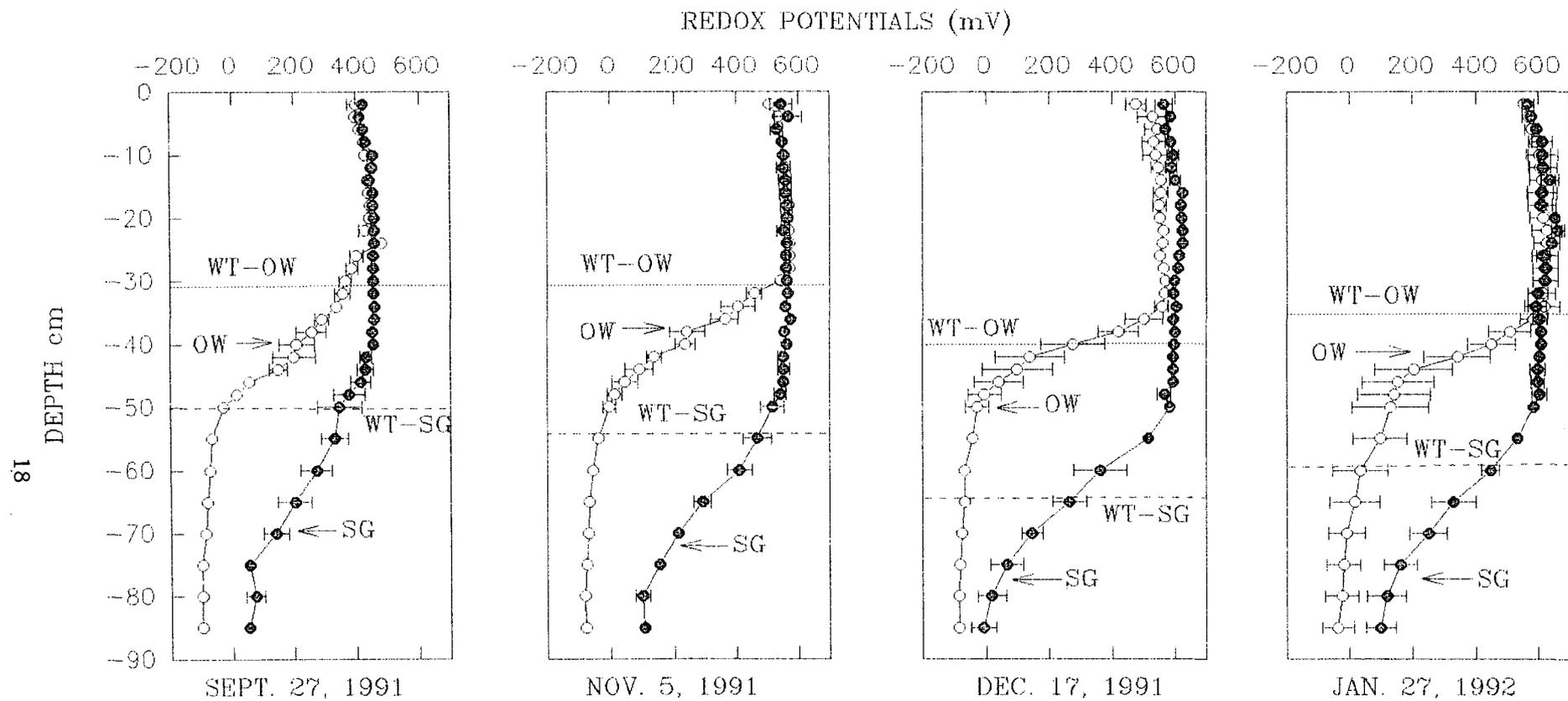


Figure 2. Continued. OW = Open water, SG = Sawgrass, WT-OW = Water table for open water and WT-SG = Water table for sawgrass

Table 5. Comparisons of redox potentials between open water (OW) and sawgrass (SG) soils in Hopkins Prairie (n=3).

DATE	DEPTH ⁺	REDOX POTENTIAL, mV		
		OW	SG	P>T
MAY 91	above	533	-- ⁺⁺	
	below	-104	--	
	P>T	0.0001*		
JUNE 91	above	440	--	
	below	-121	--	
	P>T	0.0001*		
JUL. 91	above	534	--	
	below	37	--	
	P>T	0.0003*		
AUG. 91	above	299	427	0.0002*
	below	24	185	0.0001*
	P>T	0.0001*	0.0001*	
SEPT. 91	above	421	446	0.2792
	below	-85	105	0.0001*
	P>T	0.0001*	0.0001*	
NOV. 91	above	553	555	0.9128
	below	-67	143	0.0001*
	P>T	0.0001*	0.0001*	
DEC. 91	above	548	598	0.1881
	below	-73	56	0.006*
	P>T	0.0001*	0.0001*	
JAN. 92	above	604	610	0.9322
	below	-7	156	0.039
	P>T	0.0001*	0.0001*	

⁺ Above and below the water table.

⁺⁺ Not measured.

* Significant at 1.25% level based on Bonferroni T Test.

During June 1991 through August 1991 the redox potential profile did not reflect the water table depth as well as it did during the other sampling dates (Figure 2). Heavy rainfall during this period apparently caused the water table to fluctuate within the soil profile. The redox potential response was not sufficiently rapid to reflect the fluctuating water table.

The sawgrass community showed the same trend in the redox profile (Fig 2). However, the redox potentials were generally higher in the sawgrass community than in the open water area (Table 5). The upper oxidation layer of the sawgrass community was much deeper than that of the open water site, but also corresponded to water table fluctuations. The difference between the water table depth is due to the elevation of the two areas. However, the higher redox potentials in the deep layer of the sawgrass community is not very well understood. The root system of the sawgrass community is more fibrous compared to that in the open water community which could be the reason for the more open soil structure found in the sawgrass area. The open structure could affect the movement of gases in the sawgrass soil. In addition, the sawgrass roots may be capable of pumping oxygen into the soil, although no indication of this is available in the literature.

3.1.4. Extractable-nutrient concentrations

Water-extractable nutrient concentrations were used to monitor the effect of water table fluctuation on biogeochemical

transformations within the soil profile. The nitrogen species, NH_4^+ and NO_3^- , soluble reactive phosphate (SRP) and SO_4^- were measured for each sampling period. The water-extractable component of these nutrients likely reflects the amount of nutrients in equilibrium with the pore water.

Nitrate(NO_3^-)

The upper layer (above the water table) of the open water sediment was always under oxidizing conditions (Fig. 2) therefore the nitrate concentration tended to be higher in the soil above the water table (Fig.3). Nitrate concentrations were averaged for the 0-30 and 30-60 cm soil layers to differentiate between soil that was generally under oxidized conditions versus that which was generally anaerobic. Nitrate concentrations were higher in the 0-30 cm layer than in the 30-60 cm layer for all sampling dates (Table 6). Nitrate is the first oxidant (electron acceptor) utilized when O_2 is depleted. Thus, as the soil became depleted of oxygen below the water table, NO_3^- began to disappear. The concentration gradient between the upper and lower layers causes the downward diffusion of NO_3^- to the anaerobic zone where NO_3^- can be lost either to denitrification or dissimilatory NO_3^- reduction (Reddy 1984).

Concentration of NO_3^- in the zone above the water table of the open water sediment showed considerable variation with time. Two reasons could possibly contribute to this variation. Oxidation of organic matter in the zone above the water table is primarily controlled by O_2 , which in turn is influenced by the degree of saturation of the soil. As the water table level increased, the

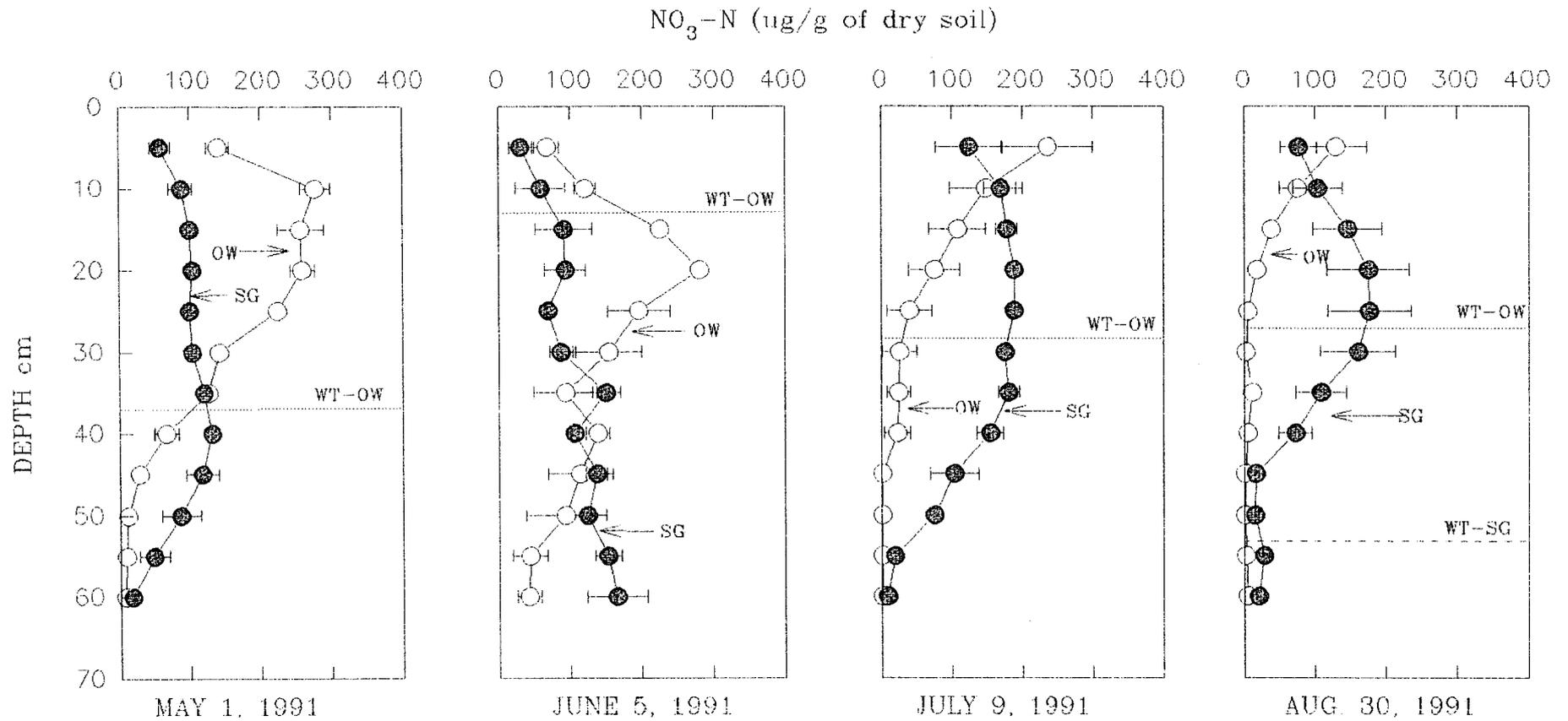


Figure 3. Water extractable $\text{NO}_3\text{-N}$ profiles for open water (OW) and sawgrass (SG) communities of Hopkins Prairie (Error bars = ± 1 std. error) (WT-OW = Water table for open water and WT-SG = Water table for sawgrass)

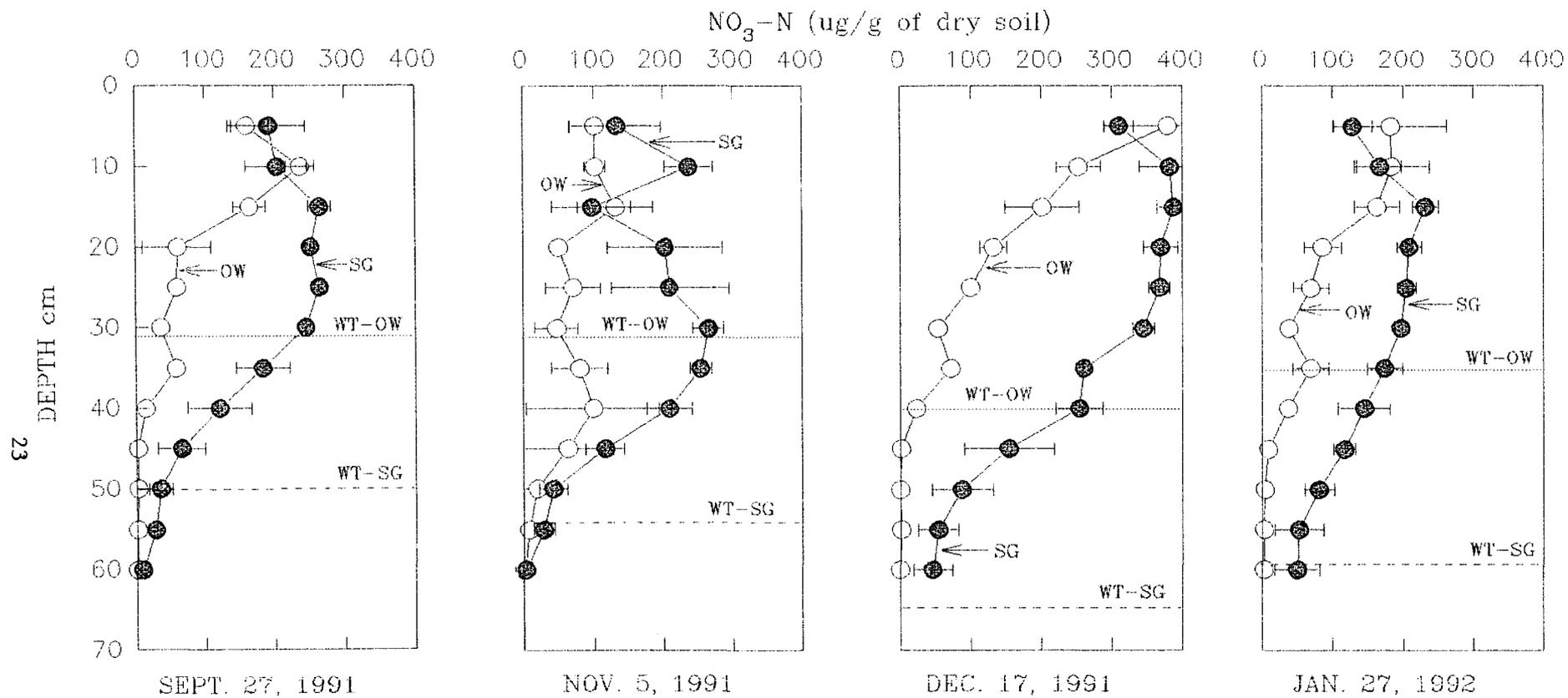


Figure 3. Continued. OW = Open water, SG = Sawgrass, WT-OW = Water table for open water and WT-SG = Water table for sawgrass

Table 6. Mean water extractable NO₃⁻-N concentrations for the 0-30 and 30-60 cm soil layers for open water (OW) and sawgrass (SG) soils.

DATE	DEPTH cm	NO ₃ ⁻ -N, ug gm ⁻¹		MEAN	P>T
		OW	SG		
MAY 91	0-30	216	92	--‡	0.0001*
	30-60	41	87	--	0.0074*
	MEAN				
	P>T	0.0001*	0.7165		
JUNE 91	0-30	173	71	--	0.0071*
	30-60	86	138	--	0.1071
	MEAN				
	P>T	0.0161	0.0455		
JULY 91	0-30	105	170	137	
	30-60	8	90	49	
	MEAN	56	130		0.0116*
	P>T			0.0044*	
AUG. 91	0-30	44	139	91	
	30-60	3	43	23	
	MEAN	24	91		0.0054*
	P>T			0.0049*	
SEPT. 91	0-30	118	236	177	
	30-60	12	72	42	
	MEAN	65	154		0.001*
	P>T			0.0001*	
NOV. 91	0-30	84	191	137	
	30-60	45	109	77	
	MEAN	64	150		0.0058*
	P>T			0.03*	
DEC. 91	0-30	187	360	273	
	30-60	16	143	79	
	MEAN	101	251		0.0002*
	P>T			0.0001*	
JAN. 92	0-30	120	189	154	
	30-60	20	103	61	
	MEAN	70	146		0.0047*
	P>T			0.0014*	

* Significant at 1.25% level based on Bonferroni T Test.
‡ Comparisons were made for each depth when the soil by depth interaction was significant. When the interaction was not significant, treatment means were used for comparisons.

upper layer of the soil would have a higher water content or even be saturated. Therefore, the oxidation of organic matter tends to slow down since the oxygen supply is limited. When the water table becomes lower, such as in December 1991, the aeration of the soil will accelerate the rate of organic matter decomposition, and NH_4^+ produced by organic N mineralization will be quickly oxidized to NO_3^- . This wet-dry cycle effect was observed in June and December 1991, where the lowest and highest NO_3^- concentrations were found in the upper layer of the open water sediment corresponding to the highest and lowest water table levels, respectively.

Nitrate concentrations were higher in the sawgrass soil than in the open water soil (Table 6) except for the 0-30 cm layer during May and June 1991. The higher nitrate values in the sawgrass soil cannot be explained by soil nitrogen content (Table 1), carbon/nitrogen ratio (Table 1) or redox potential (Table 5) as values for these parameters were similar between the two soils.

Ammonium (NH_4^+)

Water extractable ammonium levels were relatively uniform with soil depth for both soils (Fig. 4). Only occasional differences between soil layers were observed when ammonium concentrations were averaged for the 0-30 and 30-60 cm layers (Table 7). The ammonium concentration of the sawgrass soil was often higher than that of the open water soil through September 1991 (Table 7). Beyond September 1991, there were no differences in ammonium concentration between the two soils. Since ammonium is a cation, it is likely that considerable amounts of ammonium were not extracted by water.

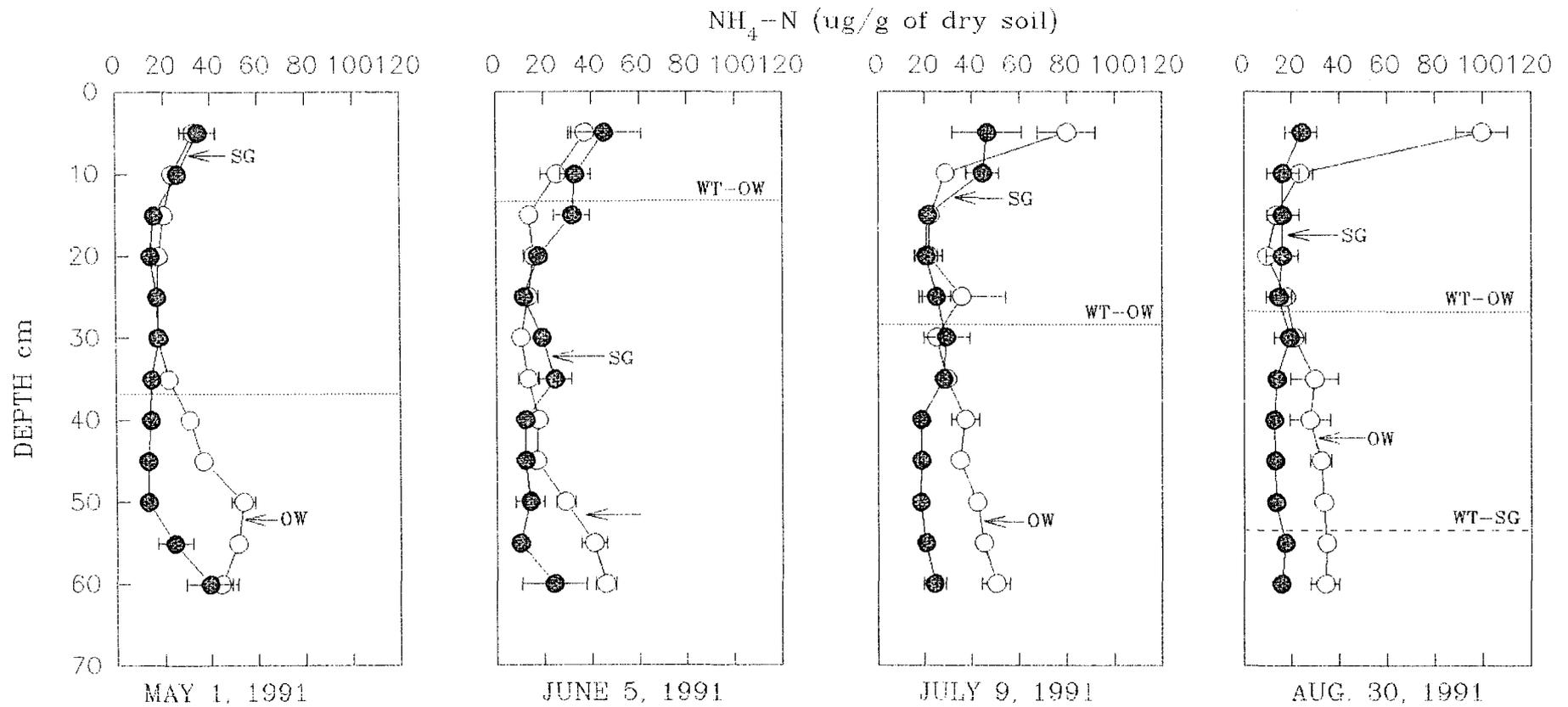


Figure 4. Water extractable $\text{NH}_4\text{-N}$ profiles for open water (OW) and sawgrass (SG) communities of Hopkins Prairie (Error bars = ± 1 std. error) (WT-OW = Water table for open water and WT-SG = Water table for sawgrass)

