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ABSTRACT

NUTRIENT CONTENT OF RUNOFF WATER FROM RICE FIELDS

Current perception is that nutrient runoff from croplands is a significant contributor to poor water quality in some areas. While extensive research has been conducted to survey and ameliorate this problem for several upland crops, little work has been done to evaluate the problem with flooded rice (*Oryza sativa*, L.) soils. Since rice production utilizes a major portion of the total irrigation water usage for certain areas, it is important to understand the contribution of rice production to non-point source N and P in surface water. Several production fields were selected to evaluate the concentrations of nutrients in the floodwater at selected distances across the field, including inlet and exit. The fields were evaluated in either 1990, 1991, or 1992 and were managed by the individual rice producer. Water samples were collected from several locations within each field weekly following establishment of the permanent flood and analyzed for inorganic N (NH_4-N, NO_3-N, and NO_2-N) and soluble P. The N concentrations in the floodwater normally peaked following N fertilizer application but rapidly declined and remained below 1 mg N L^{-1}. Water management resulted in some variation among locations with respect to the timing and magnitude of these peaks. The P concentrations were usually highest near the well and declined to less than 0.05 mg P L^{-1} as the water moved across the field. This was attributed to plant uptake, uptake by algae, and sediment deposition. The data indicates that rice fields have the potential to be utilized as a

filtration system to reduce the nutrient load of irrigation water similar to constructed wetlands. Use of catfish pondwater, in comparison to well water, resulted in only slightly higher total N and total P levels with higher amounts of the nutrients in the organic form. Although the P levels were high enough to potentially contribute to eutrophication of surface water, the water exiting the field was lower than at the entry point irrespective of the source. Also, the total P (organic + inorganic) concentration was less than 0.05 mg P L^{-1}.

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ACKNOWLEDGEMENTS

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INTRODUCTION

A. Purpose and Objectives

Recently the concern about environmental pollution resulting from application of commercial fertilizers and pesticides in agricultural situations has increased. Because of this concern, it becomes increasingly important to know how much contamination of surface water resulting from these applications is actually present. Because information concerning N and P runoff from rice fields is limited, this study was initiated to evaluate the seasonal variation in nutrient contents in the rice floodwater with distance across the field.

B. Related Research and Activities

Nitrogen and P in runoff from agricultural lands have been investigated extensively, particularly for upland crop situations (Stanford et al., 1970; Water Resources Committee, 1970; Lin, 1972; Loehr, 1974; Chichester and Richardson; 1992). Some of the major topics of recent research include N and P runoff as influenced by tillage practices, irrigation, and various cropping situations (e.g., Sharpley et al., 1992; Lowrance, 1992; Chichester and Richardson, 1992). Most of the research has focused on upland crops such as corn (***Zea mays***, L.), wheat (***Triticum aestivum***, L.) and soybean (***Glycine max***, (L.) Merr.). However, research evaluating the runoff from rice production is limited.

The use of riparian forests for filtering nutrient runoff from crop production fields has demonstrated the ability to reduce nutrients entering the surrounding watersheds (Cooper et al., 1986; Jordon et al., 1993; Lowrance et al., 1984a,b; Peterjohn and Correll, 1984, 1986; Jacobs and Gilliam, 1985; Haycock and Pinay, 1993). The riparian forests take up N, P, and other nutrients, thus reducing the loads in the runoff water. Similarly, wetland ecosystems act as a filter for nutrients contained in water moving through the system, particularly N and P (Boyt et al., 1977; Lakshman, 1979; Reddy and DeBusk, 1985; Tilton and Kadlec, 1979). The mechanisms for filtration include plant uptake, incorporation into the soil, and gaseous losses resulting from the reduced soil conditions associated with wetlands. Gaseous losses of N include nitrification - denitrification reactions (Patrick and Reddy, 1976; Reddy et al., 1980; Reddy and Patrick, 1986) and NH_3 volatilization (Mikkelsen and De Datta, 1979; Brandon and Wells, 1986; Wells and Turner, 1984). It is believed that rice fields can act as a filtration system similar to the constructed wetlands because of the vegetation and flooded soils associated with rice production.

Certain metals contained in irrigation well water, particularly Ca and Mg, are deposited due to the formation of carbonate precipitates when exposed to CO_2 (Gilmour et al., 1978). Due to this precipitation, the concentration in the floodwater usually decreases with increasing distance from the well. The result is the accumulation of calcium and magnesium carbonates in the soil which leads to increased soil pH. Subsequently, the potential for Zn deficiency exists during rice production. Data concerning the movement of other metals across the field is limited.

The majority of the irrigation water utilized in the rice-producing region of the Southern U.S. is used for the rice crop. Consequently, nutrient runoff from rice fields is a major concern in this region.

MATERIALS AND PROCEDURES

Seven production rice fields were selected to monitor the N and P concentrations of the floodwater during the 1990, 1991, and 1992 growing seasons (one field in 1990, three fields in 1991, and three fields in 1992). The fields were located in Ashley, Drew, Lincoln, and St. Francis counties in Arkansas. Each field was managed by the producer, including cultivar selection. The rice was seeded on each field and grown as an upland crop for 4-6 wk. At the four- to five-leaf growth stage, 60% of the recommended fertilizer N was applied as urea and a permanent flood was established and maintained until maturity. Fertilizer N was applied to each field as urea at rates appropriate for the particular cultivar. The N was applied in three applications with 60% of the N applied just prior to flooding, 20% applied at 1.3-cm internode elongation (IE), and 20% 10 d following IE. The fields are designated in the discussion according to the producer's name and year.

