

# Soil Nitrate as a Source of Nitrogen for Rainfed and Deep-Flooded Rice

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## ABSTRACT

Deepwater rice (DWR) is grown under rainfed upland conditions for 2–4 months, followed by deep flooding for 1–5 months. Nitrogen is important for the pre-flood growth of the crop, particularly to promote growth and development before the stress of deep flooding. Nitrate accumulated during transition from the dry to the wet season is a potential source of nitrogen. We measured soil nitrate before and during flooding in the Central Plain of Thailand on two different soil types, a Thio-gypsic Tropaquept and a Sulfic Tropaquept. Soil samples were collected from depth intervals of 0–20, 20–40 and 40–60 cm from plots without N fertilizer, and extracted with 2M KCl for analysis of N by a cadmium reduction technique. Plant samples were dried and analyses for nitrogen content by Kjeldahl analysis. Soil nitrate-N levels were less than 15 kg ha<sup>-1</sup>, and appear to have contributed little to crop N uptake. Nitrogen was lost from the crop at the beginning of flooding, but subsequently uptake of N continued, apparently from sources other than the pre-flood N transformations in the soil.

**Key words :** soil nitrate-N, deepwater rice

## Introduction

Millions of hectares of ricelands in South and Southeast Asia are subjected to uncontrolled flooding. These diverse environments incorporate many types of rice, including about 7 million ha of deepwater rice (DWR) grown on the flood plains of the major rivers of India, Bangladesh, Myanmar, Thailand, Cambodia and Vietnam where the fields are normally flooded to maximum depths of 50 cm to over 400 cm during the growing season (IRRI, 1993). Yields are low because of problem soils, unpredictable combinations of drought and flood, and lack of inputs by farmers.

Farmers sow or transplant deepwater rice early in the rainy season. The crop is initially subject to drought, then floods come 2–4 months after germination and remain 1–5 months. Maximum water depths occur around the time of flowering. Deepwater rice is able to withstand deep flooding by elongation of stem internodes (Puckridge *et al.*, 1989 and Catling, 1992), but at the start of flooding plants which are already tall are more likely to survive rapid water level increases. Differences in plant height as little as 10 cm at critical periods can make the difference between crop destruction and good grain production, and early N supply can be the key to the necessary height increase (Puckridge

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*et al.*, 1994). Nitrogen supply in the pre-flood period is therefore important to promote growth and development before the stress of deep flooding (Puckridge and Thongbai, 1988).

Appreciable soil nitrate can accumulate during the dry season fallow of tropical lowland rice fields even in the presence of appreciable weed growth (Buresh *et al.*, 1989), but can be lost during the transition from the dry to the wet season (George *et al.*, 1993) and at the start of flooding. In tropical rice soils  $\text{NO}_3^-$  disappears within a few days of flooding (Ventura and Watanabe, 1978), largely because of denitrification (Ponnamperuma, 1985). Nitrate is rapidly reduced to  $\text{N}_2\text{O}$  and  $\text{N}_2$  in the anaerobic bulk of flooded soils. The occurrence of ammonification, nitrification and denitrification and their relative rates are strongly influenced by soil moisture and soil aeration (Linn and Doran, 1984).

In Thailand deepwater rice farmers apply only small amounts of fertilizer. For example, the average nitrogen application for 52 farms sampled in 1989 (Puckridge *et al.*, 1994) was  $15.2 \text{ kg N ha}^{-1}$ . Seventeen of those fields received no fertilizer, and only three farmers applied more than  $40 \text{ kg N ha}^{-1}$ . The highest fertiliser rates were applied on acid sulfate soils of the Southeast Delta Flat, such as the Prachinburi site reported here, which is an area of low productivity (Van der Kevie and Yenmanas, 1972). Acid sulfate soils have a very low pH, high CEC and very high available K, but low to very low available P (Rojanasoonthon, 1978). These lowland rice fields have hot, dry, aerobic upland conditions during the dry season from December to April. The transition from dry season aerobic, through periodically wet to flooded anaerobic soil conditions occurs during the early wet season from around mid-April to late August, depending on location.

We know of no field measurements of nitrate accumulation and loss in the deepwater areas. The objectives of this study were therefore

to measure the amount of nitrate N in deepwater fields at the start of the wet season, to follow the changes in soil nitrate until flooding commenced and as long as possible thereafter, to compare soil nitrate-N with uptake of nitrogen by the rice crop, and to estimate the contribution of nitrate-N to the total nitrogen balance of the deepwater rice crop.