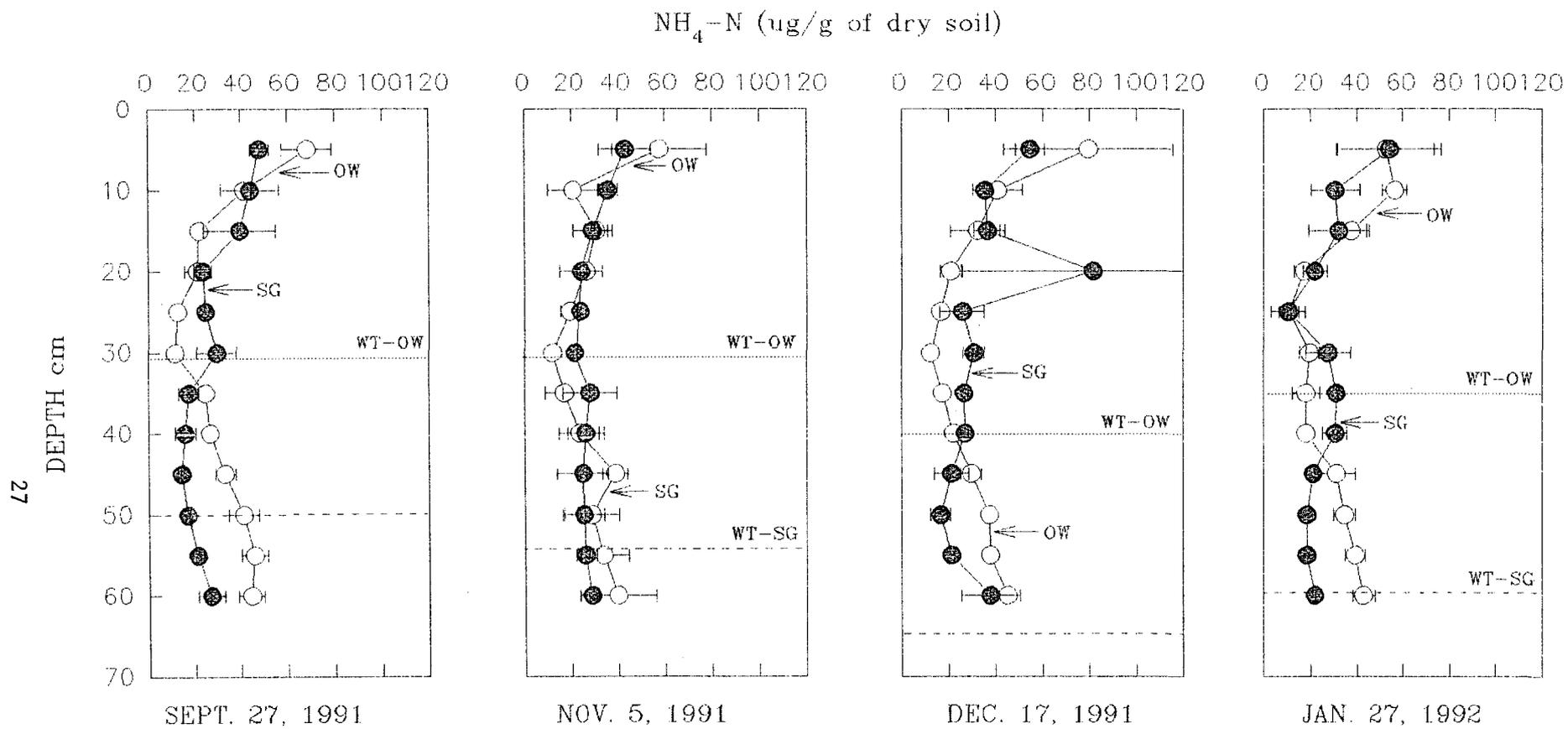


Figure 4. Continued. OW = Open water, SG = Sawgrass, WT-OW = Water table for open water and WT-SG = Water table for sawgrass

Table 7. Mean water extractable $\text{NH}_4^+\text{-N}$ concentrations for the 0-30 and 30-60 cm soil layers for open water (OW) and sawgrass (SG) soils.

DATE	Depth cm	$\text{NH}_4^+\text{-N}$, $\mu\text{g gm}^{-1}$		Mean	P>T
		OW	SG		
MAY 91	0-30	21.6	21.0	---‡	0.843
	30-60	40.0	20.0	--	0.0001*
	MEAN				
	P>T	0.0002*	0.7125		
JUNE 91	0-30	19.5	26.7	23.1	
	30-60	27.5	16.4	21.9	
	MEAN	23.5	21.5		0.6645
	P>T			0.797	
JUL. 91	0-30	35.4	31.1	--	0.2199
	30-60	39.7	21.2	--	0.0004*
	MEAN				
	P>T	0.217	0.0158		
AUG. 91	0-30	30.9	17.8	24.3	
	30-60	32.0	14.6	23.3	
	MEAN	31.4	16.2		0.0026*
	P>T			0.774	
SEPT. 91	0-30	29.6	35.0	--	0.4203
	30-60	36.1	18.8	--	0.0259
	MEAN				
	P>T	0.3364	0.0339		
NOV. 91	0-30	27.9	29.6	28.8	
	30-60	30.3	26.6	28.5	
	MEAN	29.1	28.1		0.8855
	P>T			0.9634	
DEC. 91	0-30	33.9	44.2	39.0	
	30-60	31.6	25.2	28.4	
	MEAN	32.7	34.7		0.8121
	P>T			0.2204	
JAN. 92	0-30	32.4	29.5	31.0	
	30-60	30.6	23.5	27.1	
	MEAN	31.5	26.5		0.4626
	P>T			0.5611	

* Significant at 1.25% level based on Bonferroni T Test.
 ‡ Comparisons were made for each depth when the soil by depth interaction was significant. When the interaction was not significant, treatment means were used for comparisons.

Thus, differences between soils or between soil depths were likely buffered by the ammonium held on the soil cation exchange sites. The soils in this area have been shown to retain significant amounts of ammonium on cation exchange sites (Clough, 1992).

Soluble Reactive Phosphorus (SRP)

Soluble reactive phosphorus concentration was low in the entire profile for both soils (Fig. 5). This indicates the P may be the limiting factor for plant growth in this ecosystem. There were generally no significant trends in differences between soils or between soil depths (Table 8). Soluble reactive phosphorus did not show any relationship to water table fluctuation in this field study although subsequent laboratory studies suggested that phosphorus concentrations were lower above than below the water table. (see Section 3.2.1).

Sulfate (SO₄⁻)

Water-extractable SO₄⁻ concentrations varied considerably for both sampling sites with time (Fig. 6). Concentrations went from relatively low levels at one sampling time to very high levels at the next sampling time, e.g., June 5 vs. July 9 and July 9 vs. August 30. This was also evident for later sampling dates although the trend was not consistent between the two sampling locations. We cannot explain this variation with any of the parameters measured during this study (pH,

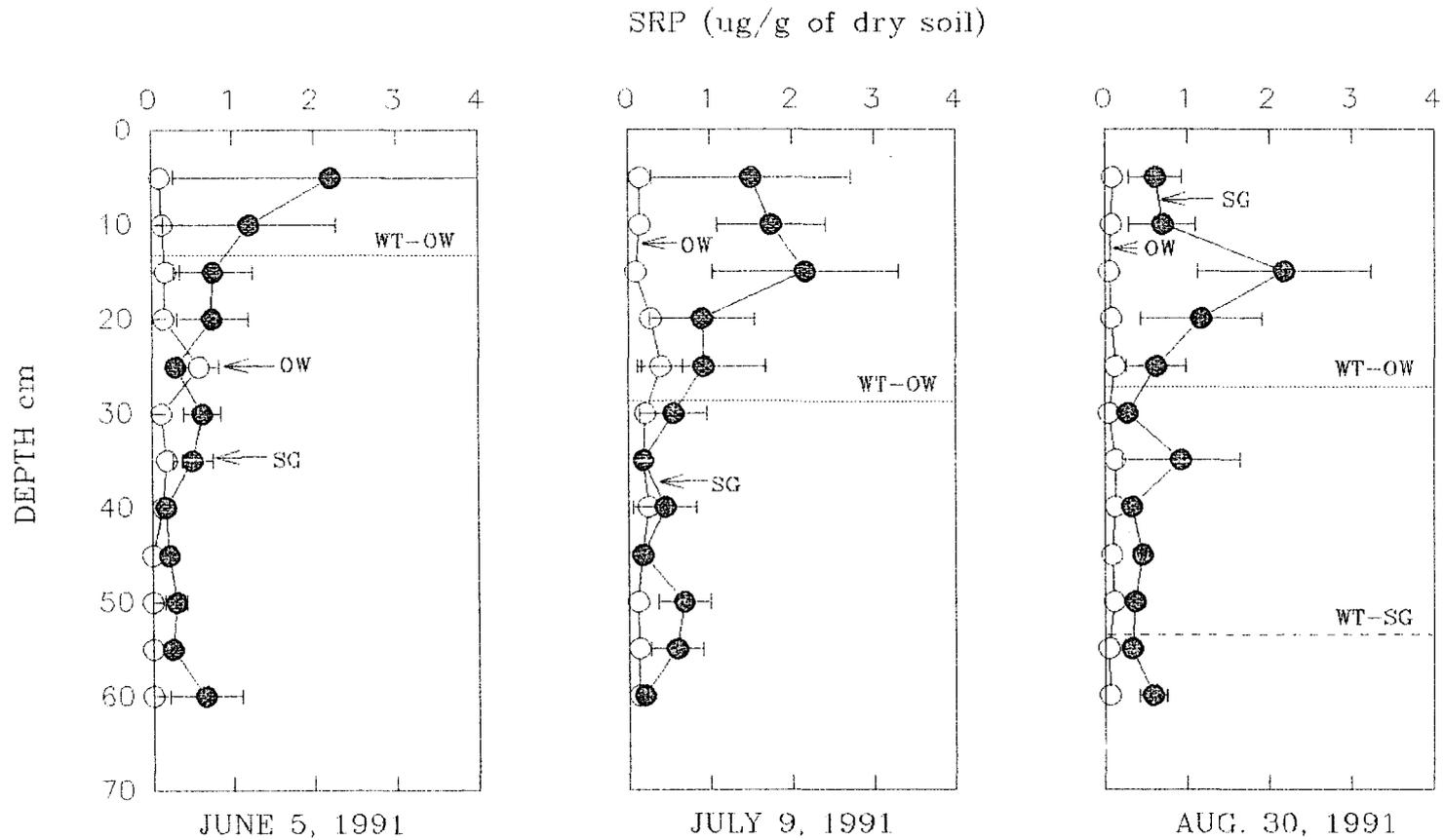


Figure 5. Water extractable SRP profiles for open water (OW) and sawgrass (SG) communities of Hopkins Prairie (Error bars = ± 1 std. error) (WT-OW = Water table for open water and WT-SG = Water table for sawgrass)

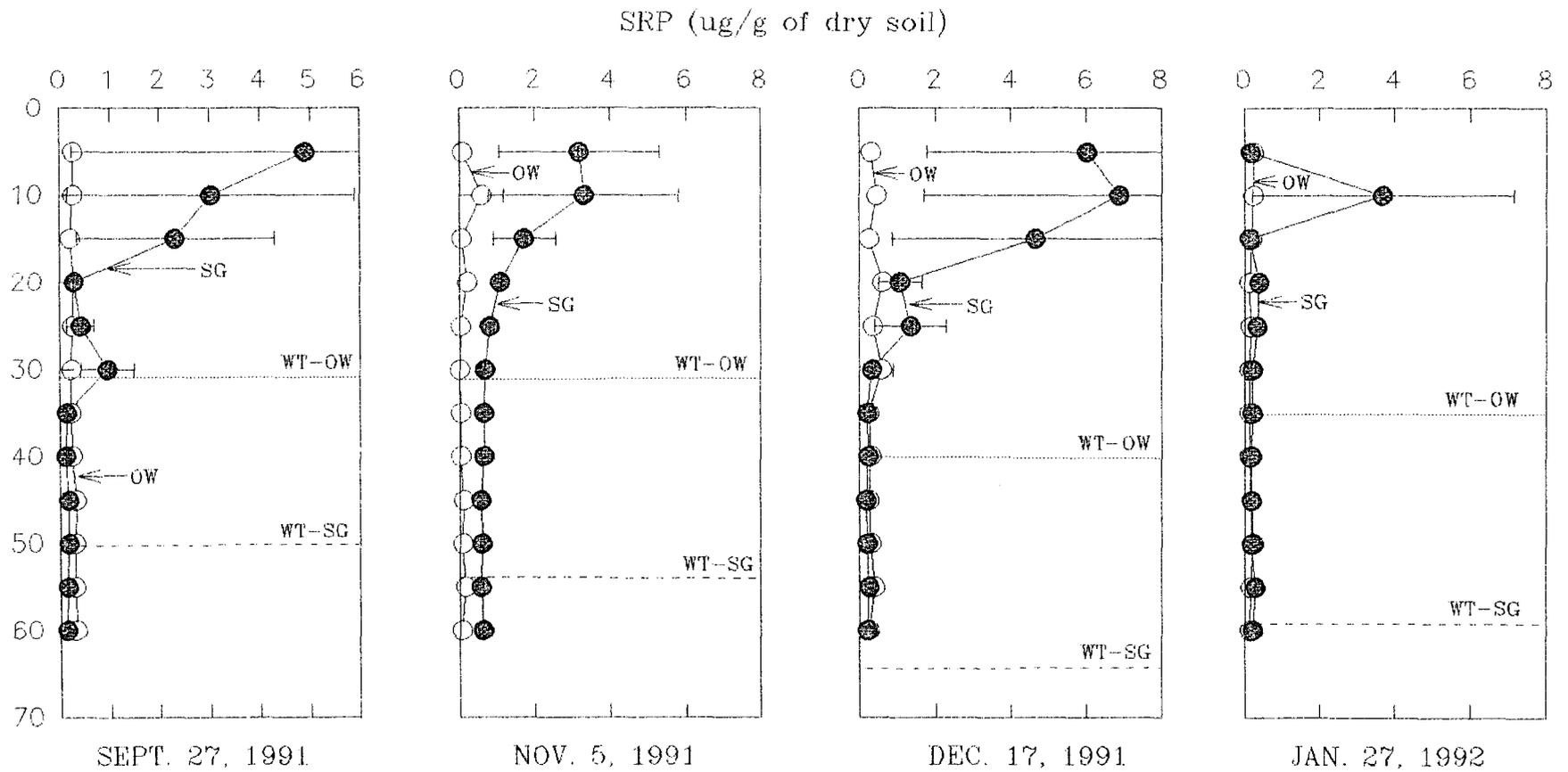


Figure 5. Continued. OW = Open water, SG, = Sawgrass, WT-OW = Water table for open water and WT-SG = Water table for sawgrass

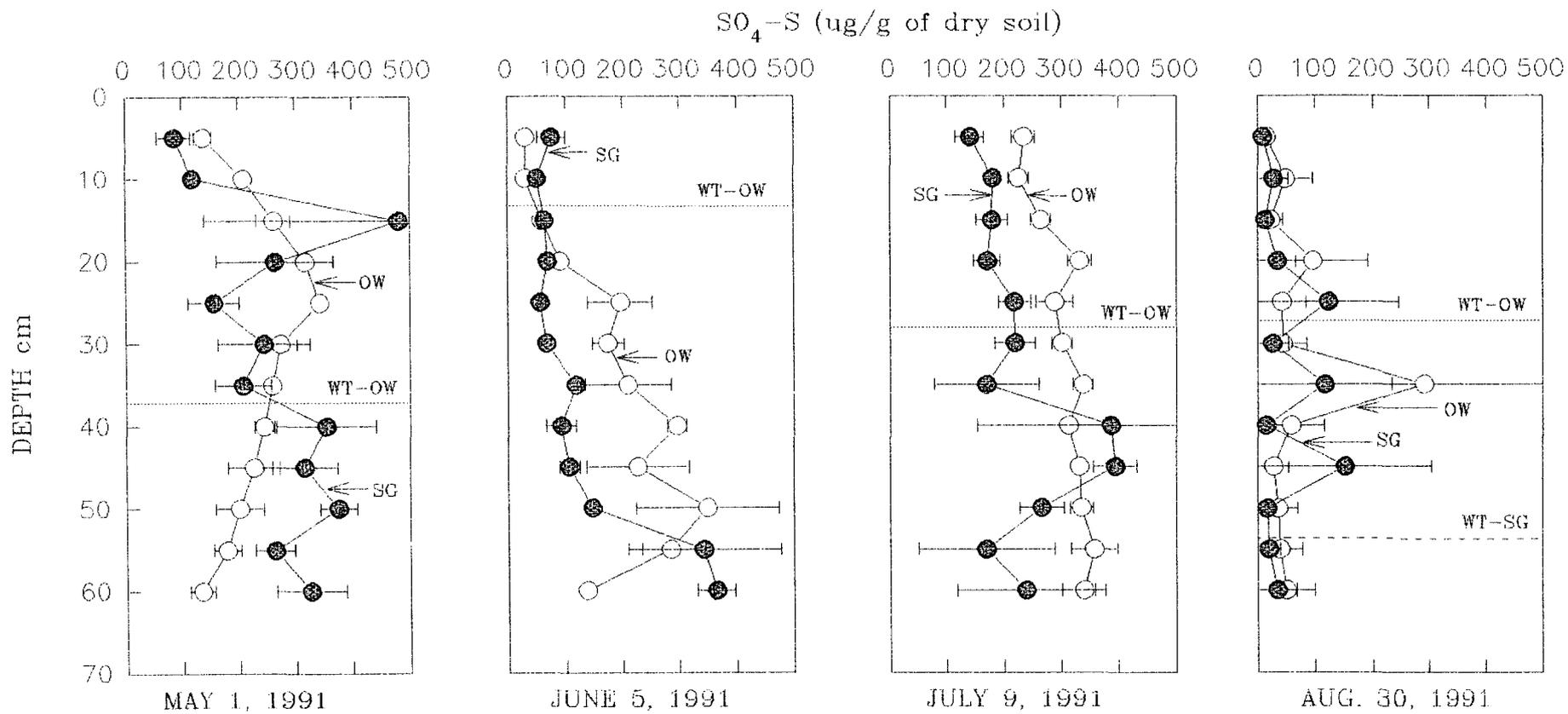


Figure 6. Water extractable $\text{SO}_4\text{-S}$ profiles for open water (OW) and sawgrass (SG) communities of Hopkins Prairie (Error bars = ± 1 std. error) (WT-OW = Water table for open water and WT-SG = Water table for sawgrass)

$\text{SO}_4\text{-S}$ ($\mu\text{g/g}$ of dry soil)

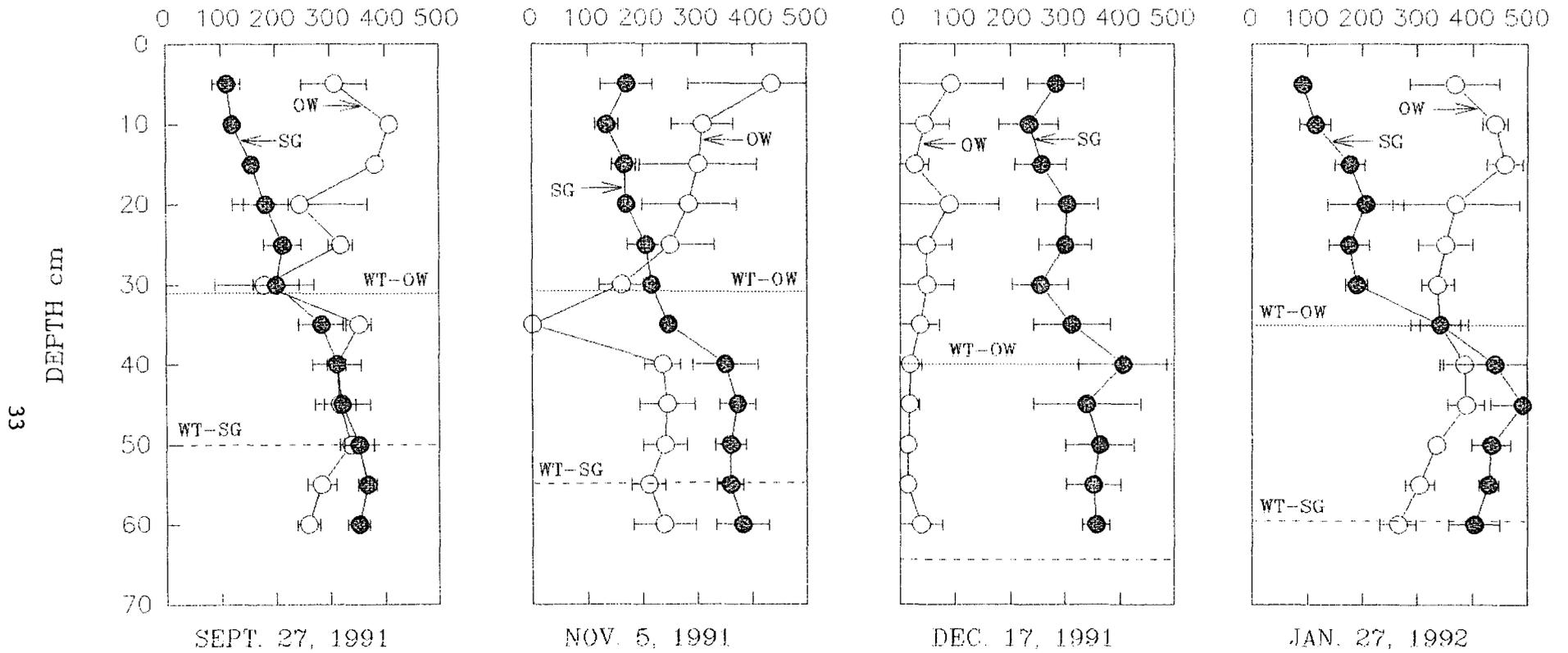


Figure 6. Continued. OW = Open water, SG = Sawgrass, WT-OW = Water table for open water and WT-SG = Water table for sawgrass

Table 8. Mean water extractable SRP concentrations for the 0-30 and 30-60 cm soil layers for open water(OW) and sawgrass (SG) soils.