Water samples from each field were taken weekly for the entire season at seven locations across the field from entry point to exit including tailwater. Samples were collected daily for the first wk following N fertilizer applications. Water samples were collected with a 60-ml syringe and filtered on location through a 0.45-um membrane filter. The electrical conductivity (EC), pH, and temperature of the floodwater was measured *in situ* at the time of sampling with a portable EC meter and a portable pH meter. The metal samples were acidified with one drop of concentrated HNO_3 for preservation until analysis was performed. The water samples were analyzed for soluble P (PO_4^{-3}) and inorganic N (NH_4^+-N, NO_3^--N, and NO_2^--N) with a Technicon AutoAnalyzer II (Technicon Industrial Systems, 1973a,b, 1976a). Metals (Ca, Mg, K, Na, Fe, Mn, Al, As, Cu, Co, Cd, Cr, Zn, and Pb) were determined by inductively coupled atomic plasma spectroscopy (Soltanpour et al., 1982).

An additional study was conducted during 1991 and 1992 to compare the nutrient content of runoff water from different irrigation water sources. Two fields were either irrigated with well water or with water pumped from a pond used for raising catfish. Samples were collected from the field as described above. In addition to the analyses described for the other fields, unfiltered water samples were collected to analyze for total dissolved P and total dissolved N. Total N and P were determined with a Technicon AutoAnalyzer II (Technicon Industrial Systems, 1976b).

PRINCIPLE FINDINGS AND SIGNIFICANCE

A. Inorganic N

The major peaks in the seasonal N concentrations in the floodwater were following N fertilizer applications (Fig. 1 and 2, respectively). As would be expected this N peak was usually NH_4-N (Fig. 1). The NO_3-N remained low throughout the season (less than 1 mg N L^{-1}) except for two locations (Fig. 2). In 1991, the M&J farm site and the Reinhart farm site in 1992 had an initially high NO_3-N due to the time between N fertilization and application of the flood. The fields required 3 d to be completely flooded. Consequently, the lower end of the field resulted in greater nitrification and, thus, NO_3-N accumulation (>2.5 mg L^{-1}). The NO_3-N peak declined to less than 0.5 mg L^{-1} for both of these locations within 10 d following establishment of the flood. Most of the peaks observed during mid-season had fallen to below 1 mg NH_4-N L^{-1} within 3 d. This is consistent with previous research indicating that mid-season N fertilizer applications are utilized by the plant, incorporated into the soil biomass, or lost within 3 d after application (Wilson et al., 1989).

The NH_4-N concentration varied with flow distance and location (Fig. 3). The NH_4-N concentration at the Summerford location remained below 0.5 mg L^{-1} during 1991 although the NH_4-N concentration exiting the field was greater than the NH4-N concentration entering the field at the other two locations in 1991 and the Pine Tree location in 1990. The Bradshaw and Reinhart locations remained relatively constant across the field during 1992. The Fischer location increased across the first 50% of the field from 0.2 to 1.8 mg N L^{-1} but decreased to 1.1 mg NH_4-N L^{-1} at the outlet. Much of the variation between locations can be attributed to differences in water management by the individual producers. The producers ability to flood and/or drain the field differed primarily due to differences in soil texture, field size, and well capacity.

The NO_3-N concentration in the floodwater with respect to distance from the inflow also varied among locations (Fig. 4). At most of the locations, the NO_3-N concentration remained constant at a level below 0.5 mg NO_3-N L^{-1}. However, at Reinhart in 1992 and M&J in 1991, the nitrate levels changed with distance. At these two locations, NO_3-N increased to levels of 1.5 mg NO_3-N L^{-1} or more. This change in NO_3-N concentration can be attributed to wetting and drying cycles associated with the inability to apply the flood to the entire field rapidly or to maintain the flood permanently once it was established.

The N concentrations reacted much as expected. The concentrations were high immediately after N application but rapidly declined to levels below that which is considered to pose a threat to surrounding watersheds. For most of the season, the N concentrations remained below 1 mg N L^{-1} as previously reported for rice fields (Moore et al., 1981).

It is important to note the variability in the N concentration in the floodwater among the locations. These differences are associated with water management which is crucial for maximum efficiency of the fertilizer N (Wells et al., 1988). If the early N application is made into the floodwater, the amount of NH_4-N in the floodwater increases, NH_3 volatilization losses increase (Fillery et al., 1986), and, with an increase in NH_4-N or NO_3-N in the floodwater, the potential for increased pollution exists (Moore et al., 1993). The optimum N management techniques are to apply the early N onto dry soil just prior to flooding and then establish a permanent flood as rapidly as possible (Brandon and Wells, 1986; Moore et al., 1993; Wells and Turner, 1984). This technique utilizes the floodwater to incorporate the N into the soil (Fillery et al., 1984; Wells and Turner, 1984) which reduces the buildup of N in the floodwater. This method of applying the early N fertilizer has also shown to increase yields and reduce NH_3 volatilization losses (Wells et al., 1988). By utilizing good water management, NO_3-N formation is reduced, less N accumulates in the floodwater, and less potential for N in runoff water exists (Fig. 2 and 4). However, when poor water management is used (i.e. M&J farms - 1991, Reinhart farms - 1992) more nitrification occurs which results in greater denitrification losses and potentially greater NO_3-N released into the surrounding surface water.