## Materials and Methods

Deepwater rice was sown at Huntra Experiment Station (HTA), latitude  $14^\circ 23' \text{ N}$ , longitude  $100^\circ 36' \text{ E}$ , elevation 2.5 m, and Prachinburi Rice Research Center (PCR), latitude  $13^\circ 55' \text{ N}$ , longitude  $101^\circ 15' \text{ E}$ , elevation 2.95 m, Thailand, in the 3 years 1990–1992. The soil at HTA is a Thio-gypsic Tropaquept of Ayutthaya series (Motomura *et al.*, 1979) and at PCR is a Sulfic Tropaquept, P-IIIa of Rangsit series (Osborn, 1985). Soil properties for both sites are shown in Table 1.

Dry rice seeds were sown in rows at  $3 \text{ gm}^{-1}$  of row, equivalent to a seed rate of  $120 \text{ kg ha}^{-1}$ , and germinated after rain. Plots were 9 m long and 8 m wide (33 rows) with rows 25 cm apart. At HTA the DWR cultivar HTA 60 was used in all three years. At PCR the cultivar SPR76' Com 3-5-2 was sown in 1990 and HTA 60 in 1991–92. Dates of seedling emergence, fertiliser application and flood details are shown in Table 2.

In 1990 & 1991 the experiment had a split-plot design with three dates of sowing as main plots (S1, S2, S3) and sub-plot treatments of 3 rates of N ( $0, 30, 60 \text{ kg N ha}^{-1}$ ) as urea broadcast pre-flood, with 4 replications. In 1991 another treatment was added to compare nitrate in unsown and sown plots. For 1992 the design was changed to an RCB with only one sowing date because the first two years showed no consistent differences in soil nitrate contents for different sowing dates. All treatments received a basal dressing of  $16 \text{ kg P ha}^{-1}$

**Table 1.** Properties of three soil layers of the experimental sites at Huntra Rice Experiment Station and Prachinburi Rice Research Center, Thailand 1990.

Properties	Huntra			Prachinburi		
	0–20 cm	20–40 cm	40–60 cm	0–20 cm	20–40 cm	40–60 cm
pH(1:1, w/v H <sub>2</sub> O)	5.3	5.2	5	4.2	4.2	4
O.M.(%)	2.4	1.2	0.7	3.1	2.8	0.8
Total N (%)	0.13	0.07	0.03	0.14	0.099	0.02
Bray II P (ppm)	12	7	3	4	1	<1
Bulk Density (g/cm <sup>3</sup> )	1.24	1.32	1.34	1.29	1.23	1.21

**Table 2.** Dates of seedling emergence, fertiliser application and commencement of flooding, and maximum water depths for deepwater rice at Huntra and Prachinburi, Thailand, 1990–1992. All dates given as days from 1 April

	Huntra			Prachinburi		
	1990	1991	1992	1990	1991	1992
Dates of seedling emergence						
First sowing (S1)	49	57	107	52	49	75
Second sowing (S2)	69	89	–	59	74	–
Third sowing (S3)	92	103	–	78	72	–
Dates of fertiliser application	156	148	153	138	136	149
Dates flooding commenced	156	154	153	148	131	163
Dates of maximum depth	193	209	206	200	193	198

Soil sampling with a 5-cm-diameter auger for measurement of nitrate commenced late April or early May and continued at 3–4 week intervals. Soil nitrate was measured only in the zero N plots. Four soil samples were collected from the three 20 cm depth intervals in each unsown plot, and between the rows of the zero N treatments in the sownplots. During flooding a 4-inch diameter rigid plastic tube was pushed into the soil and water inside the tube was pumped out before using the auger to take the soil samples.

The four samples from each plot were immediately combined for each depth and mixed thoroughly. Sub-samples were transferred to a plastic

bag for later KCl extraction. Other sub-samples were weighed for total wet weight, dried in an oven at 105 °C for 48 hr and then weighed again to calculate soil water content. Bulk density core samples (100 cm<sup>3</sup>) were collected periodically from the same depths. The bulk density was used to convert nitrate values to kilograms per hectare and to convert soil water to a volumetric basis.

For nitrate determination, 40–50 g of fresh soil sample was transferred to a plastic bottle and extracted with 100 ml of 2 M KCl for 1hr. The soil suspension was then filtered through Whatman No. 42 filter paper and the filtrate was stored in a refrigerator for later analysis. Nitrate and nitrite were

determined after reduction (Dorich and Nelson, 1984) by colorimetric determination of nitrite. Ammonium was determined by ammonia meter (Ammonia electrode model 95-12, ORION). Both nitrate and ammonium were expressed on a dry-soil basis as kilograms of N per hectare. No effort was made to separate nitrate and nitrite, and the values were reported as nitrate for the sake of simplicity.