DATE	DEPTH cm	SRP, ug gm ⁻¹		MEAN	P>T
		OW	SG		
MAY 91	0-30	0.07	0.08	0.07	0.3536
	30-60	0.90	0.00	0.45	
	MEAN	0.48	0.04		
	P>T			0.4268	
JUNE 91	0-30	0.21	0.98	0.60	0.1694
	30-60	0.05	0.35	0.20	
	MEAN	0.13	0.66		
	P>T			0.2916	
JUL. 91	0-30	0.2	1.29	0.74	0.0512
	30-60	0.16	0.37	0.26	
	MEAN	0.18	0.83		
	P>T			0.1289	
AUG. 91	0-30	0.08	0.92	0.50	0.0011*
	30-60	0.09	0.50	0.30	
	MEAN	0.08	0.71		
	P>T			0.1459	
SEPT. 91	0-30	0.24	1.98	1.11	0.3419
	30-60	0.28	0.13	0.21	
	MEAN	0.26	1.06		
	P>T			0.2832	
NOV. 91	0-30	0.44	1.79	1.12	0.1347
	30-60	0.47	0.61	0.54	
	MEAN	0.46	1.20		
	P>T			0.2348	
DEC. 91	0-30	0.42	3.38	1.9	0.2798
	30-60	0.29	0.20	0.24	
	MEAN	0.35	1.79		
	P>T			0.2173	
JAN. 92	0-30	0.18	0.81	0.49	0.2994
	30-60	0.17	0.21	0.19	
	MEAN	0.17	0.51		
	P>T			0.342	

* Significant at 1.25% level based on Bonferroni T Test.

moisture content, redox potential). Sulfate reduction could occur after a rainfall event due to short term saturation of the soil. However, our sampling frequency was not sufficient to delineate these events. Furthermore, this would not explain the apparent rapid mineralization of organic sulfur which would have to occur to cause the increase in sulfate concentration for a sample date following a period with low SO_4^- concentration. At this time we cannot develop a scenario which would clearly explain our SO_4^- data.

It is also apparent that significant SO_4^- reduction did not occur below the water table during this study as evidenced by equal or higher SO_4^- concentrations below than above the water table (Fig. 6 and Table 9). This is in contrast to the results of the previous study (Graetz, 1991) which showed that SO_4^- concentrations decreased below the water table. Sulfate reduction only occurs in an anaerobic condition when $\text{Eh} < -100$ - 150 mV. The redox potentials during this study only occasionally reached or were below -150 mV below the water table (Fig 2).

Table 9. Mean water extractable $\text{SO}_4^{2-}\text{-S}$ concentrations for the 0-30 and 30-60 cm soil layers for open water (OW) and sawgrass (SG) soils.

DATE	DEPTH cm	$\text{SO}_4^{2-}\text{-S, g gm}^{-1}$		MEAN	P>T
		OW	SG		
MAY 91	0-30	258	225	241	0.4648
	30-60	208	307	258	
	MEAN	233	266		
	P>T			0.7153	
JUNE 91	0-30	97	64	80	0.0928
	30-60	251	196	223	
	MEAN	174	130		
	P>T			0.0003*	
JUL. 91	0-30	274	185	230	0.0608
	30-60	336	271	303	
	MEAN	305	228		
	P>T			0.0717	
AUG. 91	0-30	260	172	216	0.8541
	30-60	310	382	346	
	MEAN	285	277		
	P>T			0.0149*	
SEPT. 91	0-30	307	164	--†	0.0013*
	30-60	310	332	--	
	MEAN				
	P>T	0.9163	0.0005*		
NOV. 91	0-30	290	176	--	0.1027
	30-60	195	345	--	
	MEAN				
	P>T	0.1616	0.0255		
DEC. 91	0-30	306	272	289	0.4629
	30-60	378	356	367	
	MEAN	342	314		
	P>T			0.0709	
JAN. 92	0-30	387	159	--	0.0029*
	30-60	337	423	--	
	MEAN				
	P>T	0.3758	0.0012*		

* Significant at 1.25% level based on Bonferroni T Test.
 † Comparisons were made for each depth when the soil by depth interaction was significant. When the interaction was not significant, the treatment means were used for comparisons.

3.2 Task 2: Effects of Water Table Manipulation in Laboratory Soil Columns on Nutrient Transformations.

Intact soil columns from the two sample locations were subjected to two flood/drain cycles. The first cycle consisted of four weeks flooded and two weeks drained; the second cycle consisted of four weeks flooded and four weeks drained.

Porewater from the columns was extracted with ceramic cups in contrast to the field sampling where soluble nutrients were extracted with deionized water. The same parameters were measured in the columns as in the field studies.

3.2.1 Redox Potentials

Redox potential was measured only in two columns of each soil type and the data are presented as averages of the duplicate values. Redox potential in the open water soil columns corresponded very well to the alternating flooded/drain cycles (Fig. 7). Before flooding, the top 30 cm of soil was aerobic with all redox potentials greater than 400 mV. Since the column was closed at the bottom with a rubber stopper, the water tended to accumulate in the bottom soil layer due to gravity. Thus, the soil at 40 cm remained anaerobic with redox potentials less than 200 mV (Fig. 7).

Upon flooding for the first time, the redox potential at the four depths decreased with time (Fig. 7). The rates of change varied for the different depths. The 2-5 and 10-20 cm soil layers had the greatest decreases during the initial flooding period. At

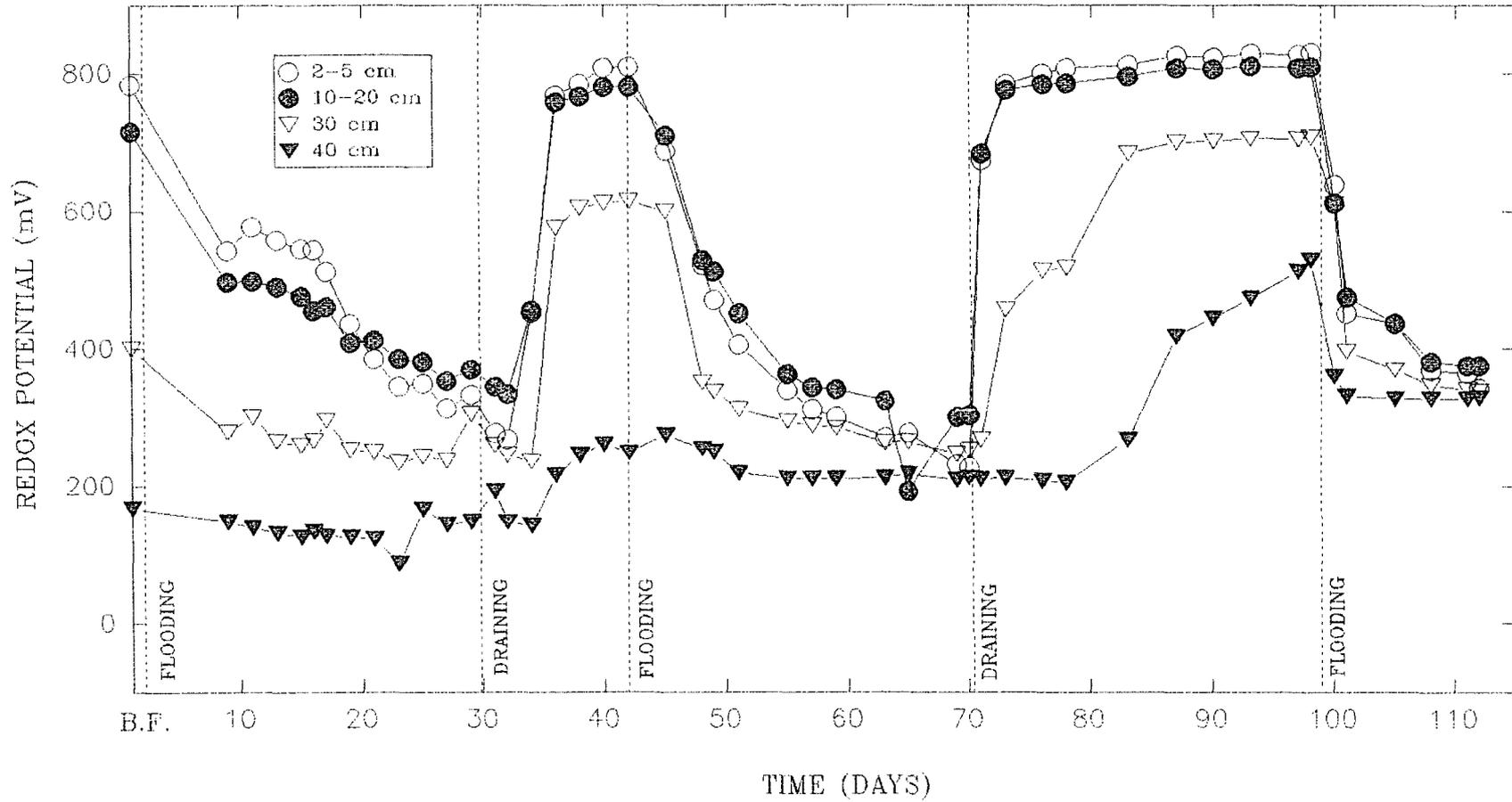


Figure 7. Redox potential changes in open water soil of Hopkins Prairie upon alternate flooding and draining in a laboratory column study (B.F. = before flooding)

the end of four weeks flooding, these two layers remained aerobic with redox potentials greater than 300 mV.

The redox potential at 30 cm decreased during the first week of flooding and remained relatively constant for the remaining three weeks. At 40 cm, the redox potential did not respond to the 4 week flooding period, remaining at about 200 mV. At the end of flooding, the redox potentials of both the 30 and 40 cm layers were under 300 mV indicating an anaerobic condition at the bottom of the columns.

Two weeks of draining following the first four week flooding period brought the redox potential of the top 30 cm back to oxidizing conditions indicating fast exchange of oxygen between the atmosphere and the soil pores. The redox potential at the 40 cm depth, however, did not reach above 300 mV during the two week period. This indicates that there was not sufficient time for oxygen to penetrate into the soil to the 40 cm depth.

The redox potentials showed the same general pattern during the second four week flooding period (Fig. 7). However, unlike the first flooding period, the whole column was depleted of oxygen with all redox potentials reaching less than 300 mV. The rate of decrease was also faster indicating that more readily-available soluble carbon for microbial respiration was present during this period. Drying of soils and sediments has been shown to increase the amount of carbon available to soil microorganisms, thus increasing their growth rate.

The redox potential during the second drainage period, which was two weeks longer than the first, increased into the oxidizing range at all depths (Fig. 7). The top two layers reached 800 mV in the first week of the period while the 30 and 40 cm depths took longer times to reach oxidizing redox potentials. This indicates that, given sufficient time, the whole column will become oxidized.

A third flooding cycle was monitored for a short period at the end of the second drainage cycle (Fig. 7). The redox potential decreased rapidly upon flooding for all depths. The rate at which the soil became reduced for the three flooding periods increased with each period, likely reflecting the above-noted increase in carbon-availability after each cycle.

Changes of redox potentials with repeated flooding and draining in sawgrass columns followed a similar pattern as in the open water soils (Fig. 8). Although the redox potential decreased and increased upon flooding and draining respectively, the difference among the different soil depths was not as great as that in the open water column. Even the 40 cm depth showed very high redox potential during the draining periods.

Redox potential is mainly affected by oxygen content and other oxidized redox species such as nitrate, ferric iron and sulfate. However, it seems that oxygen is a principle factor in controlling the redox potential in these soils. The oxygen diffusion into the

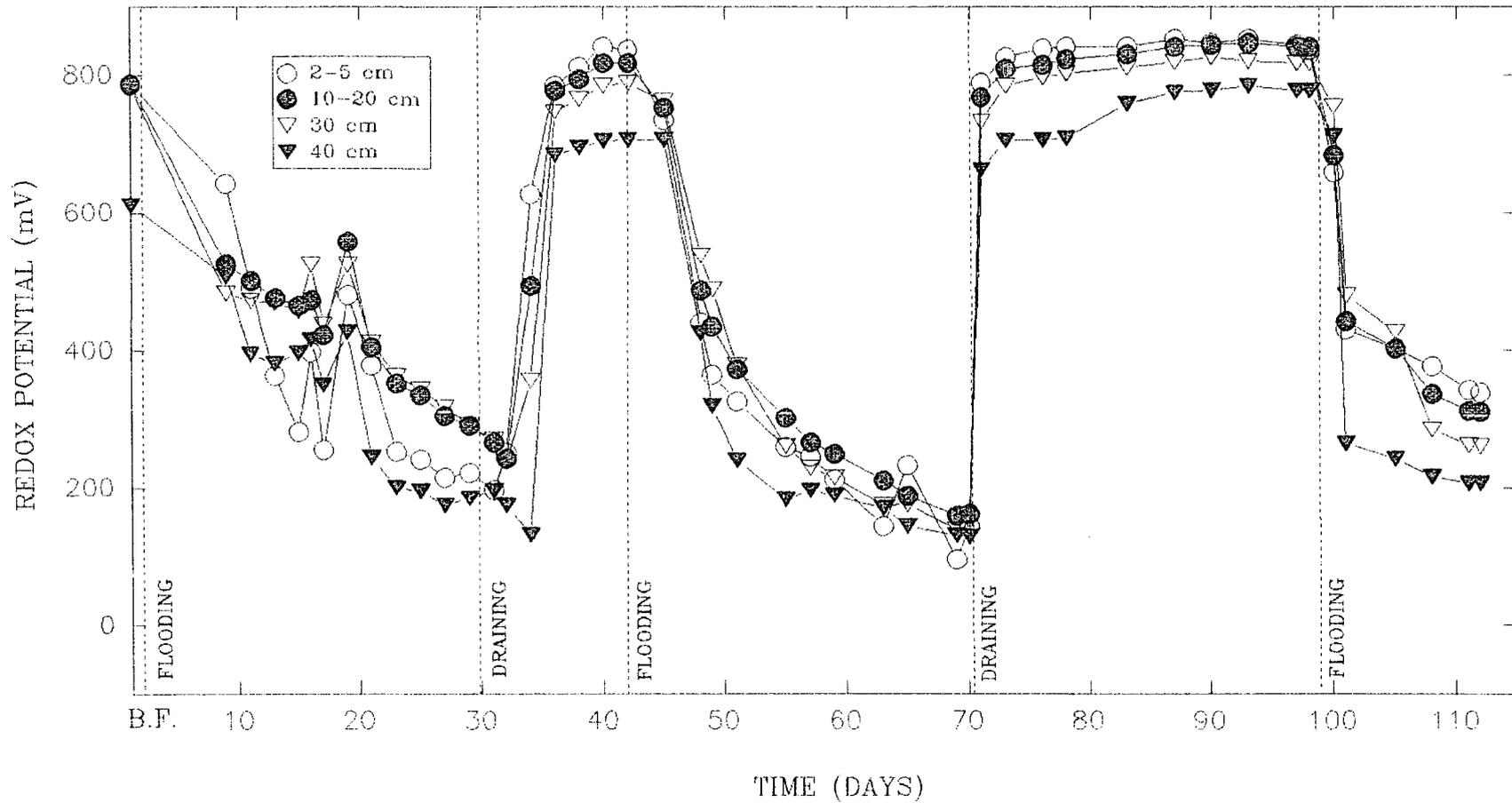


Figure 8. Redox potential changes in sawgrass soil of Hopkins Prairie upon alternate flooding and draining in a laboratory column study (B.F. = before flooding)

soil columns is primarily determined by the porosity of the soil core. It was observed during sampling that the sawgrass soil had a much more open structure than the soil at the open water site. Therefore, oxygen can reach the deeper layers of the column during the drained period more readily since the larger pores tend to allow more rapid diffusion of air.

3.2.2. Pore Water Chemistry

Nitrate (NO_3^-)

Before flooding, soils from both sites had high pore water NO_3^- concentrations in the top portion of the column (Fig. 9). The NO_3^- concentrations decreased with depth (Appendix Table 4) reflecting what was observed in the field (Fig. 3). The sawgrass soil had much higher concentrations of NO_3^- than the open water soil (Appendix Table 5). As the columns became flooded for the first time, the NO_3^- concentrations began to decrease until they reached undetectable concentrations after three weeks of flooding.

Downward diffusion and subsequent denitrification was likely the reason for the NO_3^- disappearance. Nitrate was below detection limits during the two week drainage period and the following reflooding period (Fig. 9). However, during the second drainage period, NO_3^- was again present in both the open water and sawgrass columns and concentrations increased over time. At the end of the four week drainage period, the NO_3^- concentration in the pore water was about 20 mg/l. These high concentrations of NO_3^- in the soil column was probably due to the oxidation of NH_4^+ produced during

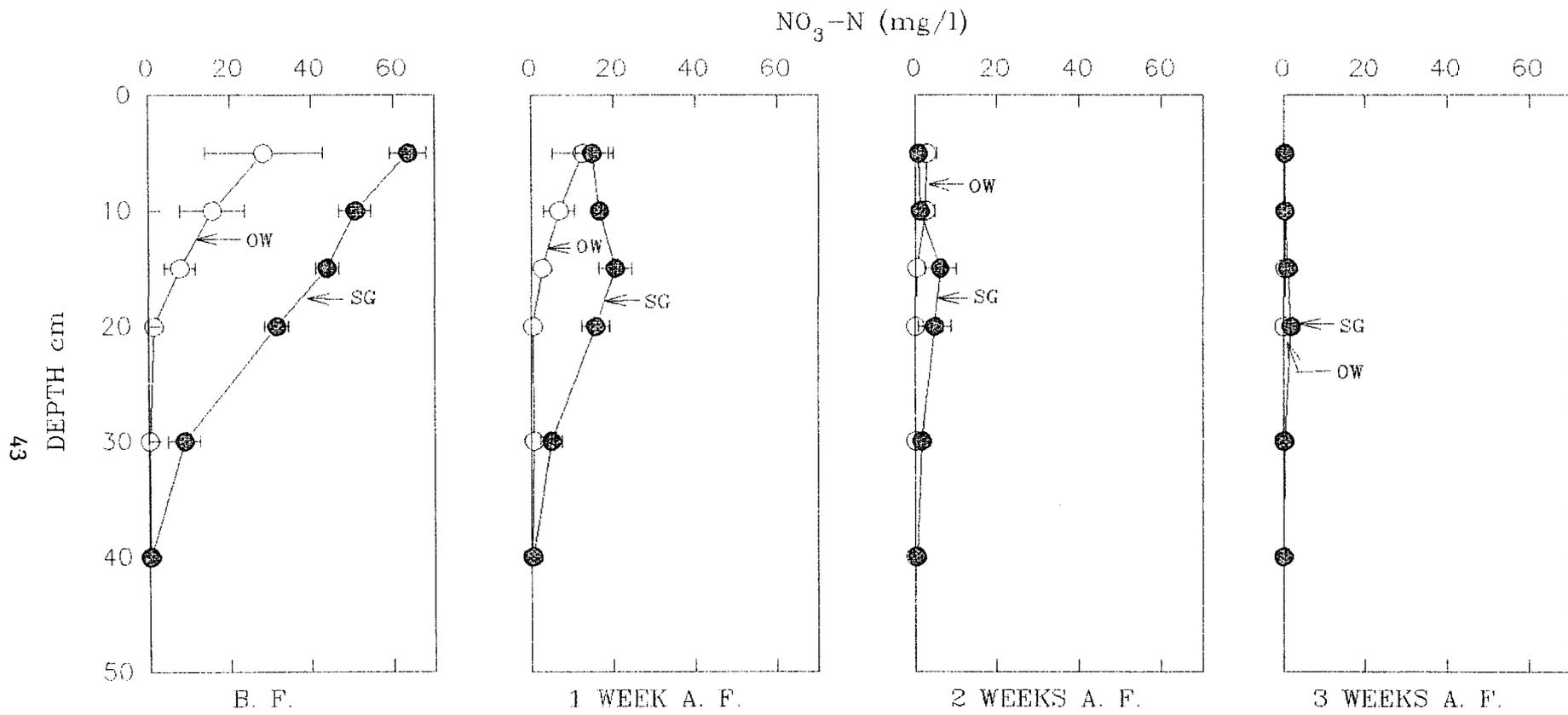


Figure 9. Pore water $\text{NO}_3\text{-N}$ profiles for open water (OW) and sawgrass (SG) soils in laboratory column studies (Error bar = ± 1 std. error) (B.F. = Before flooding, A.F. = After flooding)