B. Soluble P

The soluble reactive phosphorus (SRP) decreased with increased distance across the field in all fields except for Bradshaw-1992 (Fig. 5). The SRP increased initially at this site but decreased as the water moved across the field (Fig. 5a). The SRP in all of the fields was less than 0.05 mg P L^{-1} at the end of the field, the level established as the minimum level upon which eutrophication of surface water is possible (Sharpley et al., 1992; Sharpley and Smith, 1993). The Summerford site contained the highest initial SRP level at 0.5 mg P L^{-1}. However, this level dropped to approximately 0.15 mg P L^{-1} and remained relatively constant through the field. Although the level at this site was above the limits recognized as stimulating eutrophication of surface waters (10 ug L^{-1}) (Sharpley and Smith, 1993), the irrigation water contained less SRP at the outlet than the water entering the field from the well. Consequently, the water quality improved as a result of moving across the field.

For most locations, the SRP concentration in the well water was above that which is considered to cause eutrophication of surface water (Fig. 5). However, as the water progressed across the field, the SRP concentration declined. For the Summerford location, the SRP declined from 0.5 mg L^{-1} to approximately 0.09 mg L^{-1} within half the distance of the field (Fig. 5a). The SRP measured at Reinhart-1992 declined from 0.15 mg L^{-1} entering the field to as little as 0.02 mg L^{-1} within 50% of the flow distance (Fig. 5b). Two conclusions can be obtained from these data. First, the inherent level of soluble P in irrigation entering rice fields is variable (0.01 to 0.5 mg L^{-1}). Secondly, rice fields can potentially act as a filter for P similar to the constructed wetland ecosystems (Boyt et al., 1977; Lakshman, 1979; Reddy and DeBusk, 1985).

The seasonal concentration of soluble P in the floodwater was variable (Fig. 6). The peaks and valleys are a reflection of when the field was irrigated, particularly for Summerford farms in 1991. The well at this particular field was inherently high in soluble P as denoted by the P concentration with distance across the field (Fig. 5b). When water was being applied to the field, the soluble P concentration was relatively high. After the field was flooded and the flood stabilized, the soluble P concentration declined. When water was added to the field because of evaporation, transpiration, runoff, and plant utilization, the amount of P in the water increased.

The P concentrations were typically higher at the well than other locations across the field. As the water flowed across the field, the concentration of P generally decreased to less than 0.05 mg P L^{-1}. The pH of the incoming water was normally close to 7 (data not shown), due to a high CO_2 partial pressure. As the water moves across the field, the CO_2 degasses resulting in $CaCO_3$ precipitation and PO_4^{-3} co-precipitation or calcium phosphate precipitation (Gilmour et al., 1978). Consequently, the P in the floodwater was reduced. Also, P uptake and utilization by algae, rice plants, and any other vegetation could also have contributed to the reduction in P concentrations as the water moved across the field (Sharpley et al., 1992; Sharpley and Smith, 1993). Although the soluble P concentrations were generally in excess of the limits recognized as stimulating accelerated eutrophication of surface waters (0.01 mg P L^{-1}), they were significantly reduced from the concentration upon entering the field.

C. Metals

As expected, the Ca concentrations decreased or remained the same as the floodwater moved across the field (Table 1). The Ca concentrations ranged from 11 to 78 mg L^{-1} entering the field and ranged from 11 to 54 mg L^{-1} exiting the field. The summary presented in Table 1 also indicates the Mg was relatively low but did not change appreciably between the inlet and exit points.

As expected the Fe and Mn concentrations were relatively high at some locations (Table 1). Although most locations resulted in a decrease in the concentration as the water moved across the field, some locations actually increased. The Fe concentrations ranged from 10 to 2404 ug L^{-1} entering the field and ranged from 90 to 410 ug L^{-1}. The Mn ranged from 3 to 195 ug L^{-1} entering the field and ranged from 8 to 1745 ug L^{-1} exiting the field.

Due to the changes associated with soil reduction following flooding, Fe and Mn generally become more soluble. Consequently, it is feasible that an increase in the Fe and Mn concentrations would result. If water management for the rice crop is not optimum, it is also possible that the reduction necessary to solubilize an appreciable amount of Fe and Mn may not occur. Subsequently, Fe and Mn may be deposited in the fields as the water moves across the field because of the oxidized soil conditions. At the Summerford site, the well water contained a large amount of Fe (2404 ug L^{-1}) relative to the other locations. Poor water management leads to reduced N efficiency due to wetting and drying cycles The wetting and drying cycles at this site resulted in, in addition to the poor N efficiency (Fig. 1), a significant amount of Fe precipitation due to the oxidized soil conditions.

Table 1. Comparison of inlet and outlet metal concentrations in the floodwater of four production rice fields.