Plant samples were collected periodically for measurement of dry matter and N content. Plants were cut at ground level from an area of 3 rows x 1.5 m long, with two samples from each plot. Plant samples were oven dried and N content determined by Kjeldahl analysis. An area of 5 m x 13 rows was harvested for grain yield.

## Results and Discussion

Time of emergence of seedling, date of fertiliser application and flood details are given in Table 2. The wet (rainy) season starts in April-May and cumulative rainfall data from 1 February to 31 August are given for sites and years in Table 3. Flooding depends more on water overflow from

rivers than on local rainfall. For the first two years there were means of 89 days between first seedling emergence and flooding at PCR, and 102 days at HTA. In 1992 sowing was delayed and the period between seedling emergence and flood was 74 days at PCR and only 46 days at HTA.

Soil nitrate-N was very low in early April 1990 (Figure 1) then increased after rains in May. Both PCR and HTA showed significant differences in soil nitrate-N between layers for most sampling times, but the amount of nitrate-N was always low. The maximum total at HTA for 0-60 cm was only 8.4 kg N ha<sup>-1</sup>, and at PCR 4.6 kg N ha<sup>-1</sup>. At PCR nitrate-N decreased to less than one kg ha<sup>-1</sup> when flooded. However, at HTA in 1990 there was still nitrate-N in the soil a few days after flooding (Figure 1), which may be related to rapid flooding and slow percolation in the soil. In 1990 the water level at both sites increased rapidly in October. In the eight days from 3 October the water level at PCR rose from 78 to 135 cm, and at HTA from 67 to 115 cm. The flood destroyed all the deepwater rice in the experiments, and plant samples were obtained only before October.

**Table 3.** Cumulative rainfall from February until August, Huntra Experiment Station and Prachinburi Rice Research Center, Thailand 1990-1992.

Site/Year	Cumulative rainfall (mm)						
	Feb.	Mar.	Apr.	May	June	July	Aug.
<b>Huntra</b>							
1990	0	21	22	251	290	403	501
1991	21	34	70	222	356	481	650
1992	4	4	4	49	107	143	331
<b>Prachinburi</b>							
1990	0	4	32	145	3099	493	601
1991	31	161	246	446	637	1053	1361
1992	0	0	19	136	326	485	684