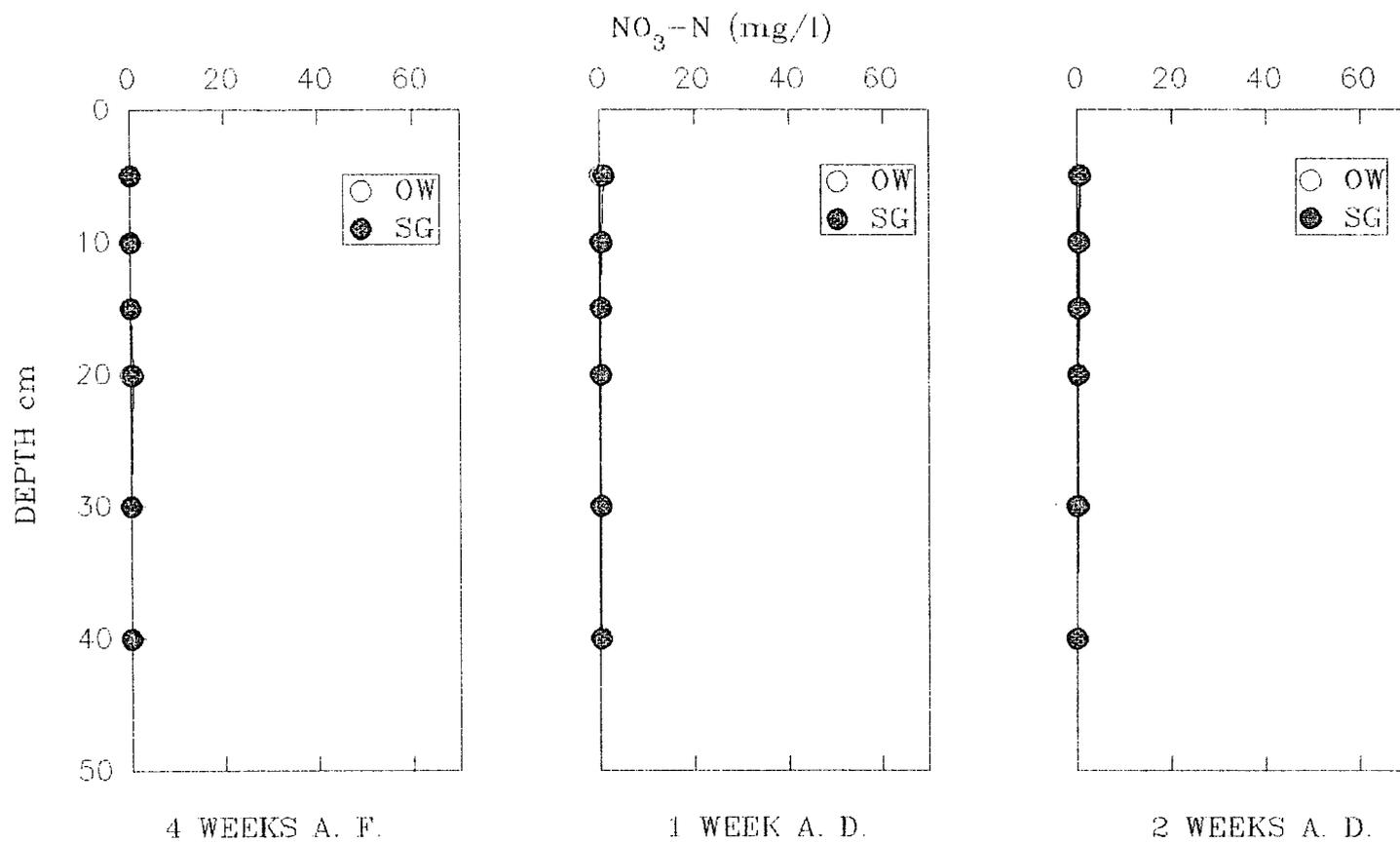


Figure 9. Continued. OW = Open water, SG = Sawgrass, A.F. = After flooding and A.D. = After draining

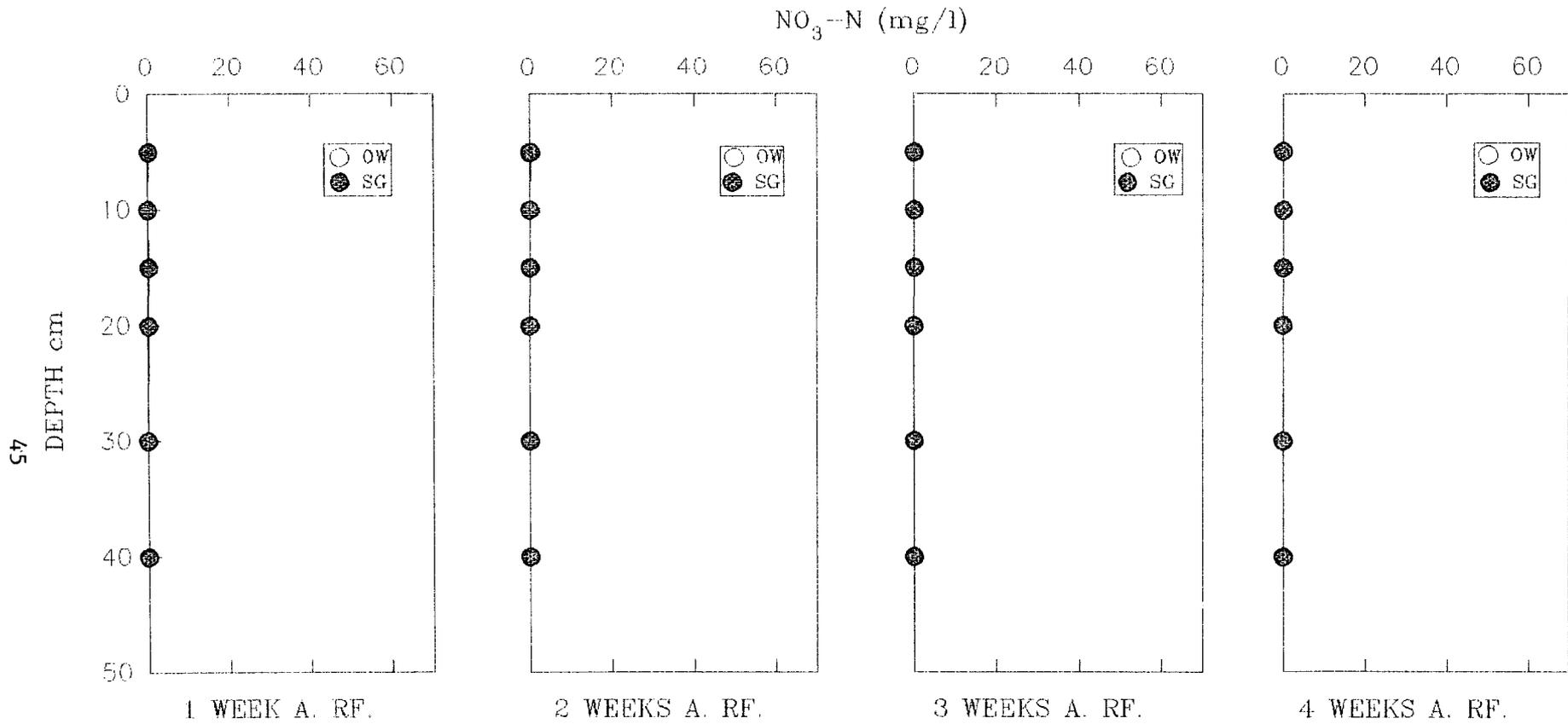


Figure 9. Continued. OW = open water, SG = sawgrass, (A.TF. = after reflooding)

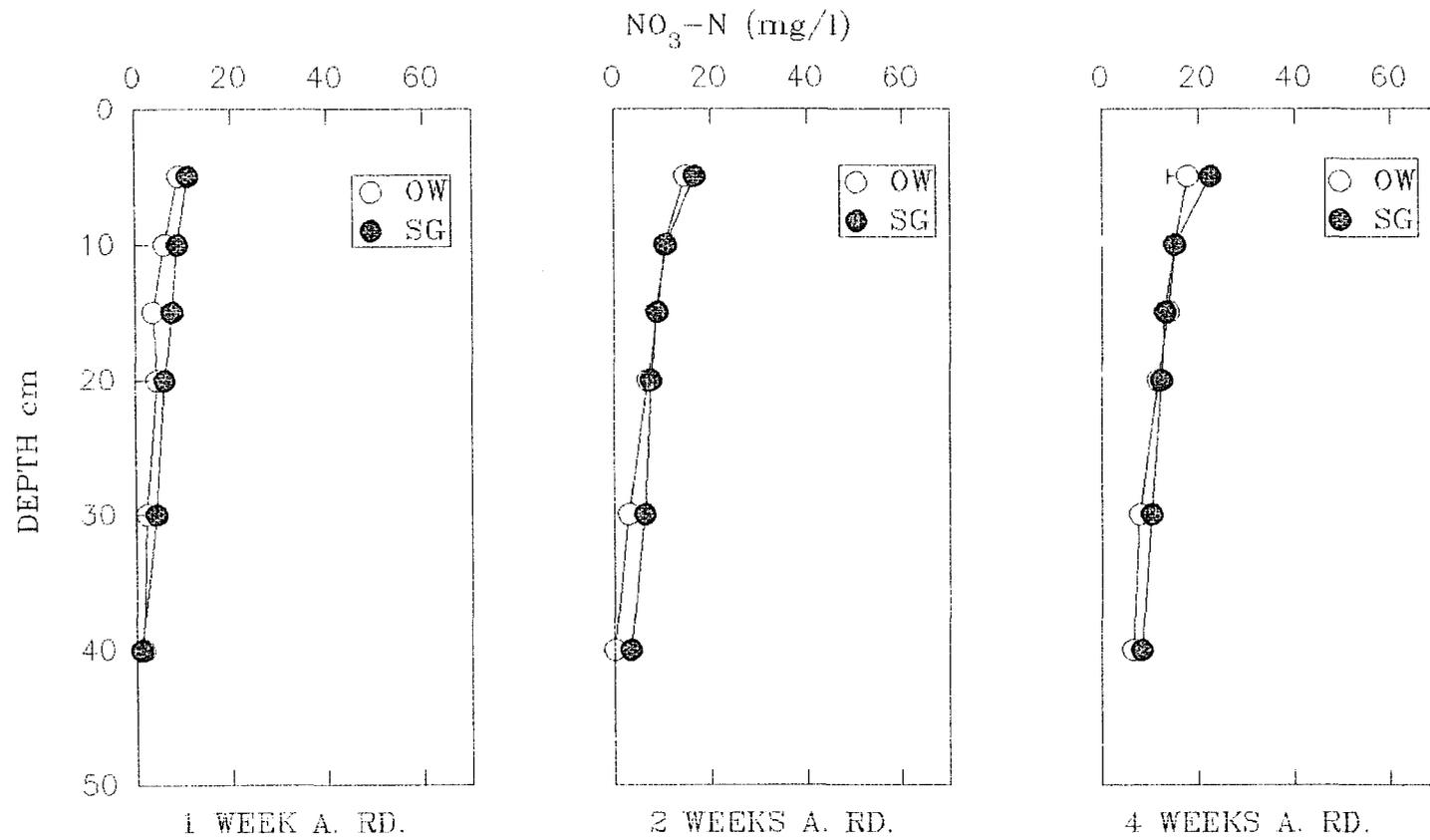


Figure 9. Continued. OW = open water, SG = sawgrass. (A.RD. = after redraining)

decomposition of organic matter. Diffusion of NH_4^- upward from more anaerobic zones was not likely contributing to the higher NO_3^- in the top layer since there was no upward gradient with respect to NH_4^+ (Fig. 10).

Ammonium-N (NH_4^+)

Before flooding, the NH_4^+ concentration in open water and sawgrass soil columns had similar distributions as those observed in the field (Fig. 10). Ammonium concentrations in the soil columns decreased with depth upon flooding for both soils (Appendix Table 4). However, the decreases were more consistently significant for the sawgrass soil (Appendix Table 4). During the first two week draining period, the NH_4^+ concentration decreased in the upper layer of both open water and sawgrass columns.

The same pattern of NH_4^+ concentrations was found in the second wet-dry cycle (Fig. 10). The decrease of NH_4^+ concentrations during the second flooding period was relatively small compared to that in the first flooding period. During the second draining period, NH_4^+ concentration in the upper layer of both soil columns decreased significantly relative to the lower layers (Appendix Table 4) and reached their lowest concentrations at the end of flooding period. Differences between the two soil types were generally not significant (Appendix Table 5). The decrease in NH_4^+ concentrations during both drainage periods (Fig. 10) and the increase in NO_3^- concentrations (Fig. 9) indicate that nitrification was occurring in both soils.

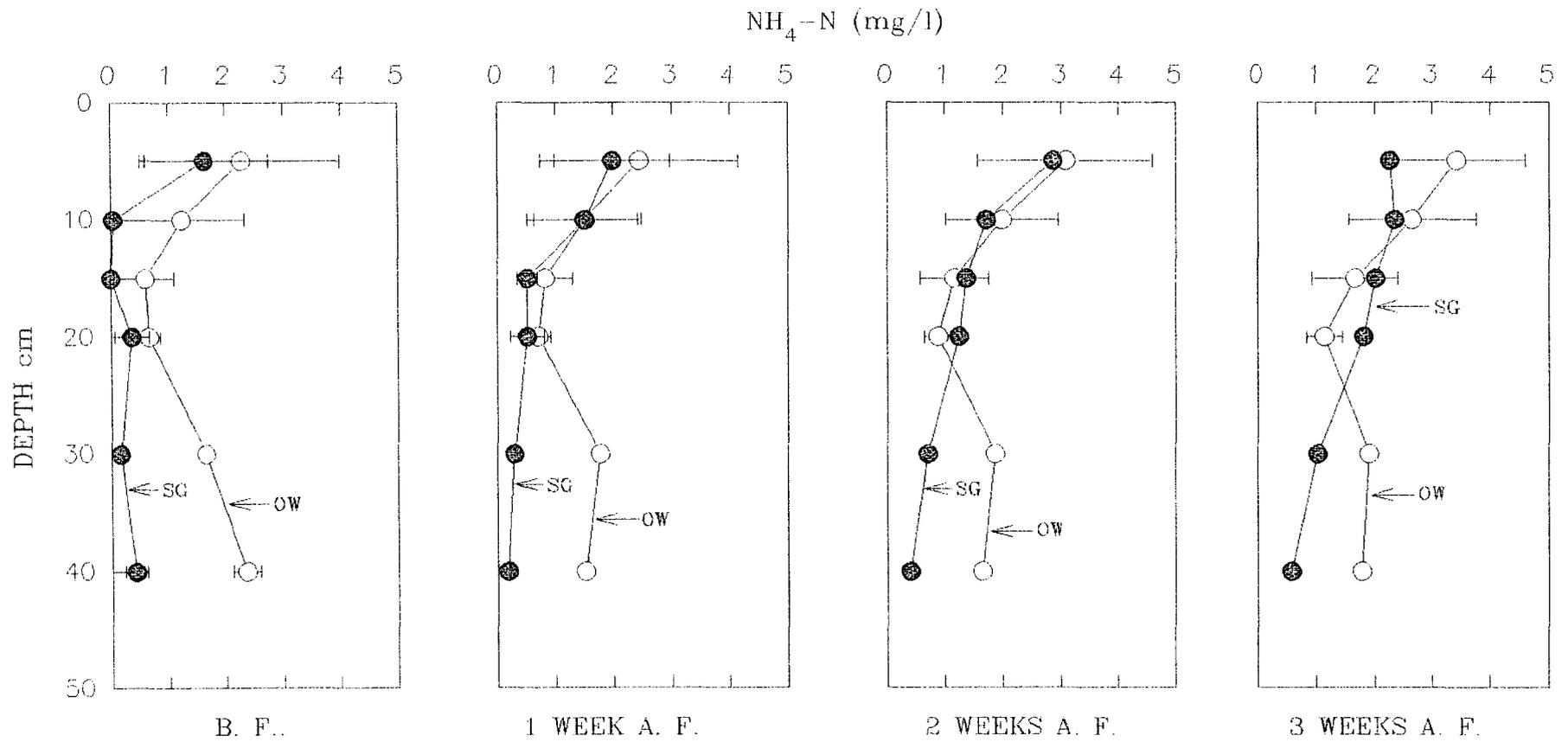


Figure 10. Pore water $\text{NH}_4\text{-N}$ profiles for open water (OW) and sawgrass (SG) soils in laboratory column studies (Error bars = ± 1 std. error) (B.F = Before flooding, A.F. = After flooding)

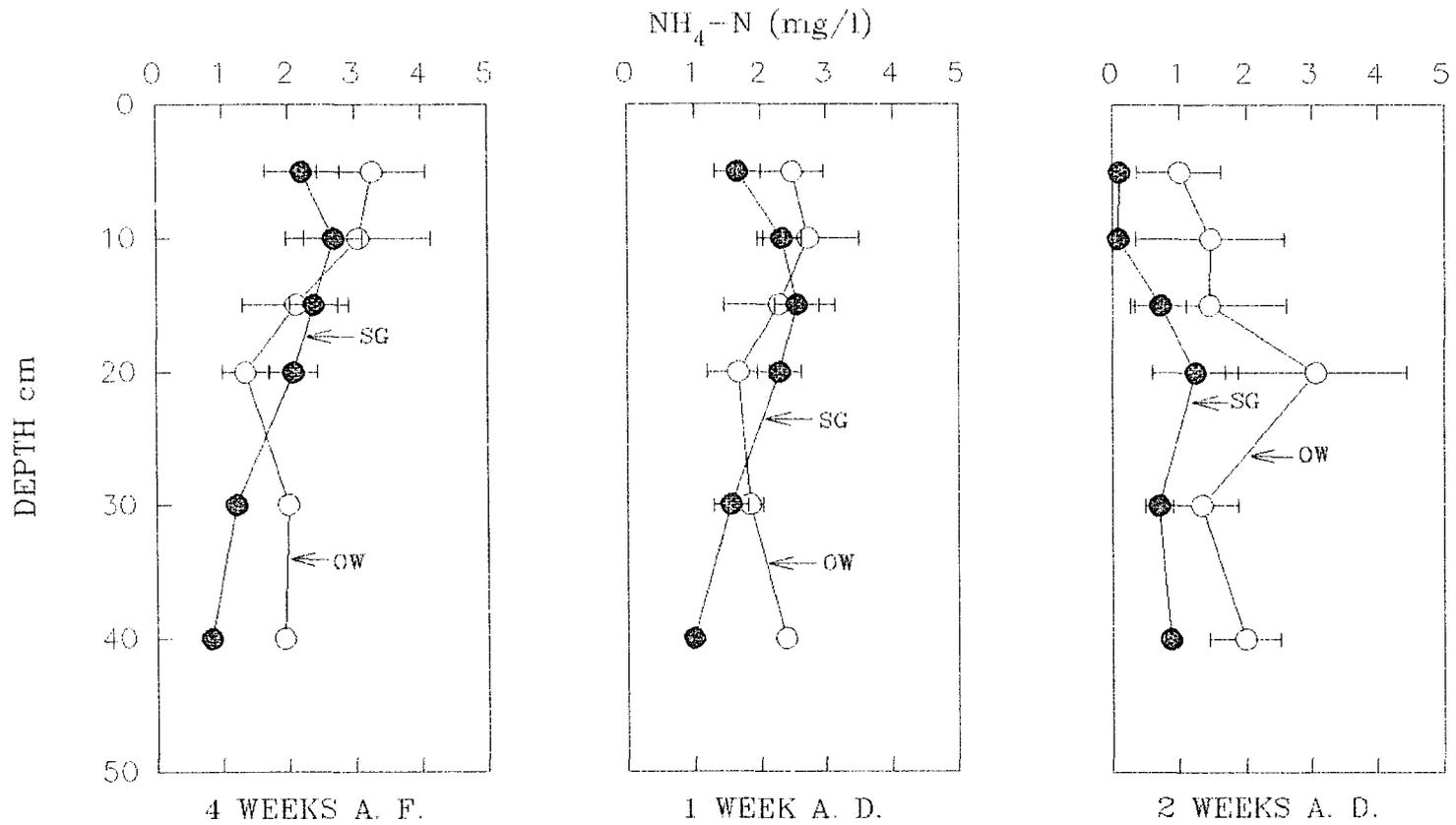


Figure 10. Continued. OW = Open water, SG = Sawgrass, A. F. = After flooding
A. D. = After draining