Metal	Bradshaw		Reinhart		Fischer		Summerford	
	In	Out	In	Out	In	Out	In	Out
				mg L^{-1}				
Ca	41	36	11	11	78	54	45	24
K	1	2	1	2	5	8	2	5
Mg	8	7	2	2	17	16	10	11
Na	13	12	11	10	29	46	28	28
S	3	3	1	1	*	*	*	*
				ug L^{-1}				
Al	0	63	62	255	0	0	0	73
As	0	0	137	108	0	0	0	0
B	26	29	11	11	94	63	69	76
Cd	40	3	0	0	0	0	0	0
Co	9	6	0	0	0	0	0	0
Cr	0	0	0	0	0	0	0	0
Cu	0	0	0	0	0	0	0	5
Fe	150	90	716	324	10	410	2404	229
Mn	183	31	71	8	3	1745	195	106
Ni	0	0	0	0	0	0	0	0
Pb	*	*	*	*	0	0	0	0
Zn	168	128	289	330	84	187	118	101
pH	6.75	7.69	6.34	8.09	7.15	6.96	6.65	7.43

* = not determined

D. Comparison of Water Sources

Water from ponds is used to raise catfish is used in some areas of the rice producing region of the Southern U.S. In fact, rice is also grown in rotation with catfish on some farms. When the nutrient load of water from catfish ponds was compared to irrigation from well water, the total N concentration was very similar between the two sources (Fig. 7). The NO_3-N concentration was very small for both sources. The NH_4-N concentration was higher in the pondwater field than in the well water field. Thus, more of the N in the well water field consisted of organic N. However, both sites had less than 3 mg N L^{-1} of total N exiting the field in the runoff with less than 0.5 mg N L^{-1} difference between the two sites.

The total P content declined from as much as 0.1 mg P L^{-1} to slightly more than 0.04 mg P L^{-1} as the water moved across the field from the catfish pond (Fig. 8). However, the well water exiting the field contained less than 0.04 mg P L^{-1}. More of the P in the catfish pond was in the organic form (total - inorganic) than in the well water. However, as the water moved across the field, the concentration of the water exiting the field was very similar for the two locations with about 50 % of the total P in the PO_4-P form.

This data confirms the data from the other locations concerning the decline in P and N concentration as rice irrigation water flows across the field. The total P and organic P in all of the fields was less than 0.05 mg P L^{-1} at the end of the field but is higher than the critical limits (0.01 and 0.02 mg P L^{-1} of soluble and total P, respectively) established as contributing to accelerated eutrophication of surface water (Sharpley et al., 1992; Sharpley and Smith, 1993). The water exiting the field irrigated by pondwater contained slightly higher concentrations of organic P than the field irrigated by well water, indicating that the contribution to surface water eutrophication is more likely used catfish pondwater for irrigation water. However, the amount of P in the water declined significantly by flowing across the rice field. Had the water been released directly from the catfish ponds, the level would have exceeded four times the critical limit for total P. Consequently, the idea was confirmed that rice fields can act similarly to constructed wetlands (Lakshman, 1979) and filter nutrients before entering surface water.

CONCLUSIONS

Since rice production utilizes a major portion of the irrigation water in the Southern Rice Belt, it is necessary to understand the potential for pollution resulting from field runoff. The results of this study emphasize the importance of water management with respect to N concentrations in the floodwater. The NO_3-N levels remained low when optimum water management was utilized. The soluble P concentrations were generally lower in the water exiting the field than in the water entering the field from the well. Although the P levels were sufficient at some locations to potentially contribute to eutrophication of surrounding surface waters, the amount of P was generally higher entering the field than exiting the field. Removal of Fe and Mn apparently depends upon water management and the oxidation state of the soil.

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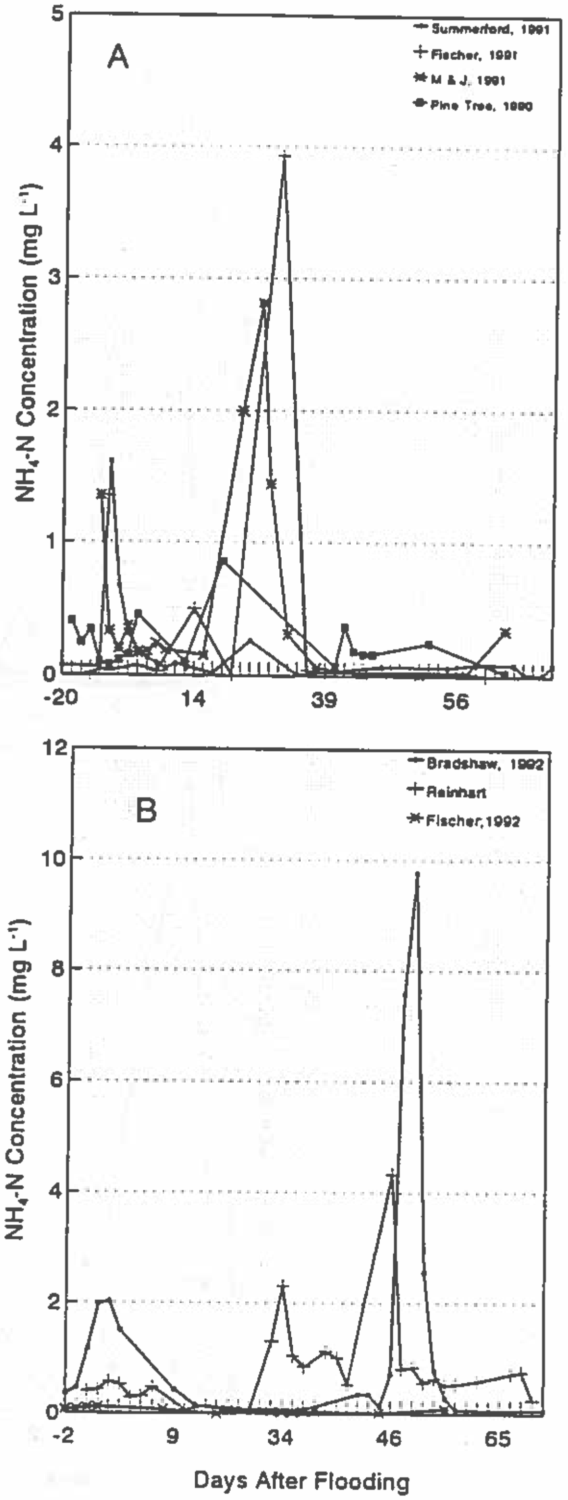