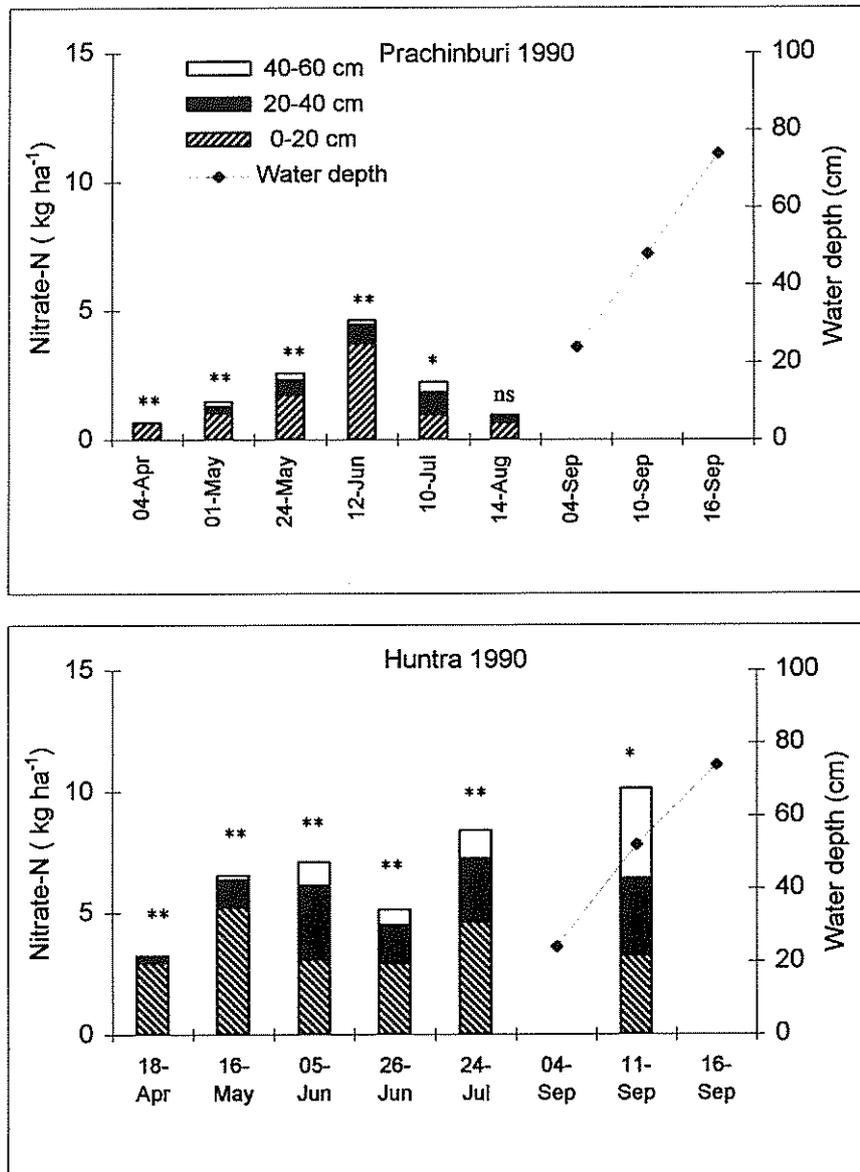


Figure 1. Comparison among soil nitrate-N for each soil layer from plots without fertiliser-N, Prachinburi and Huntra, wet season 1990. (ns=not significant, \*significant at the 5% level, \*\* significant at the 1% level)

After soil flooding, nitrate is lost by leaching and by denitrification to  $N_2$  and  $N_2O$  gases; Buresh *et al.* (1989) also reported the likely loss of 39 to 91 kg nitrate-N  $ha^{-1}$  from the top 60-cm layer following flooding of Philippine lowland soils. An incubation study with  $^{15}N$ -labelled  $NO_3^-$  of Buresh

*et al.* (1989) revealed 99 to 100% disappearance of added nitrate-N in 9 days and 5% or less of reduction of nitrate-N to  $NH_4^+$ -N and organic N.

Soil incubation measurements (Puckridge *et al.*, 1989) showed that HTA soil released over three times the amount of ammonium-N as

compared to PCR soil after 15 days of incubation, with around 21 ppm ammonium-N for HTA soil and 6.5 ppm for PCR soil. Chairaj *et al.*, (1984) found low formation of nitrate in incubation studies with Rangsit series soils (similar to the PCR soil) and concluded that nitrification, and presumably denitrification was slow in this soil.

Slightly more nitrate-N was measured in 1991, with maxima of around 15 kg ha<sup>-1</sup> at HTA and 8.5 kg ha<sup>-1</sup> at PCR (Figure 2). At HTA on 13 May most nitrate-N was in the 0–20 cm soil layer, but in June it appears that newly formed nitrate was subsequently leached downwards so that there was not difference between the three soil layers. Rainfall in May was 141 mm, and in June 134 mm. By the time flooding commenced at the beginning of September nitrate-N was negligible, around 1 kg N ha<sup>-1</sup>. At PCR 1991, the trend was similar to HTA, but the amount of soil nitrate-N was only around half that of HTA. George *et al.* (1993) reported considerable movement of nitrate down the soil profile of permeable soils following heavy rains. They measured as high as 155 kg nitrate-N ha<sup>-1</sup>, but because nitrification, denitrification, and leaching are dynamic processes which can occur simultaneously, they considered that measurements at 2- to 4-wk intervals could still have missed the highest build-up.

The low soil nitrate-N levels measured at HTA and PCR could be related to both the soil and climatic conditions. The soils at HTA and PCR dry rapidly after the flood water drains from the fields and the soil surface becomes very hard. Drying a soil tends to kill off nitrifying bacteria (Russell, 1973), so that after a pronounced dry season there may be a considerable interval between the onset of rains and the onset of nitrification. Denitrification can also be important during wet periods in warm soils well supplied with decomposable organic matter. The rains in Thailand often have high intensity and

water is ponded on the surface, so that anaerobic conditions can occur and denitrification may be rapid. Russell also records that some soils with pH between 4 and 5 will nitrify slowly, and that nitrification does not take place in very acid soils, but that there is no clear relation between soil pH and the rate of nitrification, probably because the effect of acidity is through the toxic effect of active aluminium ions. Moore *et al.*, (1990) reported that the most important constraints to rice growth on acid sulphate soils of the Central Plain of Thailand were acidity, which includes the combined effects of pH, Al toxicity and P deficiency; and Fe stress, which is due to the combined effects of Fe toxicity and deficiencies of other divalent cations such as Ca.

In the first two years there was little plant growth on the fields until early in the wet season, and crop residues were mainly rice straw which was ploughed in. Rice straw may return little N. Norman *et al.* (1990) reported that only 3% of rice residue N was recovered in a subsequent rice crop.