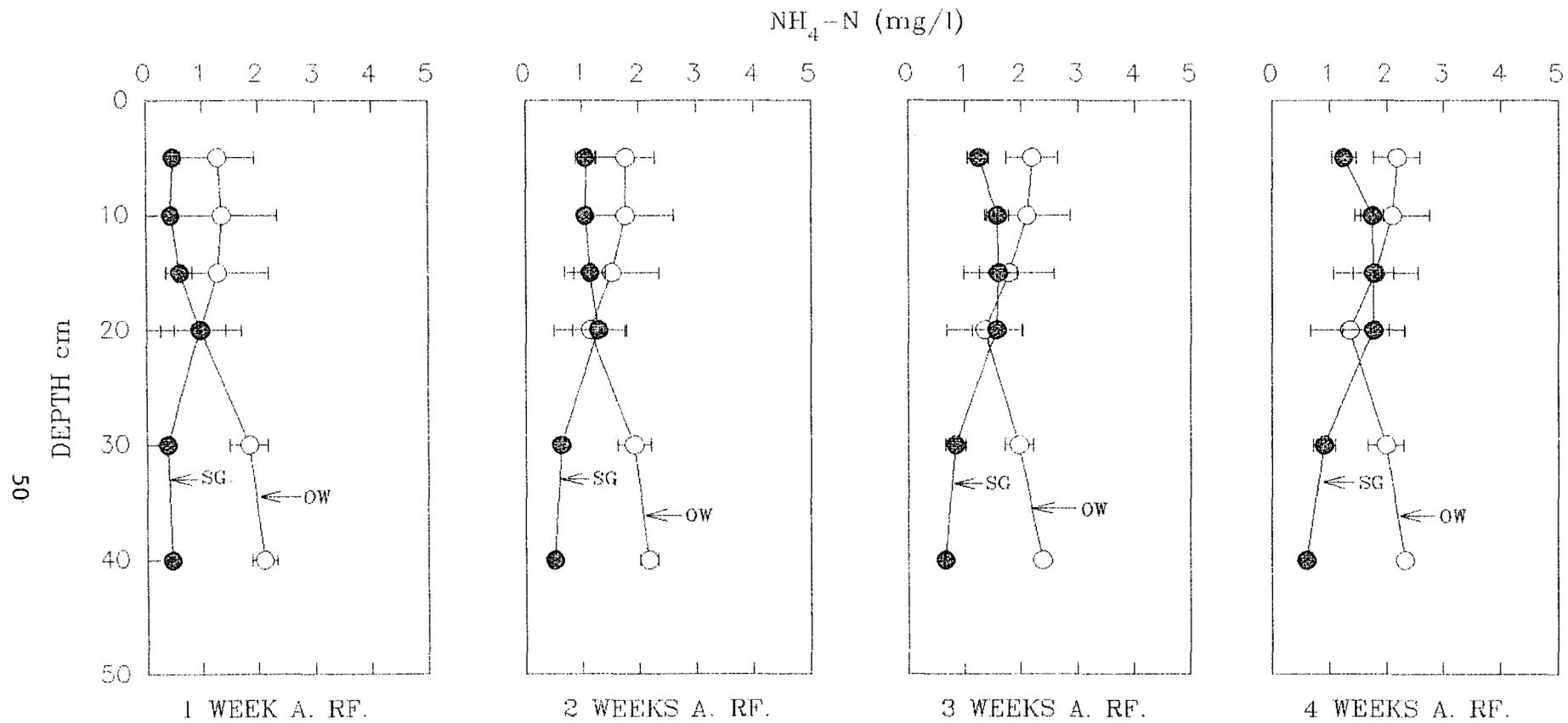


Figure 10. Continued. OW = open water, SG = sawgrass, (A.RF. = after reflooding)

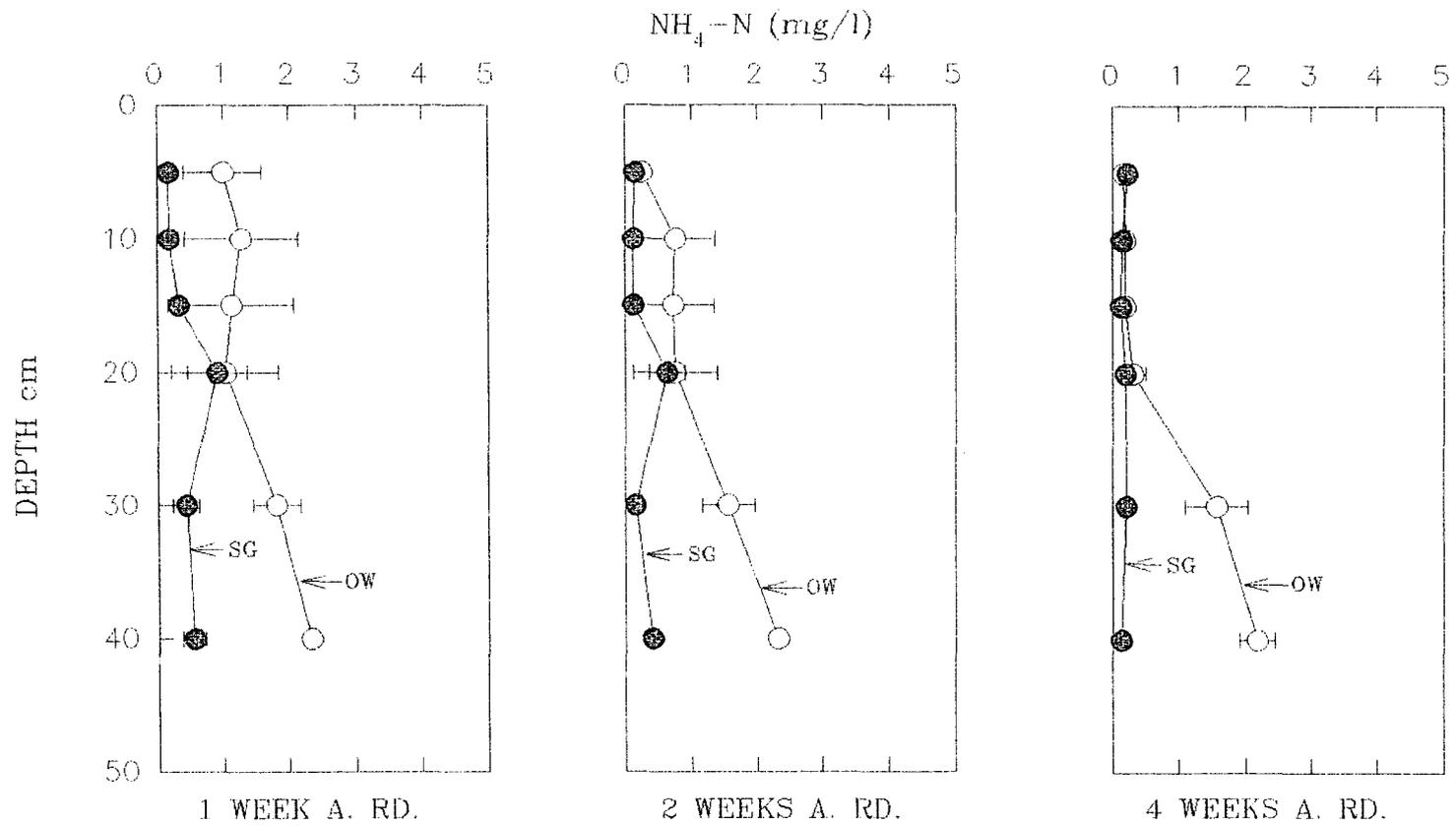


Figure 10. Continued. OW = open water, SG = sawgrass (A.R.D. = after redraining)

The lower portion of the columns did not show very much variation in NH_4^+ concentration during the entire study period (Fig. 10). There apparently was not sufficient oxygen present to allow nitrification to occur in the lower part of the soil profile.

Soluble Reactive Phosphorus

Concentrations of SRP in the open water columns were very low and quite often below the detection limit during the study period (Fig. 11). Soluble reactive phosphate concentrations were generally higher for the sawgrass soil than the open water soil, especially in the upper 30 cm layer (Appendix Table 5). Concentrations of SRP in the sawgrass soil were relatively high in the upper layer and showed a response to the alternate flooding and draining cycles (Appendix Table 4). The concentrations of SRP in the upper layer of the sawgrass soil increased upon flooding and decreased upon draining (Fig. 11). The same trend was found in the second wet/dry cycle. Since phosphorus is not directly affected by redox potential, the variation of SRP during the cycles was probably governed by the solubility of phosphate in the pore water.

Since Hopkins Prairie soil has an acidic pH, phosphorus is not likely bound to Ca-containing materials. Hopkins Prairie soil contains a moderate amount of Fe and Al (D. Ivanoff, personal communication), therefore, Fe and Al and their oxides could play an important role in regulating the solubility of phosphate ions. Phosphate can be bound to Fe and Al oxides during drained conditions, taking the phosphate out of solution. When the soil is

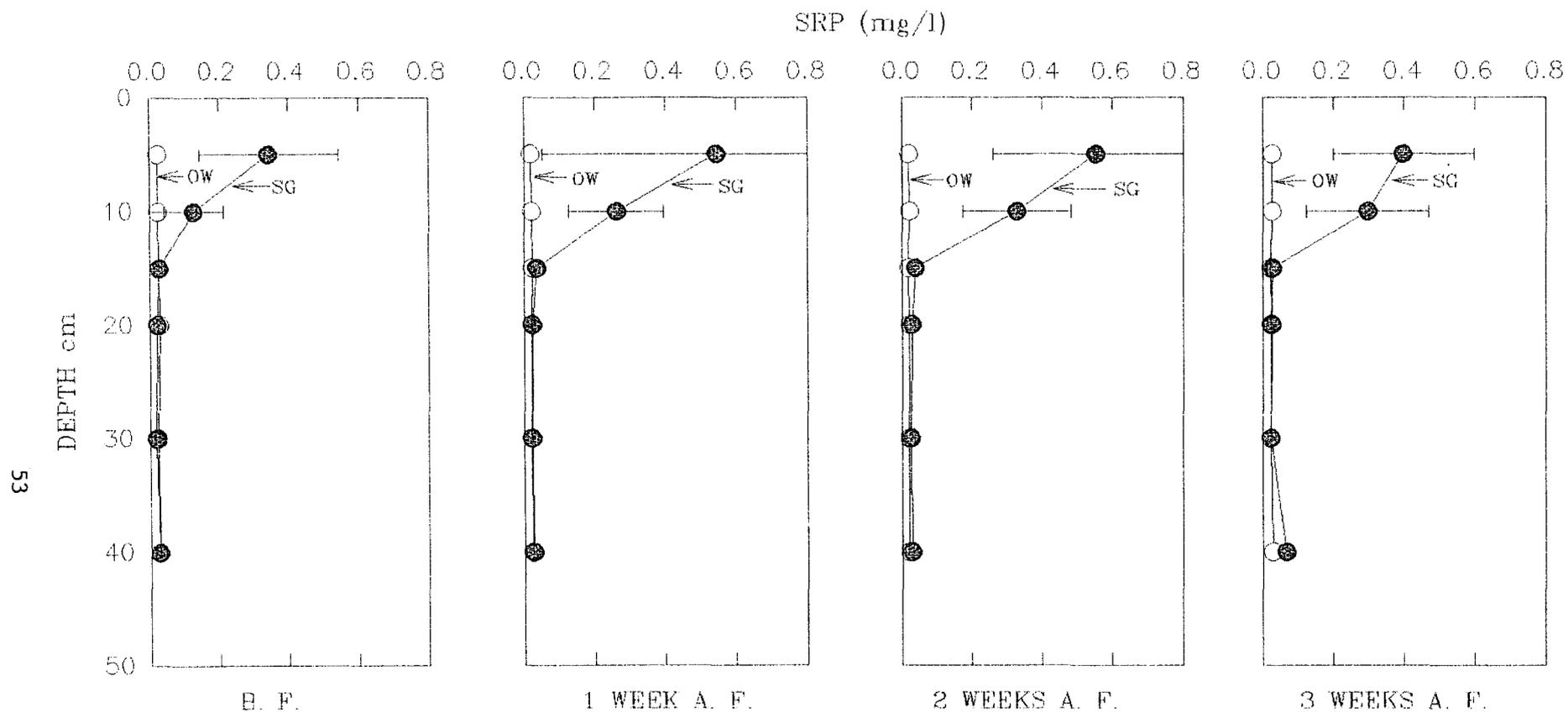


Figure 11. Pore water SRP profiles for open water (OW) and sawgrass (SG) soil in laboratory column studies (Error bar = ± 1 std. error) (B.F. = Before flooding and A.F. = After flooding)

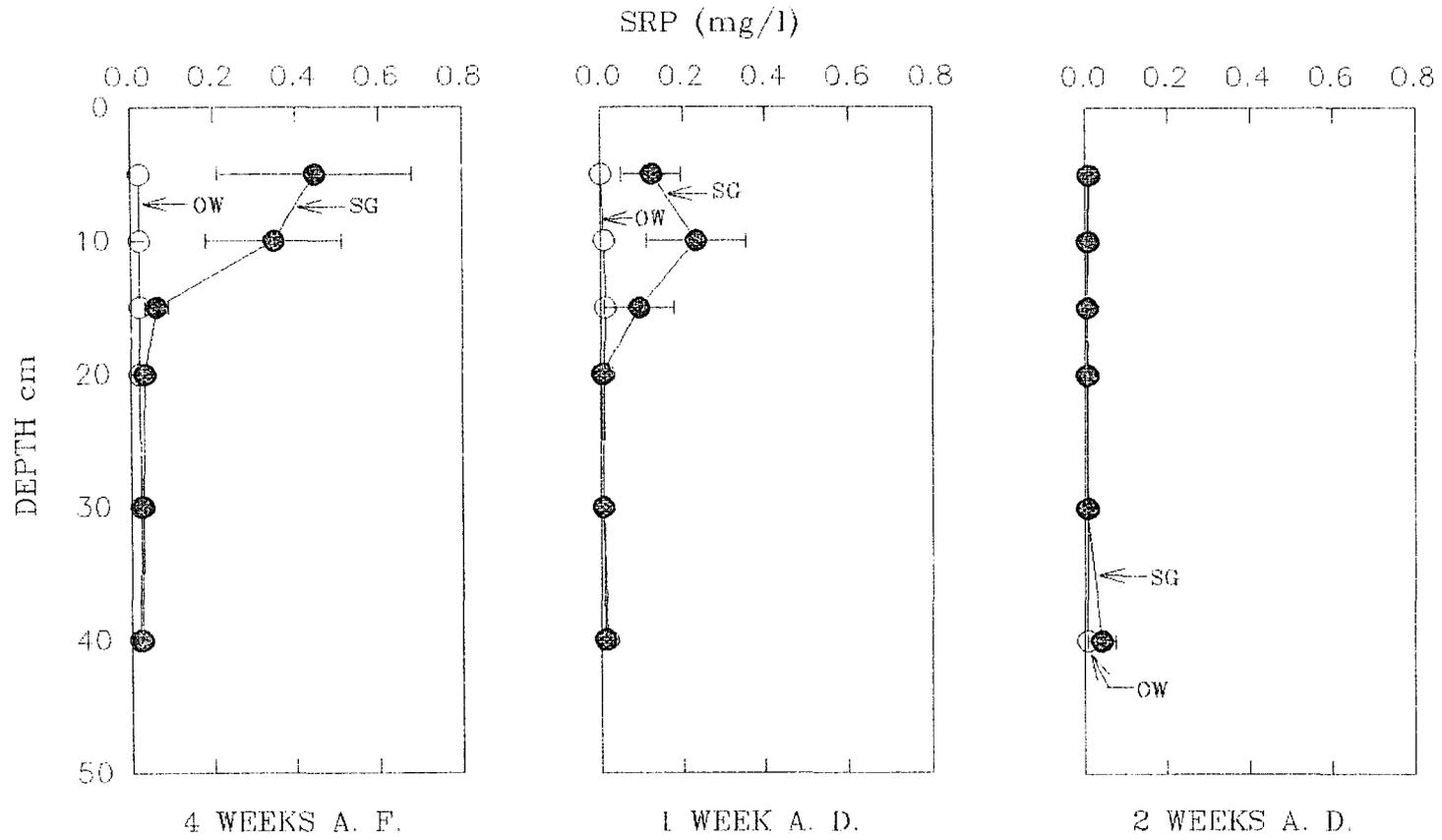


Figure 11. Continued. OW = Open water, SG = Sawgrass, A.F. = After flooding, A.D. = After draining

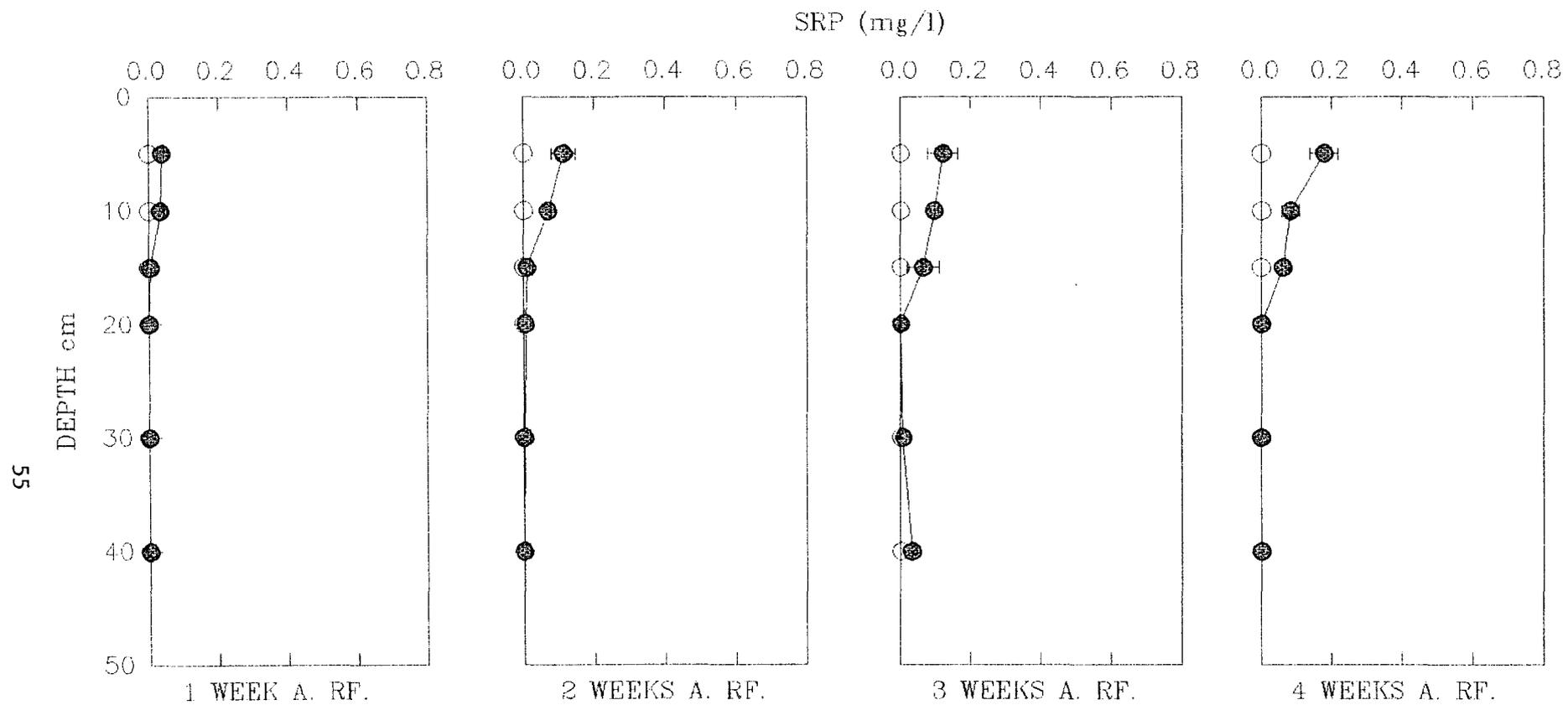


Figure 11. Continued. OW = open water, SG = sawgrass, (A.RF. = after reflooding)

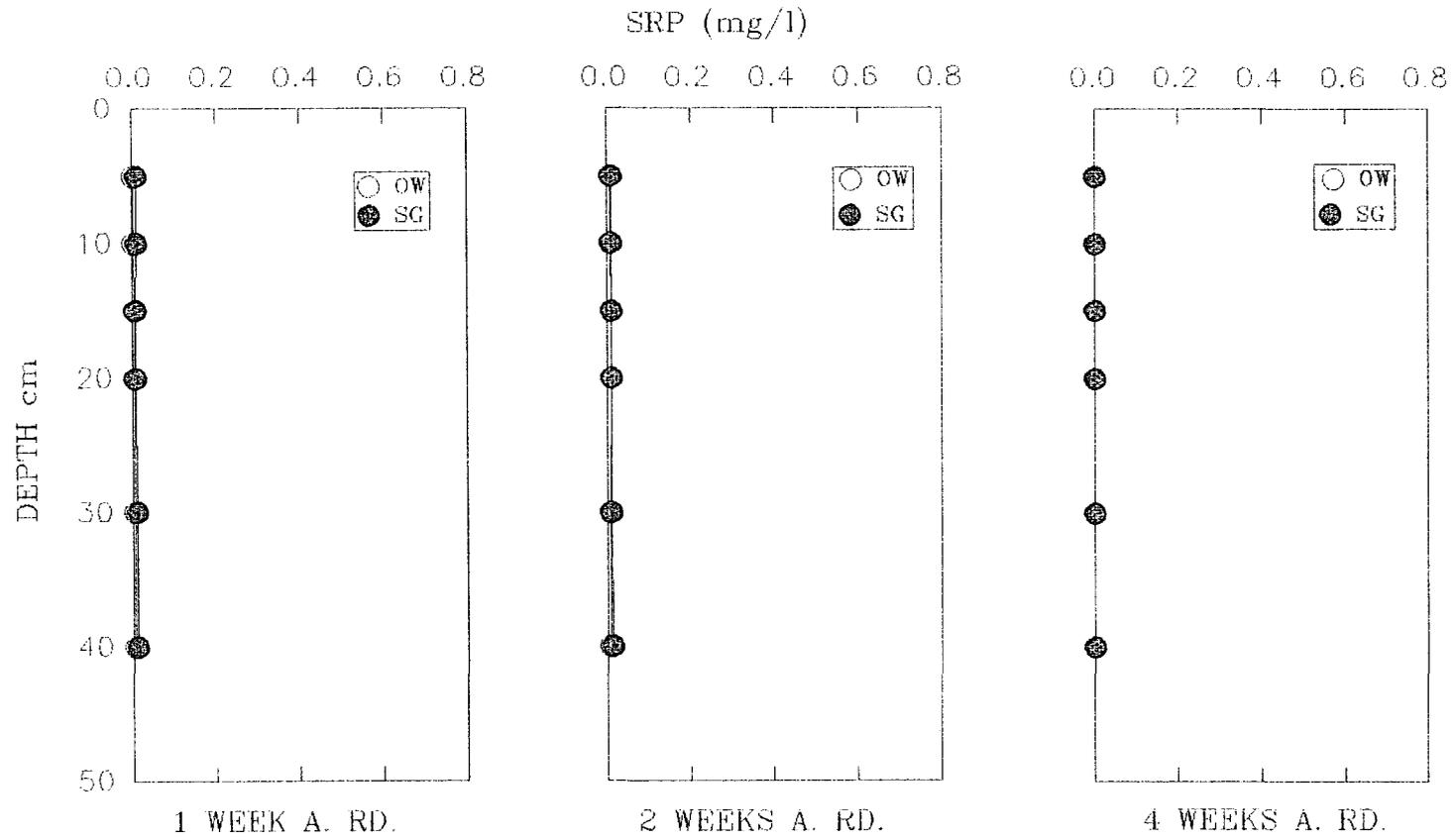


Figure 11. Continued. OW = Open water, SG = Sawgrass, (A.RD. = after redrainig)

flooded, Fe^{+3} is reduced to Fe^{+2} releasing phosphate back into the solution.