Fig. 1. Seasonal changes in NH_4-N concentration in rice irrigation water during 1991 (A) and 1992 (B).

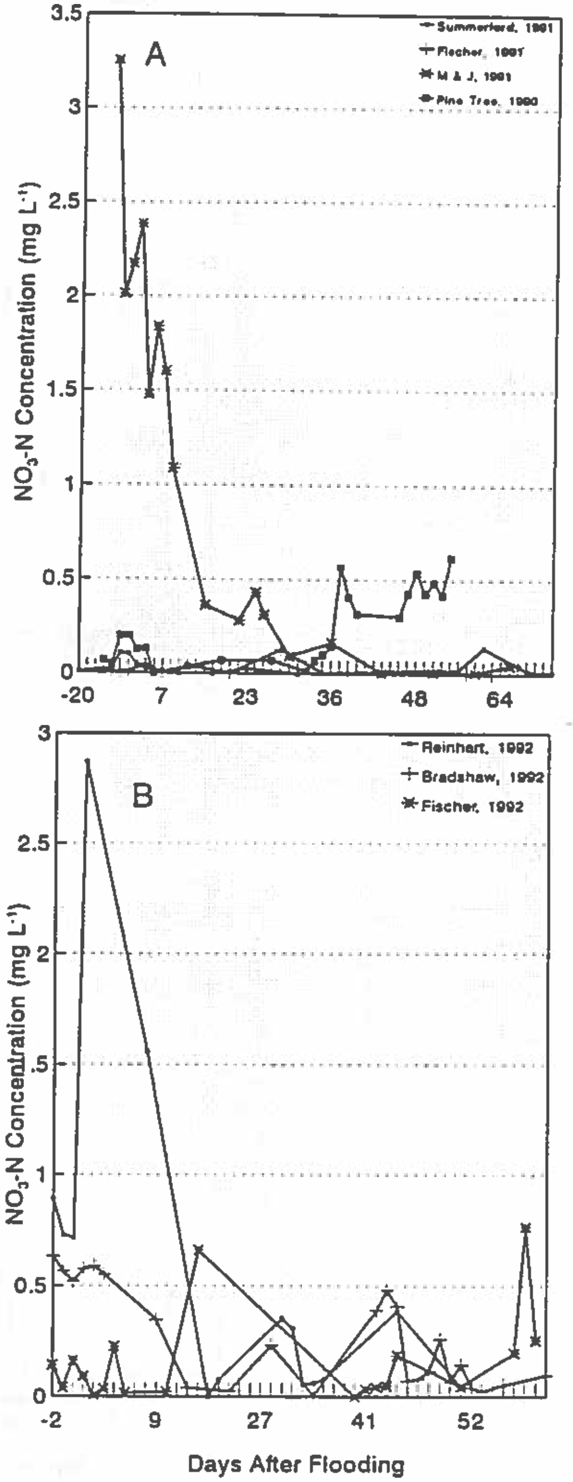

Fig. 2. Seasonal changes in NO$_3$-N concentration in rice irrigation water during 1991 (A) and 1992 (B).

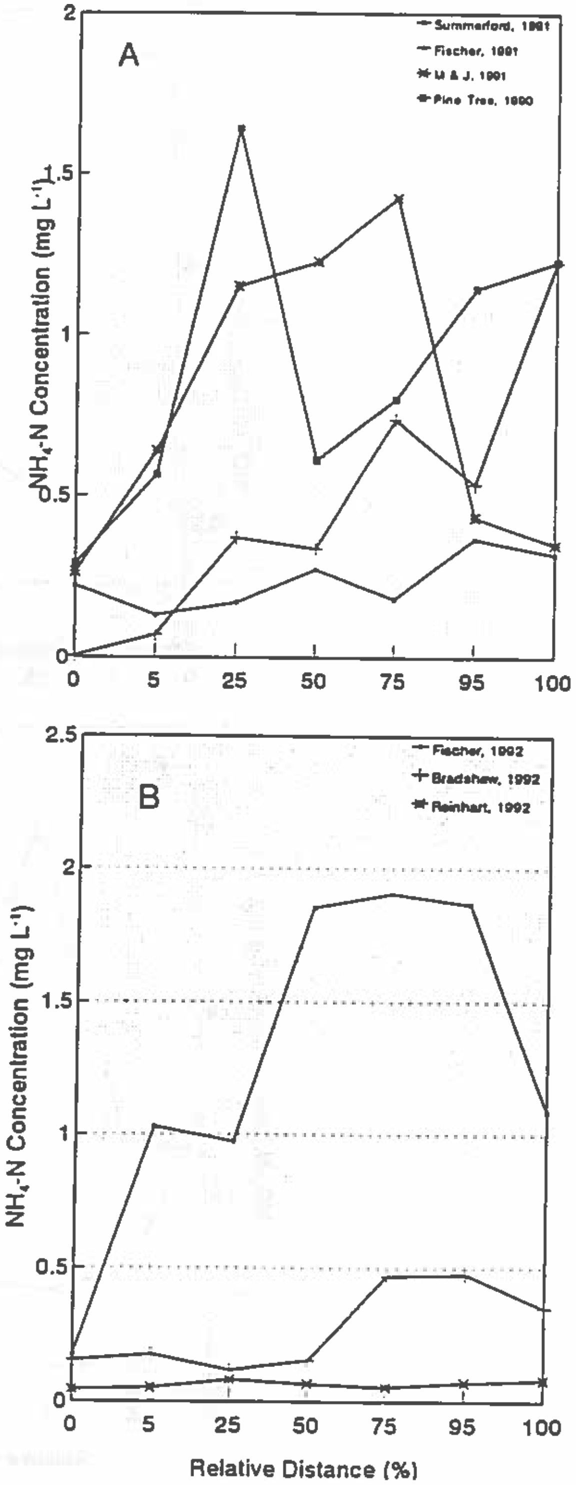

Fig. 3. Changes in NH_4-N concentration in rice irrigation water with respect to relative distance from the well during 1991 (A) and 1992 (B).

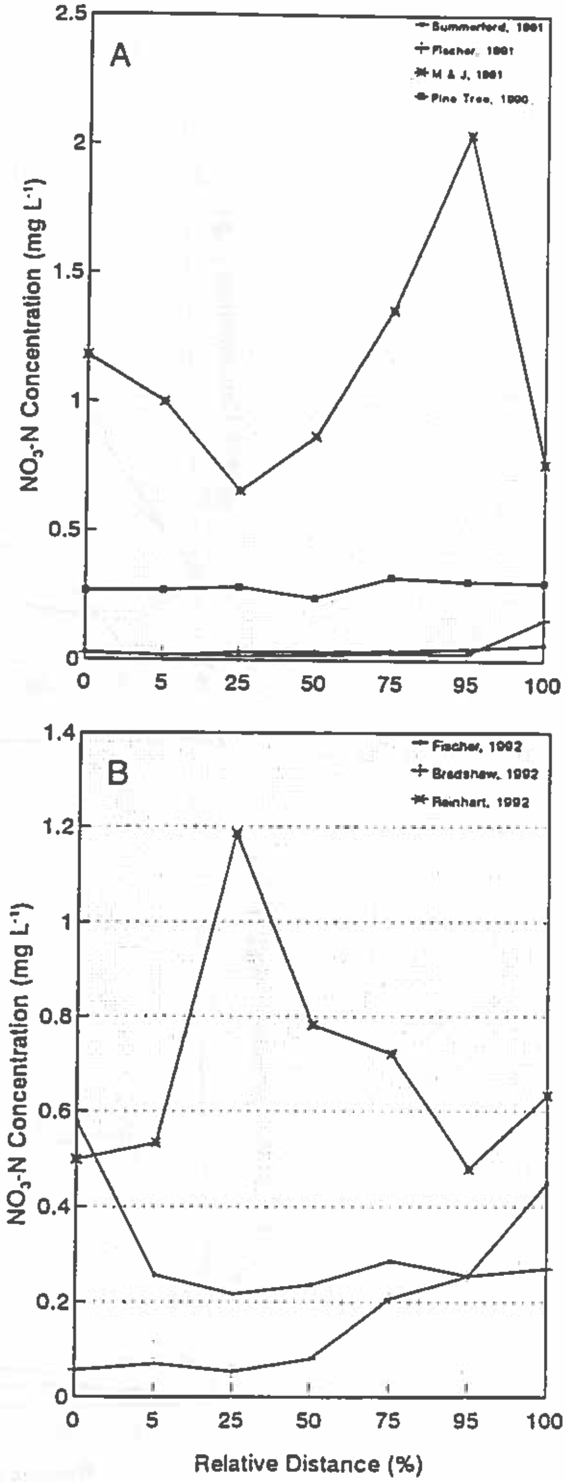

Fig. 4. Changes in NO_3-N concentration in rice irrigation water with respect to relative distance from the well during 1991 (A) and 1992 (B).