Sulfate (SO_4^-)

Sulfate concentrations did not show much change in response to alternate flooding and draining (Fig. 12; Appendix Table 4). Redox potentials in all depths of the two soil columns were always greater than 0 mV (Figs. 7 and 8). Since SO_4^- reduction occurs at a redox potential of -200 mv, it was not likely that SO_4^- reduction occurred during the study period. The changes in SO_4^- concentrations between flooded and drained periods may reflect the effects of removal or addition of water more than any biogeochemical process. Sulfate concentrations were generally lower in the sawgrass soil than in the open water soil, especially during the periods of flooding (Appendix Table 5). This trend was also observed quite often in the field (Table 9) and is likely due to the lower total sulfur concentrations in the sawgrass soil (Table 1).

During the two flooding periods, SO_4^- did not disappear, even in the lower part of the column, however, NO_3^- was quickly depleted indicating the redox system may be poised by other redox couples such as Fe and Mn. Coincidentally, the redox potentials, at the end of flooding periods, were always stabilized between 100-300 mV which is within the range that Fe and Mn reductions normally occur. Due to the lack of Fe and Mn data for these soils, this hypothesis cannot be verified.

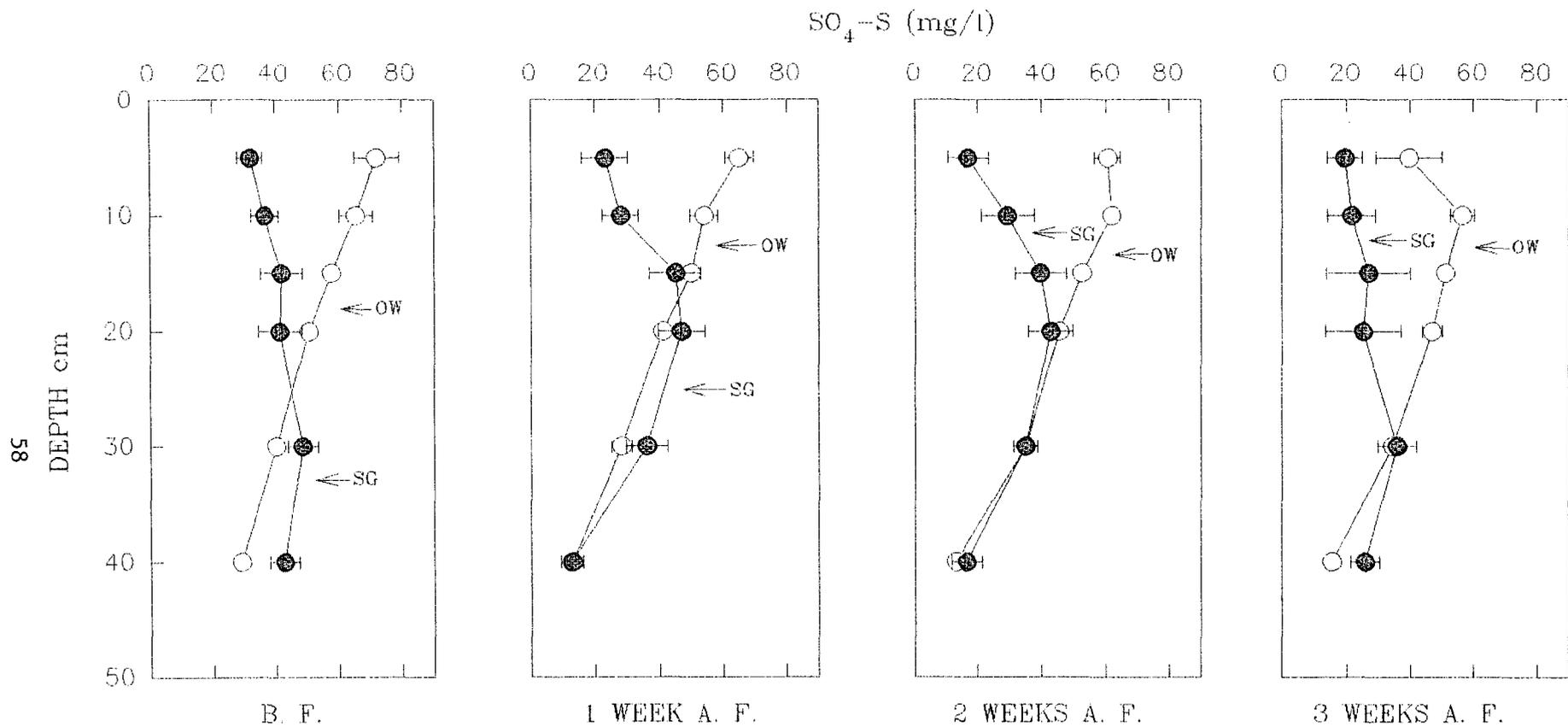


Figure 12. Pore water SO₄-S profiles for open water (OW) and sawgrass (SG) soils in laboratory column studies (Error bar = ± 1 std. error) (B.F. = Before flooding, A.F. = After flooding)

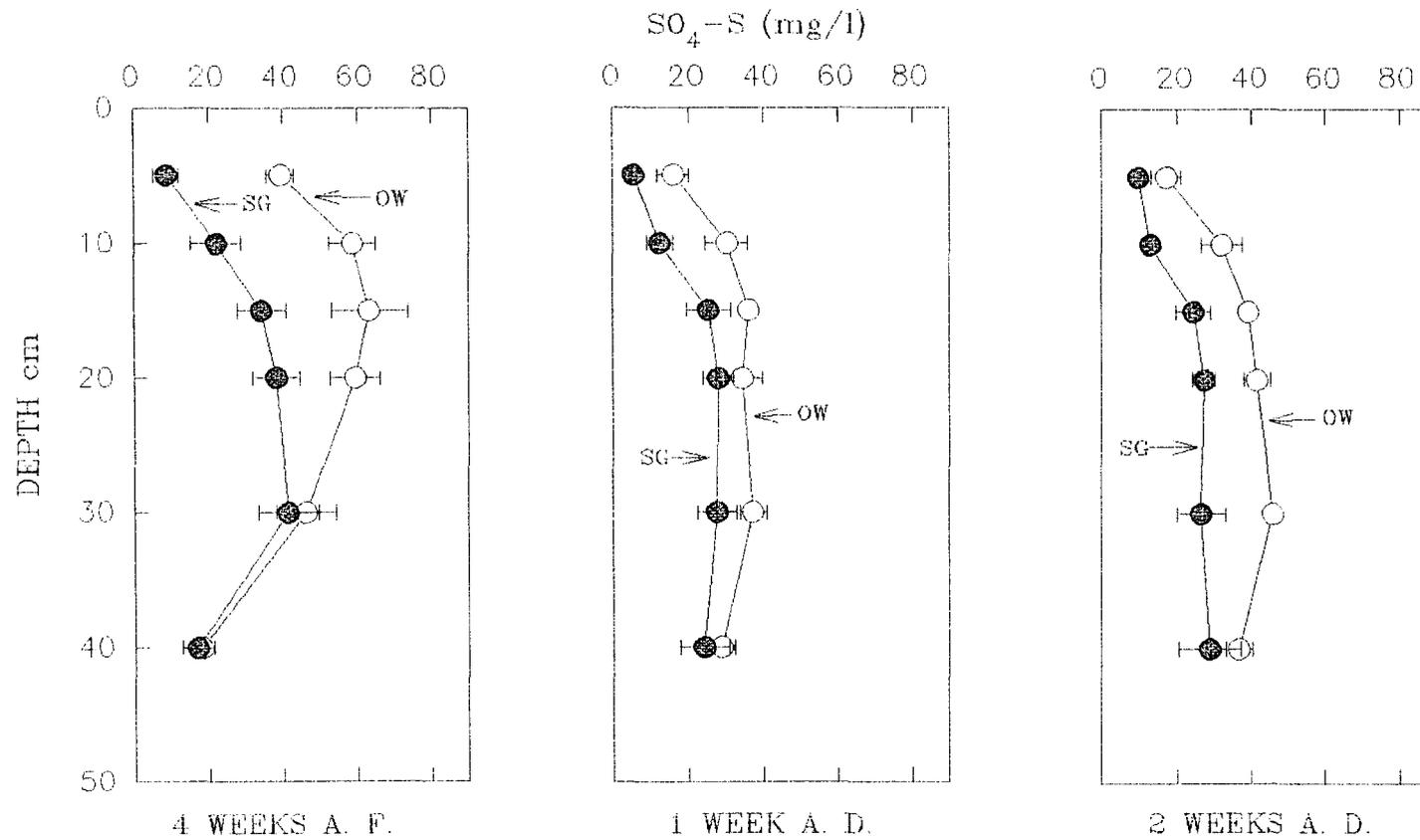


Figure 12. Continued. OW = Open water, SG = Sawgrass, A.F. = After flooding and A.D. = After draining

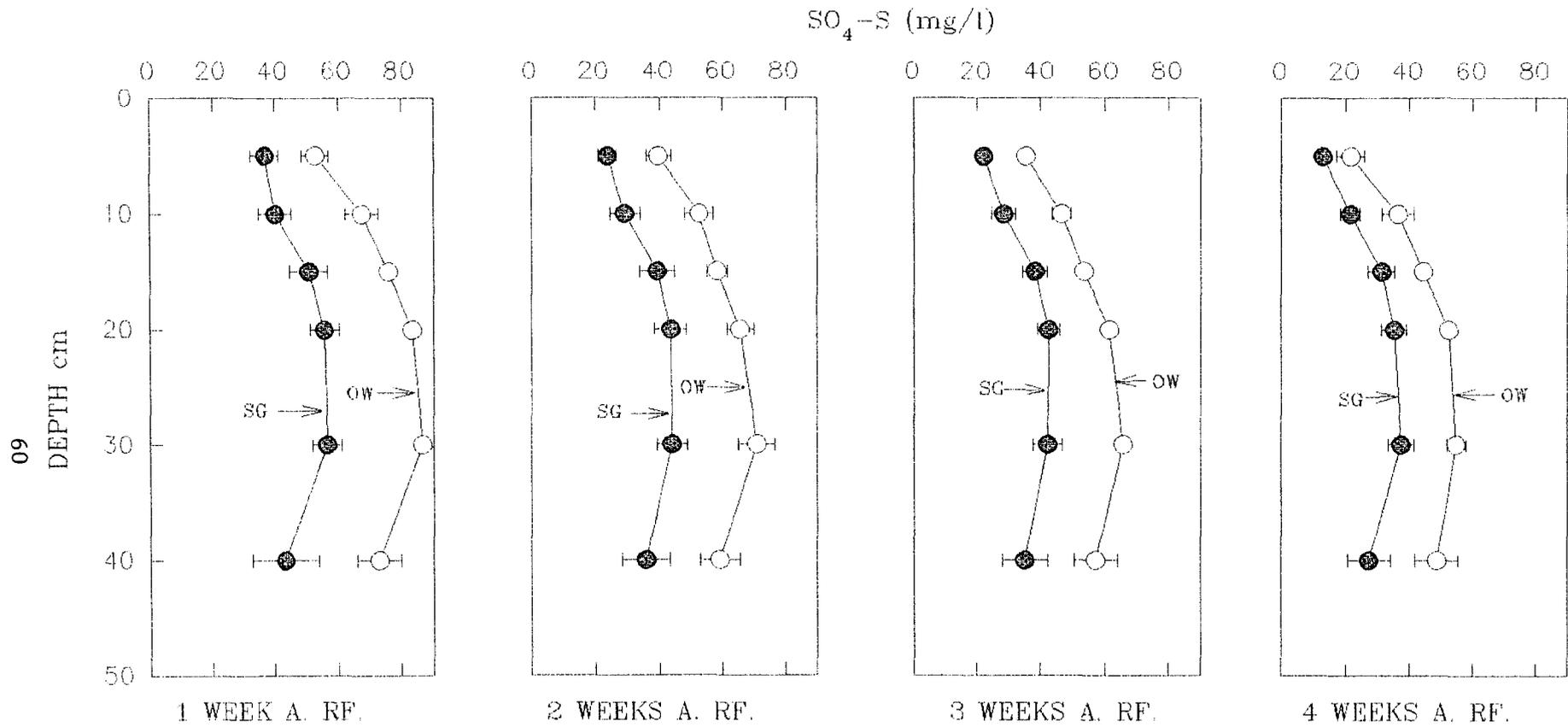


Figure 12. Continued. OW = open water, SG = sawgrass, (A.R.F. = after reflooding)

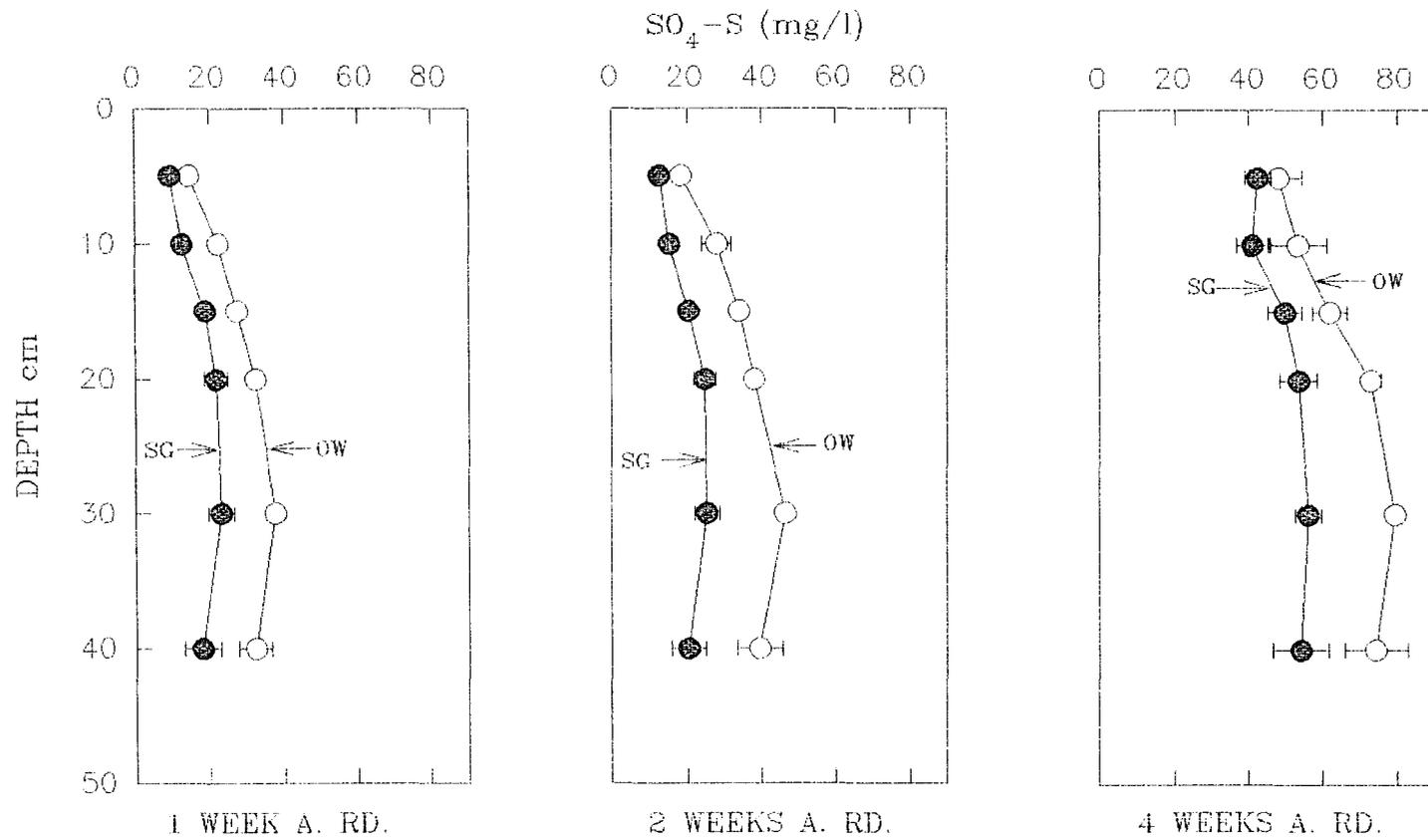


Figure 12. Continued. OW = open water, SG = sawgrass, (A.R.D. = after redraining)

3.3. Task 3: Sulfate Reduction and Organic Matter Decomposition

CO₂ production and soluble organic carbon (SOC) release

Decomposition of organic matter in a wetland soil is the major source of nutrients for plant and microbial growth, and the rate of organic matter decomposition directly affects the persistence of the wetland ecosystem. Under flooded conditions, the decomposition of organic matter is mainly conducted by facultative and anaerobic microorganisms. The rate of decomposition is determined by the type and the amount of substrate and inorganic oxidants (electron acceptors).

Surface soil from the Hopkins Prairie open water area was amended with glucose and different levels of SO_4^- to evaluate the effect of SO_4^- on organic matter decomposition under anaerobic conditions. Glucose was added as an energy source to ensure high microbial activity and to deplete any NO_3^- present in the system.