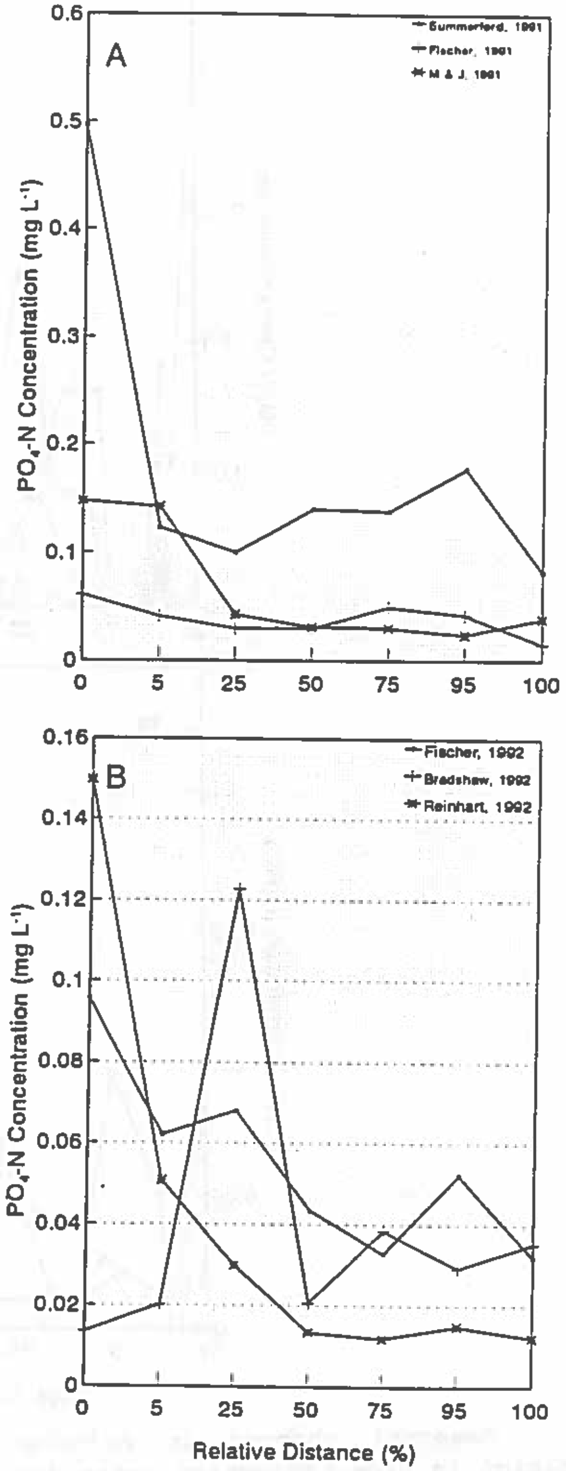

Fig. 5. Changes in soluble reactive phosphorus (PO_4-P) concentration in rice irrigation water with respect to distance across the field during 1991 (A) and 1992 (B).

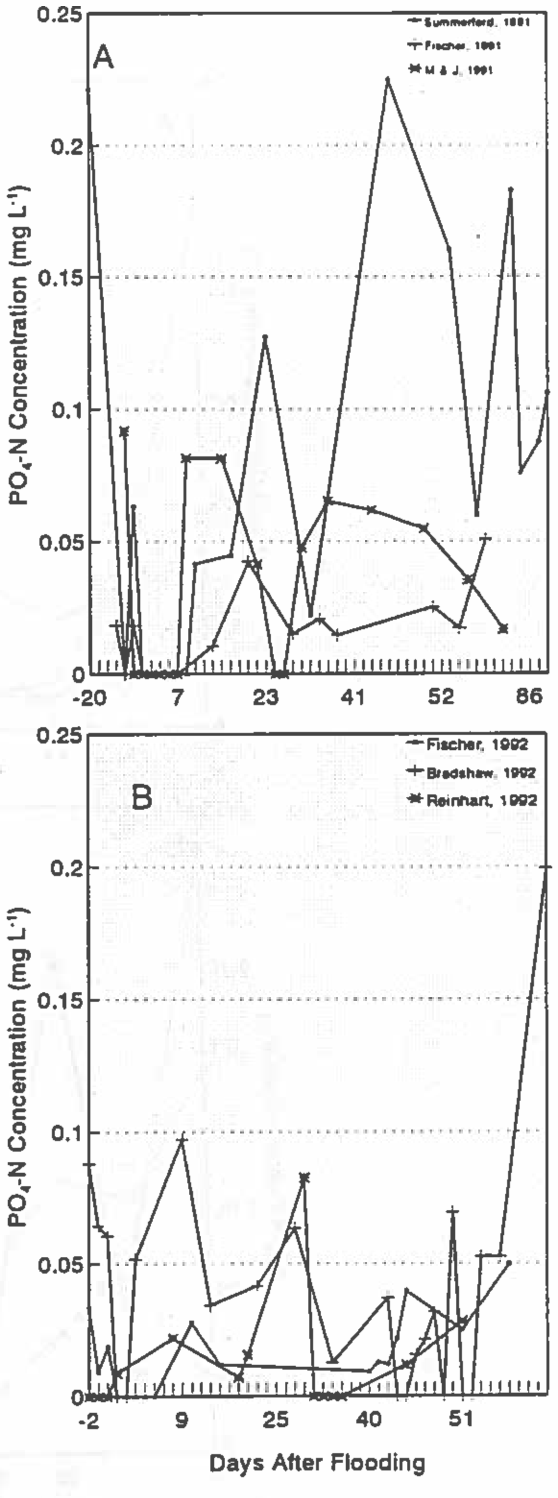

Fig. 6. Seasonal changes in soluble reactive phosphorus (PO_4-P) concentration in rice irrigation water during 1991 (A) and 1992 (B).