Carbon dioxide production is a good indicator of organic matter decomposition. During the first week of incubation, all the soils with glucose addition showed rapid CO_2 production compared to the control soil (Fig. 13). The CO_2 production in the soil with only glucose addition was most rapid. This fast production of CO_2 upon glucose addition has been referred to as a "priming effect" (Reddy et al. 1986). During this period, microorganisms consumed the labile carbon (C) source (glucose) using NO_3^- as the electron

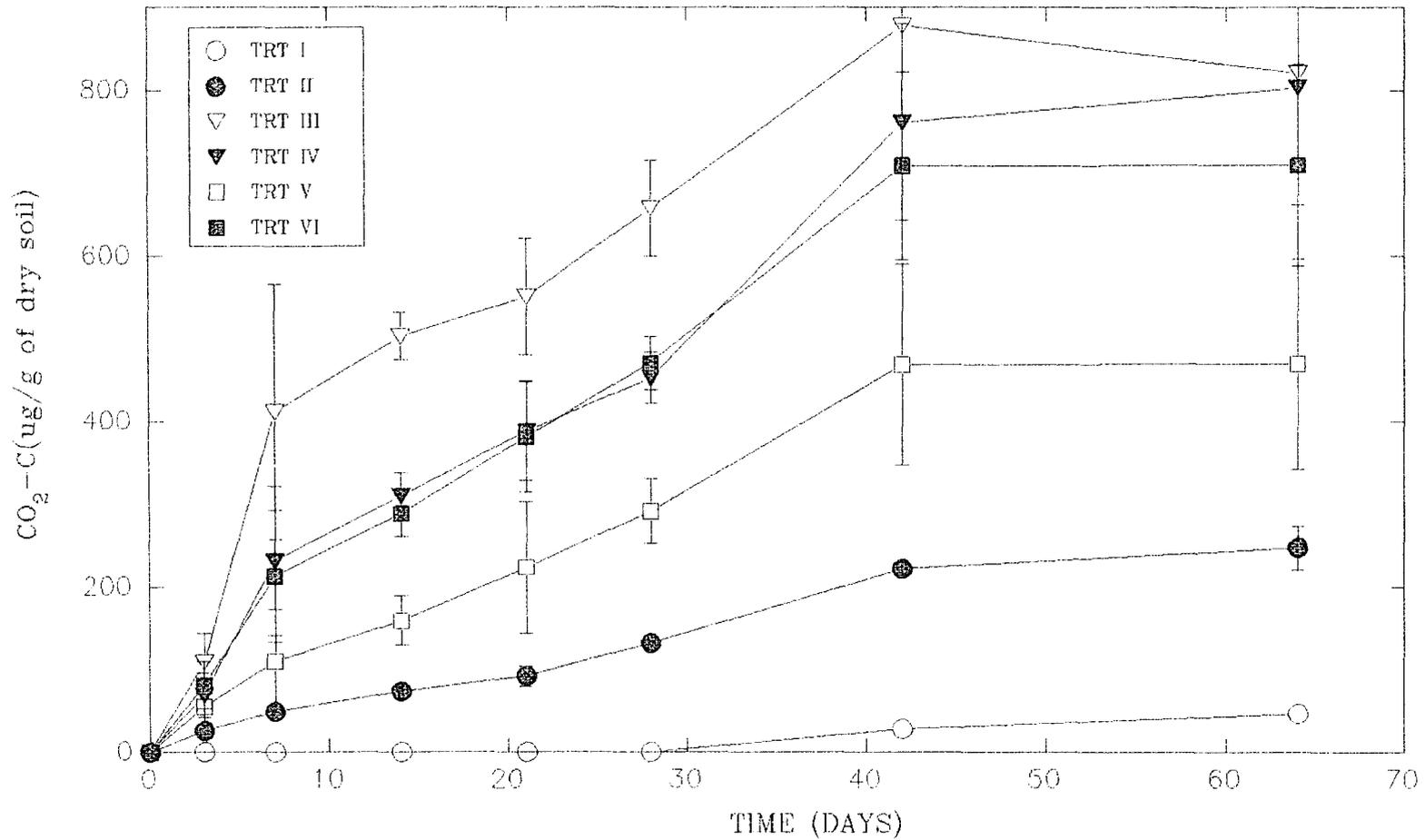


Figure 13. Cumulative CO₂ production as a function of incubation time under different levels of SO₄ for Hopkins Prairie soil (TRT I = Blank, TRT II = Soil only, TRT III = SOil + 300 ug of glucose-C/gram of dry soil, TRT IV = Soil + glucose + 100 ug of SO₄-S/gram of dry soil, TRT V = Soil + glucose + 200 SO₄-S/gram of dry soil, TRT VI = Soil + glucose + 400 ug of SO₄-S/gram of dry soil) (Error bar = ± 1 std. error)

acceptor. The pulse of CO_2 production suggests that organic matter decomposition in this soil is limited by readily-decomposable organic matter.

The rate of CO_2 production slowed after the first week and leveled off at the 6th week of incubation. The change in the rate of CO_2 production reflected the change of substrate used by the microorganisms. After the most labile C source (glucose) was consumed during the first week, the microbes began to use the native organic C which is more resistant to the decomposition, therefore the rate of CO_2 production decreased. The rate of CO_2 production during the first week of incubation was highest when glucose was added to the soil (Table 10). It also appeared that when the soil was amended with C, sulfate had an inhibitory effect on CO_2 production (Fig. 13), but this trend was not statistically significant with the number of replications used (Table 10).

After the first week of incubation, CO_2 production rates were relatively constant for all treatments (Fig. 13 and Table 10). Glucose and SO_4^{2-} amendments did not have any significant effect on CO_2 production (Table 10). This was unexpected since it was hypothesized that SO_4^{2-} would act as an electron acceptor and increase the amount of CO_2 produced and the amount of organic matter decomposed. The redox potential in Hopkins Prairie soil

Table 10. Effect of glucose and sulfate amendments on CO₂ production from anaerobically incubated Hopkins Prairie sediment.

Treatment #	Glucose Added	Sulfate Added	Rate of CO ₂ production*	
			0-7 day	7-42 day
I	0	0	0 b‡	0.79
II	0	0	7.03 b	4.92
III	300	0	58.76 a	13.33
IV	300	100	33.03 ab	15.14
V	300	200	15.67 b	10.25
VI	300	400	30.35 ab	14.17

* rate = μg of CO₂-C/g of dry soil/day

‡ Means within a column followed by the same letter do not differ significantly, $P < 0.05$, based on Duncan's Multiple Range Test.

did not reach sufficiently low levels to allow SO_4^- reduction in the previous study (Task 2), and apparently we did not add enough glucose in this study to drive the redox potential sufficiently low to allow SO_4^- reduction. It appears that the organic matter in this soil is quite resistant to decomposition and that it takes a longer incubation period than nine weeks to drop the redox potential sufficiently low to allow SO_4^- reduction. We do know that under field conditions, the redox potential can decrease to levels which allow SO_4^- reduction (Fig. 2). However, it apparently takes a relatively long period of time to reach these low levels.

4.0 CONCLUSIONS

4.1 Task 1

There was no water overlying the prairie surface during this study, therefore the effect of hydrology was mainly through the water table depth fluctuation in the soil profile. Although the water table depth fluctuated during the study period, the redox potentials in the top 10 cm of open water soil were always greater than +300 mV, indicating that an oxidizing condition existed in the surface soil throughout the study. The redox potential decreased in the zone near the water table and the soil remained anaerobic below the water table throughout the study.

The redox potentials were generally higher in the sawgrass community than in the open water area. The root

system of the sawgrass community is more fibrous compared to that in the open water community resulting in a more open soil structure. This could affect the movement of gases in the sawgrass soil and allow more rapid aeration of the sawgrass soil.

Nutrient concentrations and transformations were affected by water table depth. Ammonium concentrations in water extracts of the two soil types were relatively uniform with depth. However, water extraction likely did not remove all the ammonium from the soil due to the soil's cation retention ability. Nitrate concentrations were highest in the oxidized soil layer indicating that nitrification was occurring in both soils. In the field studies, SRP concentration did not show any effect due to water table fluctuation. Soluble reactive phosphorus concentration was low in the entire profile for both soils. This indicates the P may be the limiting factor for plant growth in this ecosystem.

Sulfate concentrations varied considerably over time in a non-consistent manner. This may be related to fluctuations in water table depth between sampling periods. It was also apparent that significant sulfate reduction did not occur below the water table as evidenced by higher sulfate concentrations below than above the water table. Apparently the organic matter deeper in the soil profile is not sufficiently available to microorganism to drive the sulfate reduction process at a measurable rate. When the water table

is closer to the soil surface, sulfate reduction has been shown to occur (Graetz 1991).

4.2 Task 2

Intact soil columns were brought to the laboratory where the effect of flooding and drainage could be studied under controlled conditions, and the effects of rainfall events between field sampling dates could be eliminated. The soil redox potential decreased rapidly upon flooding and increased during drainage cycles. The rate at which the soil became reduced increased with each flooding period likely reflecting increased carbon availability after each cycle. Nitrogen transformations were also influenced by flooding and drainage cycles. Ammonium accumulated during flooding periods due to organic matter mineralization and was nitrified (converted to nitrate) during drainage periods. Nitrate was subsequently denitrified (converted to nitrogen gas) upon flooding. Concentrations of SRP from the open water site were often below detectable levels. However, concentrations of SRP in the sawgrass soil were relatively high in the upper soil layer and showed a response to alternate flooding and draining cycles, which was not observed in the field study. Concentrations of SRP in the upper layer of the sawgrass soil increased upon flooding and decreased upon draining in laboratory columns. In the field studies, SRP did not show any effect of fluctuating water table. Since phosphorus is not directly affected by redox potential, the variation of SRP during the cycles was

probably governed by the solubility of phosphate in the pore water. Hopkins Prairie soil contains a moderate amount of Fe and Al, therefore, Fe and Al and their oxides could play an important role in regulating the solubility of phosphate ions. Phosphate can be bound to Fe and Al oxides during drained conditions, thereby taking the phosphate out of solution. When the soil is flooded, Fe^{+3} is reduced to Fe^{+2} releasing phosphate back into the solution.

Sulfate concentrations did not show much change in response to alternate flooding and draining. Redox potentials at all depths of the two soil columns were always greater than 0 mV indicating SO_4^- reduction was not likely occurring during the study period.

4.3 Task 3

Organic matter decomposition in this soil, as measured by CO_2 production, was limited by low amounts of readily-decomposable organic matter. Glucose and SO_4^- amendments did not have any significant effect on CO_2 evolution after the first week of incubation. This was unexpected since it was hypothesized that SO_4^- would act as an electron acceptor and increase the amount of CO_2 evolved and the amount of organic matter decomposed. It appears that the organic matter in this soil is quite resistant to decomposition and that it takes an incubation period longer than nine weeks to drop the redox potential sufficiently low to allow SO_4^- reduction. Under field

conditions, the redox potential can decrease to levels which allow SO_4^- reduction. However, it apparently takes a relatively long period of time to reach these low redox potential levels.

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6.0 APPENDIX

Table 1. Mean carbon, nitrogen and sulfur contents of soil samples collected from open water and sawgrass areas of Hopkins Prairie (n=3).

Sample depth	Carbon	Nitrogen	Sulfur	C/N	C/S
cm	-----	gm/kg	-----		
			Open water		
0-5	457E ⁺	34A	11F	13C	38A
5-10	466ED	33AB	13FE	13C	35AB
10-15	485CD	32AB	15FE	15C	31CB
15-20	501CB	27CB	17FED	18CB	28CD
20-25	509CBA	22CD	20CED	23AB	26CDE
25-30	512 BA	20 D	23C D	24AB	23FDE
30-35	516 BA	21 D	25CBD	24AB	21FGE
35-40	523 BA	21CD	26CB	25A	20FG
40-45	515 BA	22CD	31AB	24AB	16 G
45-50	534 A	23CD	34A	23AB	15 G
50-55	519 BA	22CD	32AB	24AB	16
55-60	521 BA	23CD	35A	21AB	15 G
			Sawgrass		
0-5	449FG	26AB	7 D	16AB	62A
5-10	461FGE	27AB	7 D	17AB	61AB
10-15	464F E	29AB	8 DC	16AB	53ABC
15-20	468F ED	28AB	9 DC	16AB	50ABC
20-25	475C ED	26 B	8 DC	18AB	54ABC
25-30	439 G	24 B	9 DC	18AB	48ABC
30-35	483CBED	38A	10DC	12 B	47ABC
35-40	489CBAD	24 B	11 CB	19A	41ABC
40-45	493CBA	26 B	10DC	18AB	49AB
45-50	498 BA	27AB	11 CB	18AB	42ABC
50-55	500 BA	26 B	15 AB	19AB	33 BC
55-60	507 A	27AB	16 A	18AB	30 C

+ Means within a column followed by the same letter do not differ significantly, Alpha=0.05, based on Least Significant Difference Test.

Table 2. Moisture contents of soil samples collected from open water and sawgrass areas of Hopkins Prairie (n=3).

DEPTH	5/1/91	6/5/91	7/9/91	8/30/91	9/27/91	11/5/91	12/17/91	1/27/92
CM	-----§-----							
	-----OPEN WATER-----							
0-5	86.6 B*	85.8 B	86.2 BC	86.5 C	84.2 B	88.1 ABCD	83.8 B	86.1 D
5-10	89.1 AB	88.2 AB	88.3 AB	88.7 AB	88.1 A	89.9 A	87.9 A	87.6 BCD
10-15	88.7 A	89.0 A	88.5 AB	89.2 AB	88.5 A	87.8 ABCD	88.4 A	88.8 ABC
15-20	89.6 A	89.7 A	90.2 A	89.9 A	89.1 A	89.7 AB	90.1 A	86.6 CD
20-25	90.1 AB	89.9 A	88.0 ABC	88.2 ABC	87.4 A	84.9 BCD	90.2 A	85.9 D
25-30	88.8 AB	87.4 AB	85.6 C	87.8 BC	87.3 A	83.7 D	89.1 A	88.5 ABCD
30-35	88.7 AB	88.2 AB	88.5 AB	89.1 AB	88.6 A	86.9 ABCD	89.9 A	87.7 BCD
35-40	88.2 AB	88.5 AB	88.4 AB	89.0 AB	87.7 A	88.6 ABCD	88.3 A	89.4 AB
40-45	87.4 AB	89.0 A	89.1 A	89.4 AB	88.1 A	89.1 ABC	87.6 A	90.7 A
45-50	89.2 AB	89.9 A	88.5 AB	89.1 AB	89.9 A	84.8 CD	89.1 A	89.0 ABC
50-55	89.3 AB	89.1 A	89.8 A	87.4 BC	89.9 A	84.8 CD	89.0 A	90.0 AB
55-60	88.3 AB	89.1 A	88.7 AB	88.1 BC	88.8 A	87.5 ABCD	89.4 A	89.2 AB
	-----SAWGRASS-----							
0-5	85.4 C	86.4 BC	81.4 B	84.9 B	84.1 C	84.9 B	80.7 B	84.0 C
5-10	86.8 BC	87.4 ABC	87.2 A	86.4 B	86.0 BC	86.4 B	87.2 A	86.3 BC
10-15	87.9 ABC	89.0 ABC	88.5 A	88.4 A	87.4 ABC	88.4 A	87.8 A	89.2 A
15-20	88.2 AB	89.2 ABC	88.7 A	88.5 A	88.3 AB	88.5 A	87.9 A	88.6 AB
20-25	88.4 AB	85.6 C	88.8 A	89.1 A	88.7 AB	89.1 A	88.1 A	88.4 AB
25-30	88.1 AB	89.3 AB	88.6 A	88.5 A	88.2 AB	88.5 A	88.0 A	88.7 AB
30-35	89.0 AB	90.0 AB	89.5 A	89.3 A	88.3 AB	89.3 A	88.3 A	89.7 A
35-40	89.5 A	89.6 AB	89.2 A	90.0 A	88.5 AB	90.0 A	89.4 A	90.4 A
40-45	88.6 AB	90.0 AB	67.6 A	90.0 A	87.9 AB	90.0 A	88.4 A	90.0 A
45-50	89.0 AB	89.5 AB	89.6 A	89.5 A	89.5 A	89.5 A	90.1 A	89.1 A
50-55	88.6 AB	90.0 A	89.5 A	89.2 A	90.5 A	89.2 A	89.9 A	88.2 AB
55-60	87.9 ABC	90.7 A	89.2 A	89.8 A	89.4 AB	89.8 A	90.3 A	89.1 A

* Means within a column followed by the same letter do not differ significantly, Alpha=0.05, based on Least Significant Difference Test.

Table 3. Soil pH of samples collected from open water and sawgrass areas of Hopkins Prairie (n=3).

DEPTH	5/1/91	6/5/91	7/9/91	9/27/91	11/5/91	12/17/91	1/27/92
-----OPEN WATER-----							
cm							
0-5	3.85 H*	4.06 H	3.71 G	3.57 E	3.71 I	3.43 I	3.62 H
5-10	4.08 G	4.19 H	3.90 F	3.86 DE	3.96 H	3.67 H	3.76 H
10-15	4.36 F	4.46 G	4.37 E	4.34 DEC	4.34 G	4.11 G	4.13 G
15-20	4.48 EF	4.55 GF	4.50 ED	4.53 DBC	4.55 F	4.39 F	4.43 F
20-25	4.60 ED	4.65 E F	4.58 CD	4.67 DBC	4.64 FE	4.53 E	4.53 FE
25-30	4.64 ED	4.76 ED	4.67 CD	4.79 BC	4.77 D	4.67 D	4.70 CD
30-35	4.68 CD	4.71 E F	4.69 C	4.72 BC	4.69 DE	4.63 DE	4.65 DE
35-40	4.84 C	4.90 DC	4.73 CB	4.93 BC	4.98 C	4.87 C	4.83 C
40-45	5.08 B	4.91 DC	4.89 AB	6.00 A	5.06 C	4.95 BC	5.03 B
45-50	5.13 AB	5.02 BC	4.98 A	5.06 BC	5.19 B	4.96 ABC	5.11 AB
50-55	5.20 AB	5.13 AB	4.97 A	5.13 BC	5.22 AB	5.01 AB	5.18 AB
55-60	5.30 A	5.25 A	4.96 A	5.24 AB	5.32 A	5.07 A	5.23 A
-----SAWGRASS-----							
cm							
0-5	3.98 GH	4.14 CED	3.73 DEF	3.63 D	3.46 G	3.39 G H	3.49 E
5-10	3.96 GH	4.10 CED	3.52 F	3.55 D	3.47 G	3.33 H	3.39 E
10-15	3.95 H	3.90 E	3.63 EF	3.59 D	3.55 FG	3.42 G H	3.48 E
15-20	4.12 GHF	3.95 E	3.69 DEF	3.77 D C	3.74 EFG	3.55 G H	3.62 DE
20-25	4.23 GEF	4.02 ED	3.75 DEF	3.91 DBC	3.87 EFGD	3.61 GFH	3.61 DEC
25-30	4.32 DEF	4.11 CED	3.81 CDEF	3.88 DBC	3.91 EFGD	3.66 GF	3.77 DBC
30-35	4.39 DEC	4.05 CED	3.94 CDE	3.26 D	3.98 EFGD	3.90 EF	4.01 BC
35-40	4.51 DBC	4.26 CBD	3.98 CD	4.45 ABC	4.13 EBCD	4.15 ED	4.17 ABC
40-45	4.68 AB	4.33 CB	4.11 CB	4.53 ABC	4.30 ABCD	4.33 CD	4.25 AB
45-50	4.63 BC	4.33 CB	4.32 AB	4.65 AB	4.46 ABC	4.45 CB	4.37 AB
50-55	4.75 AB	4.53 AB	4.47 A	4.79 A	4.57 AB	4.67 AB	4.51 A
55-60	4.90 A	4.63 A	4.57 A	4.93 A	4.75 A	4.75 A	4.55 A

* Means within a column followed by the same letter do not differ significantly, Alpha=0.05, based on Least Significant Difference Test.

Table 4.

Pore water nutrient profiles for open water and sawgrass soils in laboratory column studies (n=4). BF, AF, and AD represent before flooding, after initiation of flooding, and after initiation of drainage, respectively.

DATE	DEPTH cm	OPEN WATER				SAWGRASS			
		NH ₄	SRP	NO ₃	SO ₄	NH ₄	SRP	NO ₃	SO ₄
		-----mg l ⁻¹ -----							
BF	0-5	2.3 A*	0.022 A	28.4 A	72 A	1.6 A	0.343 A	63.6 A	32 A
	5-10	1.2 A	0.023 A	15.6 AB	65 AB	0.0 B	0.126 AB	50.7 B	36 AB
	10-15	0.6 A	0.025 A	7.6 B	58 CB	0.0 B	0.029 B	43.9 B	42 AB
	15-20	0.7 A	0.027 A	1.3 B	50 CD	0.4 AB	0.021 B	31.7 C	41 AB
	20-30	1.7 A	0.023 A	0.2 B	40 ED	0.2 B	0.018 B	8.7 D	49 AB
	30-40	2.4 A	0.026 A	0.2 B	29 E	0.4 AB	0.025 B	0.4 D	43 B
1 WK AF	0-5	2.4 A	0.018 A	12.6 A	65 A	2.0 A	0.543 A	14.9 A	23 BC
	5-10	1.5 A	0.020 A	6.7 AB	54 B	1.5 AB	0.260 A	16.6 A	28 ABC
	10-15	0.8 A	0.021 A	2.8 AB	50 BC	0.5 AB	0.036 A	20.5 A	45 A
	15-20	0.7 A	0.019 A	0.4 B	41 C	0.5 AB	0.022 A	15.8 A	47 A
	20-30	1.8 A	0.021 A	0.6 B	28 D	0.3 B	0.019 A	4.8 B	36 AB
	30-40	1.5 A	0.024 A	0.2 B	13 E	0.2 B	0.021 A	0.5 B	13 C
2 WK AF	0-5	3.1 A	0.017 A	2.7 A	61 A	2.9 A	0.552 A	0.7 A	17 B
	5-10	2.0 A	0.019 A	2.4 A	62 A	1.7 B	0.327 AB	1.1 A	29 AB
	10-15	1.2 A	0.018 A	0.2 A	52 B	1.4 BC	0.036 B	6.2 A	40 A
	15-20	0.9 A	0.019 A	0.0 A	45 B	1.2 BC	0.028 B	4.9 A	43 A
	20-30	1.9 A	0.019 A	0.0 A	35 C	0.7 C	0.024 B	1.6 A	35 AB
	30-40	1.6 A	0.020 A	0.0 A	13 D	0.4 C	0.026 B	0.4 A	17 B
3 WK AF	0-5	3.4 A	0.023 A	0.1 A	40 BC	2.3 A	0.398 A	0.1 A	19 A
	5-10	2.7 AB	0.023 A	0.1 A	56 A	2.3 A	0.295 AB	0.1 A	22 A
	10-15	1.7 AB	0.022 A	0.1 A	51 AB	2.0 AB	0.028 B	0.7 A	27 A
	15-20	1.1 B	0.024 A	0.0 A	47 ABC	1.8 AB	0.021 B	1.6 A	25 A
	20-30	1.9 AB	0.021 A	0.0 A	35 C	1.0 CB	0.021 B	0.2 A	36 A
	30-40	1.8 AB	0.027 A	0.0 A	16 D	0.6 C	0.066 B	0.0 A	26 A
4 WK AF	0-5	3.3 A	0.021 A	0.0 AB	39 B	2.2 AB	0.446 A	0.1 A	9 D
	5-10	3.1 A	0.021 A	0.1 A	59 AB	2.7 A	0.346 AB	0.1 A	22 BDC
	10-15	2.1 A	0.020 A	0.0 AB	63 A	2.4 A	0.063 B	0.1 A	34 B CA
	15-20	1.4 A	0.021 A	0.0 AB	59 AB	2.1 AB	0.033 B	0.4 A	38 B A
	20-30	2.0 A	0.024 A	0.0 B	46 AB	1.2 CB	0.029 B	0.0 A	41 A
	30-40	1.9 A	0.021 A	0.0 B	18 C	0.8 C	0.025 B	0.0 A	17 D
1 WK AD	0-5	2.5 A	0.002 B	0.1 A	16 B	1.6 BC	0.123 AB	0.7 A	5 C
	5-10	2.7 A	0.009 AB	0.1 A	30 A	2.3 AB	0.232 A	0.4 B	12 BC
	10-15	2.3 A	0.011 AB	0.2 A	36 A	2.5 A	0.093 AB	0.1 C	25 BA
	15-20	1.7 A	0.009 AB	0.0 A	34 A	2.3 AB	0.004 B	0.1 C	28 A
	20-30	1.8 A	0.007 AB	0.0 A	37 A	1.5 BC	0.007 B	0.0 C	27 A
	30-40	2.4 A	0.016 A	0.0 A	29 A	1.0 C	0.011 B	0.0 C	24 BA

Table 4. Continued.

DATE	DEPTH cm	OPEN WATER				SAWGRASS			
		NH ₄	SRP mg l ⁻¹	NO ₃	SO ₄	NH ₄	SRP mg l ⁻¹	NO ₃	SO ₄
2 WK AD	0-5	1.0 A	0.007 A	0.4 A	17 C	0.1 B	0.011 A	0.6 A	10 C
	5-10	1.5 A	0.006 A	0.3 A	32 B	0.1 B	0.007 A	0.4 AB	13 C
	10-15	1.4 A	0.006 A	0.2 AB	39 AB	0.7 AB	0.006 A	0.3 AB	24 CBA
	15-20	3.1 A	0.007 A	0.2 AB	42 AB	1.2 A	0.006 A	0.3 CB	27 BA
	20-30	1.3 A	0.007 A	0.1 AB	46 A	0.7 AB	0.006 A	0.0 C	27 BA
	30-40	2.0 A	0.008 A	0.0 B	37 AB	0.9 AB	0.041 A	0.1 C	29 A
1 WK AF	0-5	1.3 A	0.000 A	0.2 A	53 D	0.5 A	0.028 A	0.2 A	37 B
	5-10	1.4 A	0.000 A	0.1 A	68 C	0.4 A	0.025 AB	0.1 A	40 AB
	10-15	1.3 A	0.000 A	0.2 A	76 ABC	0.6 A	0.001 AB	0.2 A	51 AB
	15-20	1.0 A	0.000 A	0.2 A	83 AB	1.0 A	0.000 B	0.3 A	56 A
	20-30	1.8 A	0.000 A	0.1 A	87 A	0.4 A	0.000 B	0.1 A	57 A
	30-40	2.1 A	0.000 A	0.0 A	73 BC	0.5 A	0.000 B	0.1 A	43 AB
2 WK AF	0-5	1.8 A	0.000 A	0.1 A	40 C	1.1 AB	0.084 A	0.1 A	24 B
	5-10	1.8 A	0.000 A	0.0 AB	52 CB	1.1 AB	0.052 A	0.1 AB	29 AB
	10-15	1.5 A	0.000 A	0.0 AB	58 AB	1.1 AB	0.007 A	0.0 AB	39 AB
	15-20	1.1 A	0.000 A	0.0 AB	66 AB	1.3 A	0.003 A	0.0 AB	43 A
	20-30	1.9 A	0.000 A	0.0 AB	71 A	0.6 AB	0.099 A	0.0 B	44 A
	30-40	2.2 A	0.000 A	0.0 B	59 AB	0.5 B	0.000 A	0.0 B	36 AB
3 WK AF	0-5	2.2 A	0.000 A	0.0 AB	35 D	1.2 AB	0.121 A	0.1 A	22 C
	5-10	2.1 A	0.000 A	0.0 A	46 C	1.6 A	0.074 AB	0.0 AB	28 BC
	10-15	1.8 A	0.000 A	0.0 AB	54 CB	1.6 A	0.033 CB	0.0 AB	38 AB
	15-20	1.3 A	0.000 A	0.0 AB	62 AB	1.6 A	0.000 C	0.0 AB	42 A
	20-30	2.0 A	0.000 A	0.0 B	66 A	0.8 AB	0.001 C	0.0 B	42 A
	30-40	2.4 A	0.000 A	0.0 AB	57 AB	0.7 B	0.008 CB	0.0 B	35 ABC
4 WK AF	0-5	2.2 A	0.000 A	0.1 A	22 C	1.2 AB	0.133 A	0.1 A	13 C
	5-10	2.1 A	0.000 A	0.0 AB	37 B	1.7 A	0.081 AB	0.0 AB	22 CB
	10-15	1.8 A	0.000 A	0.0 B	44 BA	1.8 A	0.015 CB	0.0 ABC	31 AB
	15-20	1.3 A	0.000 A	0.0 B	53 A	1.8 A	0.000 C	0.0 ABC	35 A
	20-30	2.0 A	0.000 A	0.0 B	55 A	0.9 AB	0.000 C	0.0 BC	37 A
	30-40	2.3 A	0.000 A	0.0 B	49 BA	0.6 B	0.000 C	0.0 C	27 AB
1 WK AD	0-5	1.0 A	0.002 A	8.9 A	14 D	0.2 B	0.010 A	10.9 A	9 C
	5-10	1.3 A	0.003 A	6.0 AB	22 C	0.2 B	0.010 A	8.8 AB	12 BC
	10-15	1.1 A	0.005 A	3.6 B	28 CB	0.3 BA	0.009 A	7.6 B	19 AB
	15-20	1.0 A	0.006 A	4.4 AB	32 AB	0.9 A	0.009 A	6.2 CB	22 A
	20-30	1.8 A	0.005 A	2.3 B	38 A	0.4 BA	0.010 A	4.3 C	23 A
	30-40	2.3 A	0.005 A	1.5 B	32 AB	0.5 BA	0.010 A	1.2 D	18 ABC

Table 4. Continued.

DATE	DEPTH cm	OPEN WATER				SAWGRASS			
		NH ₄	SRP mg l ⁻¹	NO ₃	SO ₄	NH ₄	SRP mg l ⁻¹	NO ₃	SO ₄
2 WK AD	0-5	0.3 B	0.009 A	14.6 A	18 D	0.1 B	0.011 A	16.7 A	13 B
	5-10	0.8 B	0.009 A	10.5 B	28 DC	0.1 B	0.011 A	10.7 B	15 B
	10-15	0.7 B	0.011 A	8.8 CB	34 BC	0.1 B	0.011 A	8.6 BC	20 BA
	15-20	0.8 B	0.010 A	6.9 C	38 BA	0.6 A	0.010 A	7.6 C	25 A
	20-30	1.6 BA	0.009 A	2.8 D	46 A	0.2 B	0.012 A	6.3 C	25 A
	30-40	2.3 A	0.009 A	0.0 D	39 BA	0.4 BA	0.013 A	3.2 D	20 BA
4 WK AD	0-5	0.2 B	0.000 A	17.7 A	48 C	0.2 A	0.000 A	22.5 A	42 AB
	5-10	0.2 B	0.000 A	15.1 AB	53 C	0.1 A	0.000 A	15.1 B	41 B
	10-15	0.2 B	0.000 A	13.6 AB	62 CB	0.1 A	0.000 A	13.0 BC	50 AB
	15-20	0.3 B	0.000 A	11.5 CB	73 AB	0.2 A	0.000 A	12.4 BC	54 AB
	20-30	1.6 A	0.000 A	7.9 C	80 A	0.2 A	0.000 A	10.3 DC	56 A
	30-40	2.2 A	0.000 A	6.4 C	74 AB	0.1 A	0.000 A	8.3 D	54 AB

* Means within a column followed by the same letter do not differ significantly, ALPHA=0.05, based on Least Significant Difference Test.

Table 5. Comparison of pore water nutrient concentrations between open water (OW) and sawgrass (SG) soils in laboratory column studies.

DATE	DEPTH cm	Ammonium			SRP			Nitrate			Sulfate		
		OW mg l ⁻¹	SG mg l ⁻¹	P>T	OW mg l ⁻¹	SG mg l ⁻¹	P>T	OW mg l ⁻¹	SG mg l ⁻¹	P>T	OW mg l ⁻¹	SG mg l ⁻¹	P>T
B .F.	0-5	2.3	1.6	0.5064	0.022	0.343	0.0010*	28.4	63.6	0.0001*	72	32	0.0001*
	5-10	1.2	0.0	0.2355	0.023	0.126	0.2576	15.6	50.7	0.0001*	65	36	0.0001*
	10-15	0.6	0.0	0.5539	0.025	0.029	0.9668	7.6	43.9	0.0001*	58	42	0.0268
	15-20	0.7	0.4	0.7666	0.027	0.021	0.9459	1.3	31.7	0.0004*	50	41	0.187
	20-30	1.7	0.2	0.1379	0.023	0.018	0.9552	0.2	8.7	0.2773	40	49	0.2207
	30-40	2.4	0.4	0.057	0.026	0.025	0.9849	0.2	0.4	0.9738	29	43	0.0484
1 WK A.F.	0-5	2.4	2.0	0.6493	0.018	0.543	0.0162	12.6	14.9	0.616	65	23	0.0001*
	5-10	1.5	1.5	0.9796	0.020	0.260	0.2567	6.7	16.6	0.0366	54	28	0.001*
	10-15	0.8	0.5	0.7682	0.021	0.036	0.9448	2.8	20.5	0.0004*	50	45	0.4859
	15-20	0.7	0.5	0.8414	0.019	0.022	0.9874	0.4	15.8	0.0017*	41	47	0.4157
	20-30	1.8	0.3	0.1504	0.021	0.019	0.9907	0.6	4.8	0.3528	28	36	0.2829
	30-40	1.5	0.2	0.1929	0.024	0.021	0.9904	0.2	0.5	0.9365	13	13	0.98
2 WK A.F.	0-5	3.1	2.9	0.8018	0.017	0.552	0.0003*	2.7	0.7	0.4638	61	17	0.0001*
	5-10	2.0	1.7	0.7591	0.019	0.327	0.0275	2.4	1.1	0.6334	62	29	0.0001*
	10-15	1.2	1.4	0.8069	0.018	0.036	0.8904	0.2	6.2	0.0367	52	40	0.077
	15-20	0.9	1.2	0.6843	0.019	0.028	0.948	0.0	4.9	0.0909	45	43	0.7052
	20-30	1.9	0.7	0.1781	0.019	0.024	0.9666	0.0	1.6	0.5658	35	35	0.998
	30-40	1.6	0.4	0.1536	0.020	0.026	0.9635	0.0	0.4	0.8954	13	17	0.6332
3 WK A.F.	0-5	3.4	2.3	0.1724	0.023	0.398	0.0014*	0.1	0.1	0.9817	40	19	0.0505
	5-10	2.7	2.3	0.7021	0.023	0.295	0.0164	0.1	0.1	0.9951	56	22	0.0013*
	10-15	1.7	2.0	0.6661	0.022	0.028	0.9551	0.1	0.7	0.3386	51	27	0.0199
	15-20	1.1	1.8	0.4194	0.024	0.021	0.9767	0.0	1.6	0.0241	47	25	0.0373
	20-30	1.9	1.0	0.2912	0.021	0.021	0.9983	0.0	0.2	0.7998	35	36	0.9011
	30-40	1.8	0.6	0.1504	0.027	0.066	0.7235	0.0	0.0	0.9996	16	26	0.3091
4 WK A.F.	0-5	3.3	2.2	0.1792	0.021	0.446	0.0009*	0.0	0.1	0.7011	39	9	0.0019*
	5-10	3.1	2.7	0.6247	0.021	0.346	0.009*	0.1	0.1	0.9473	59	22	0.0003*
	10-15	2.1	2.4	0.7229	0.020	0.063	0.7186	0.0	0.1	0.708	63	34	0.0029*
	15-20	1.4	2.1	0.3482	0.021	0.033	0.9161	0.0	0.4	0.013	59	38	0.0259
	20-30	2.0	1.2	0.3097	0.024	0.029	0.9692	0.0	0.0	0.8962	46	41	0.5993
	30-40	1.9	0.8	0.1541	0.021	0.025	0.9724	0.0	0.0	0.9772	18	17	0.9182
1 WK A.D.	0-5	2.5	1.6	0.1927	0.002	0.123	0.0784	0.1	0.7	0.0001*	16	5	0.1088
	5-10	2.7	2.3	0.5262	0.009	0.232	0.0021*	0.1	0.4	0.0077*	30	12	0.0084*
	10-15	2.3	2.5	0.6636	0.011	0.093	0.2274	0.2	0.1	0.4184	36	25	0.1093
	15-20	1.7	2.3	0.3127	0.009	0.004	0.9416	0.0	0.1	0.7827	34	28	0.3196
	20-30	1.8	1.5	0.6467	0.007	0.007	0.9997	0.0	0.0	0.9627	37	27	0.1326
	30-40	2.4	1.0	0.0302	0.016	0.011	0.946	0.0	0.0	0.9917	29	24	0.4848

Table 5. Continued.

DATE	DEPTH cm	Ammonium			SRP			Nitrate			Sulfate		
		OW	SG	P>T	OW	SG	P>T	OW	SG	P>T	OW	SG	P>T
		mg l ⁻¹			mg l ⁻¹			mg l ⁻¹			mg l ⁻¹		
2 WK A.D.	0-5	1.0	0.1	0.3844	0.007	0.011	0.7543	0.4	0.6	0.1905	17	10	0.2542
	5-10	1.5	0.1	0.1787	0.006	0.007	0.9749	0.3	0.4	0.2731	32	13	0.0043*
	10-15	1.4	0.7	0.4731	0.006	0.006	0.9637	0.2	0.3	0.0043*	39	24	0.0236
	15-20	3.1	1.2	0.0783	0.007	0.006	0.9637	0.2	0.3	0.5786	42	27	0.0279
	20-30	1.3	0.7	0.529	0.007	0.006	0.9094	0.1	0.0	0.4176	46	27	0.0041*
	30-40	2.0	0.9	0.2764	0.008	0.041	0.0273	0.0	0.1	0.603	37	29	0.217
1 WK R.F.	0-5	1.3	0.5	0.2855	0.000	0.028	0.0039*	0.2	0.2	0.822	53	37	0.0403
	5-10	1.4	0.4	0.2169	0.000	0.025	0.0073*	0.1	0.1	0.9171	68	40	0.0009*
	10-15	1.3	0.6	0.3661	0.000	0.001	0.8982	0.2	0.2	0.9959	76	51	0.002*
	15-20	1.0	1.0	0.9821	0.000	0.000	1.0000	0.2	0.3	0.8644	83	56	0.0009*
	20-30	1.8	0.4	0.0563	0.000	0.000	1.0000	0.1	0.1	0.9683	87	57	0.0003*
	30-40	2.1	0.5	0.0306	0.000	0.000	1.0000	0.0	0.1	0.7646	73	43	0.0004*
2 WK R.F.	0-5	1.8	1.1	0.2802	0.000	0.084	0.0633	0.1	0.1	0.329	40	24	0.0313
	5-10	1.8	1.1	0.2863	0.000	0.052	0.2468	0.0	0.1	0.7551	52	29	0.0024*
	10-15	1.5	1.1	0.5548	0.000	0.007	0.8741	0.0	0.0	0.6094	58	39	0.0109
	15-20	1.1	1.3	0.8273	0.000	0.003	0.9531	0.0	0.0	0.5705	66	43	0.0036*
	20-30	1.9	0.6	0.0546	0.000	0.099	0.0301	0.0	0.0	0.5898	71	44	0.0006*
	30-40	2.2	0.5	0.0152	0.000	0.000	1.0000	0.0	0.0	0.9881	59	36	0.0021*
3 WK R.F.	0-5	2.2	1.2	0.141	0.000	0.121	0.0001*	0.0	0.1	0.1677	35	22	0.025
	5-10	2.1	1.6	0.4086	0.000	0.074	0.0031*	0.0	0.0	0.979	46	28	0.0025*
	10-15	1.8	1.6	0.7661	0.000	0.033	0.1648	0.0	0.0	0.7417	54	38	0.0088*
	15-20	1.3	1.6	0.7245	0.000	0.000	1.0000	0.0	0.0	0.0955	62	42	0.0016*
	20-30	2.0	0.8	0.0802	0.000	0.001	0.9497	0.0	0.0	0.6654	66	42	0.0002*
	30-40	2.4	0.7	0.0097	0.000	0.008	0.7333	0.0	0.0	0.7235	57	35	0.0003*
4 WK R.F.	0-5	2.2	1.2	0.1393	0.000	0.133	0.0001*	0.1	0.1	0.0478	22	13	0.151
	5-10	2.1	1.7	0.5701	0.000	0.081	0.0023*	0.0	0.0	0.8682	37	22	0.0151
	10-15	1.8	1.8	0.9498	0.000	0.015	0.5457	0.0	0.0	0.8212	44	31	0.0329
	15-20	1.3	1.8	0.5021	0.000	0.000	1.0000	0.0	0.0	0.4619	53	35	0.0062*
	20-30	2.0	0.9	0.088	0.000	0.000	1.0000	0.0	0.0	0.8559	55	37	0.0056*
	30-40	2.3	0.6	0.0084	0.000	0.000	1.0000	0.0	0.0	0.976	49	27	0.001*
1 WK R.D.	0-5	1.0	0.2	0.2502	0.002	0.010	0.0205	8.9	10.9	0.3027	14	9	0.216
	5-10	1.3	0.2	0.1345	0.003	0.010	0.0205	6.0	8.8	0.1516	22	12	0.0178
	10-15	1.1	0.3	0.276	0.005	0.009	0.2129	3.6	7.6	0.0437	28	19	0.035
	15-20	1.0	0.9	0.867	0.006	0.009	0.4184	4.4	6.2	0.373	32	22	0.0123
	20-30	1.8	0.4	0.0633	0.005	0.010	0.119	2.3	4.3	0.3056	38	23	0.0008*
	30-40	2.3	0.5	0.174	0.005	0.010	0.1086	1.5	1.2	0.8775	32	18	0.0011*

Table 5. Continued.

DATE	DEPTH cm	Ammonium			SRP			Nitrate			Sulfate		
		OW mg l ⁻¹	SG mg l ⁻¹	P>T	OW mg l ⁻¹	SG mg l ⁻¹	P>T	OW mg l ⁻¹	SG mg l ⁻¹	P>T	OW mg l ⁻¹	SG mg l ⁻¹	P>T
2 WK R.D.	0-5	0.3	0.1	0.801	0.009	0.011	0.3441	14.6	16.7	0.1694	18	13	0.2238
	5-10	0.8	0.1	0.1975	0.009	0.011	0.2726	10.5	10.7	0.9117	28	15	0.008*
	10-15	0.7	0.1	0.2227	0.011	0.011	0.8875	8.8	8.6	0.9078	34	20	0.0044*
	15-20	0.8	0.6	0.8076	0.010	0.010	0.9487	6.9	7.6	0.6839	38	25	0.0047*
	20-30	1.6	0.2	0.0066*	0.009	0.012	0.2781	2.8	6.3	0.0284	46	25	0.0001*
	30-40	2.3	0.4	0.0004*	0.009	0.013	0.0194	0.0	3.2	0.0439	39	20	0.0001*
4 WK R.D.	0-5	0.2	0.2	0.7812	0.000	0.000	-----	17.7	22.5	0.0324	48	42	0.4557
	5-10	0.2	0.1	0.8325	0.000	0.000	-----	15.1	15.1	0.9991	53	41	0.1072
	10-15	0.2	0.1	0.7997	0.000	0.000	-----	13.6	13.0	0.7929	62	50	0.123
	15-20	0.3	0.2	0.6335	0.000	0.000	-----	11.5	12.4	0.7044	73	54	0.0161
	20-30	1.6	0.2	0.0001*	0.000	0.000	-----	7.9	10.3	0.2723	80	56	0.0044*
	30-40	2.2	0.1	0.0001*	0.000	0.000	-----	6.4	8.3	0.3995	74	54	0.0122

* Significant at 0.83% level based on Bonferroni T test.