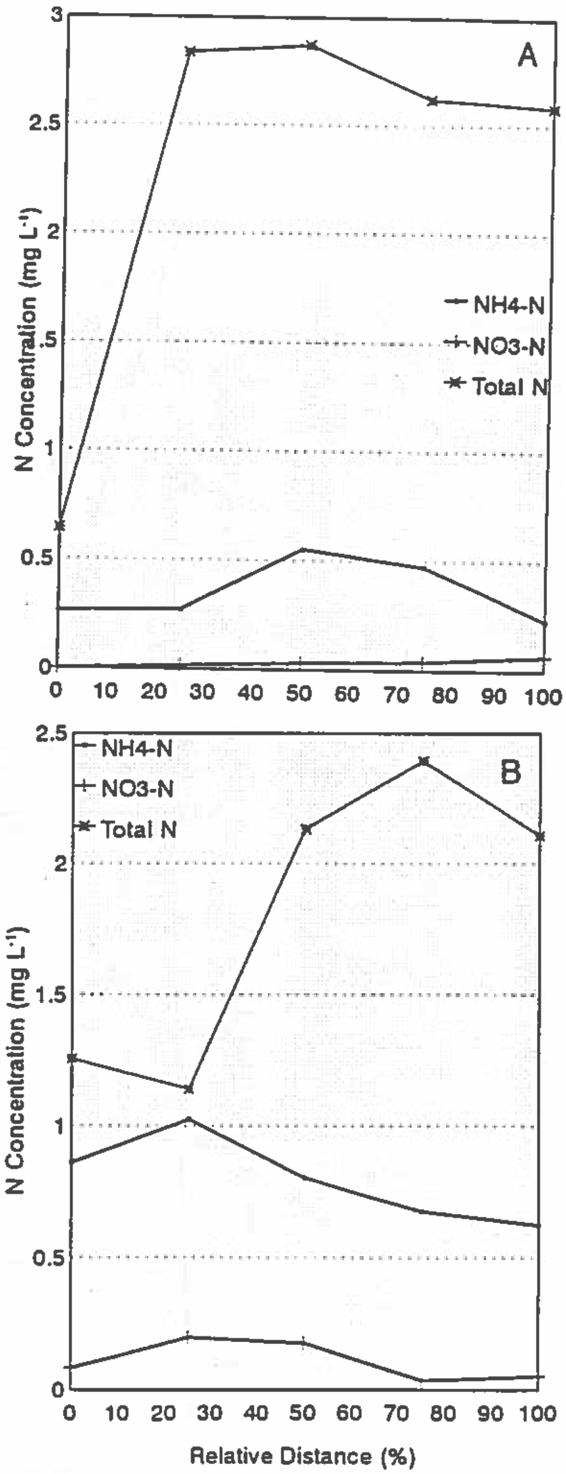

Fig. 7. Concentrations of NH_4-N, NO_3-N, and total N in rice irrigation water from a well (A) or catfish pond (B) with respect to relative distance from the source.

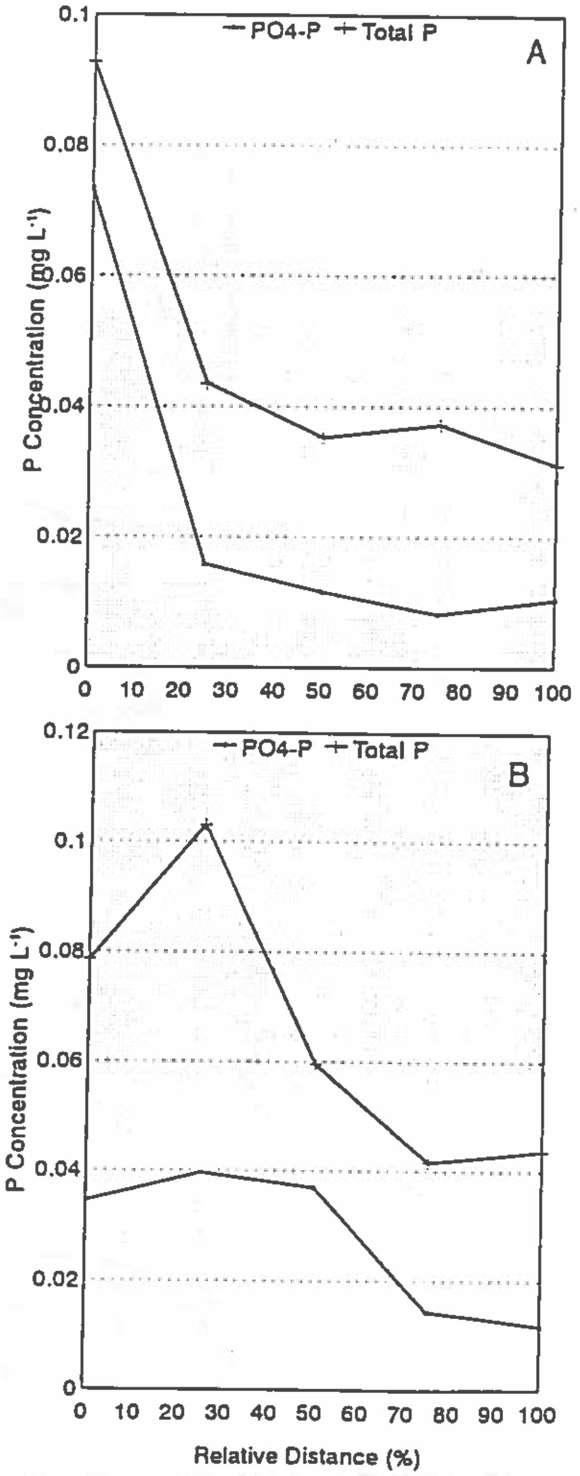

Fig. 8. Concentrations of soluble reactive phosphorus (PO_4-P) and total P in rice irrigation water from a well (A) or catfish pond (B) with respect to relative distance from the source.