Figure 3 compares nitrate-N (0–60 cm) of the unsown plots with that of the three different times of sowing of 1991. It also gives the water levels and the uptake of N by the first sown crop during flooding. As time progressed there was a trend for soil from the first sowing to have less nitrate-N than the unsown plots, indicating removal of soil N by the crop, but the differences were not significant except at HTA on the fifth sampling occasion.

There was a marked contrast between the small amount of soil nitrate-N measured and the much greater amount of N uptake by the rice crop, suggesting that other sources of N were available to the crop. Puckridge *et al.* (1991) give several references indicating the possibility of up to 20 kg N ha<sup>-1</sup> from biological fixation, mostly from blue-green algae, and up to 13 kg ha<sup>-1</sup> from one meter

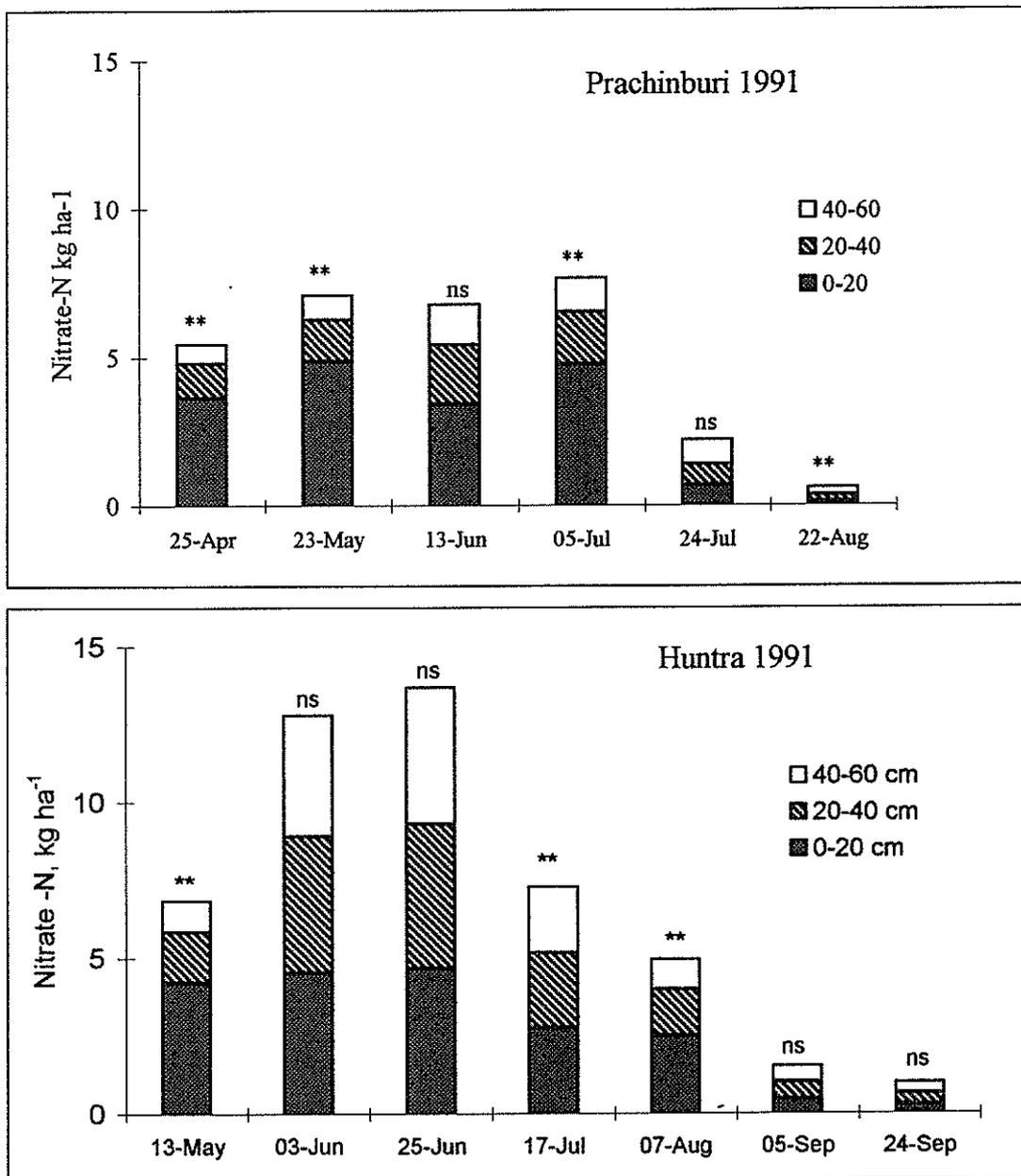
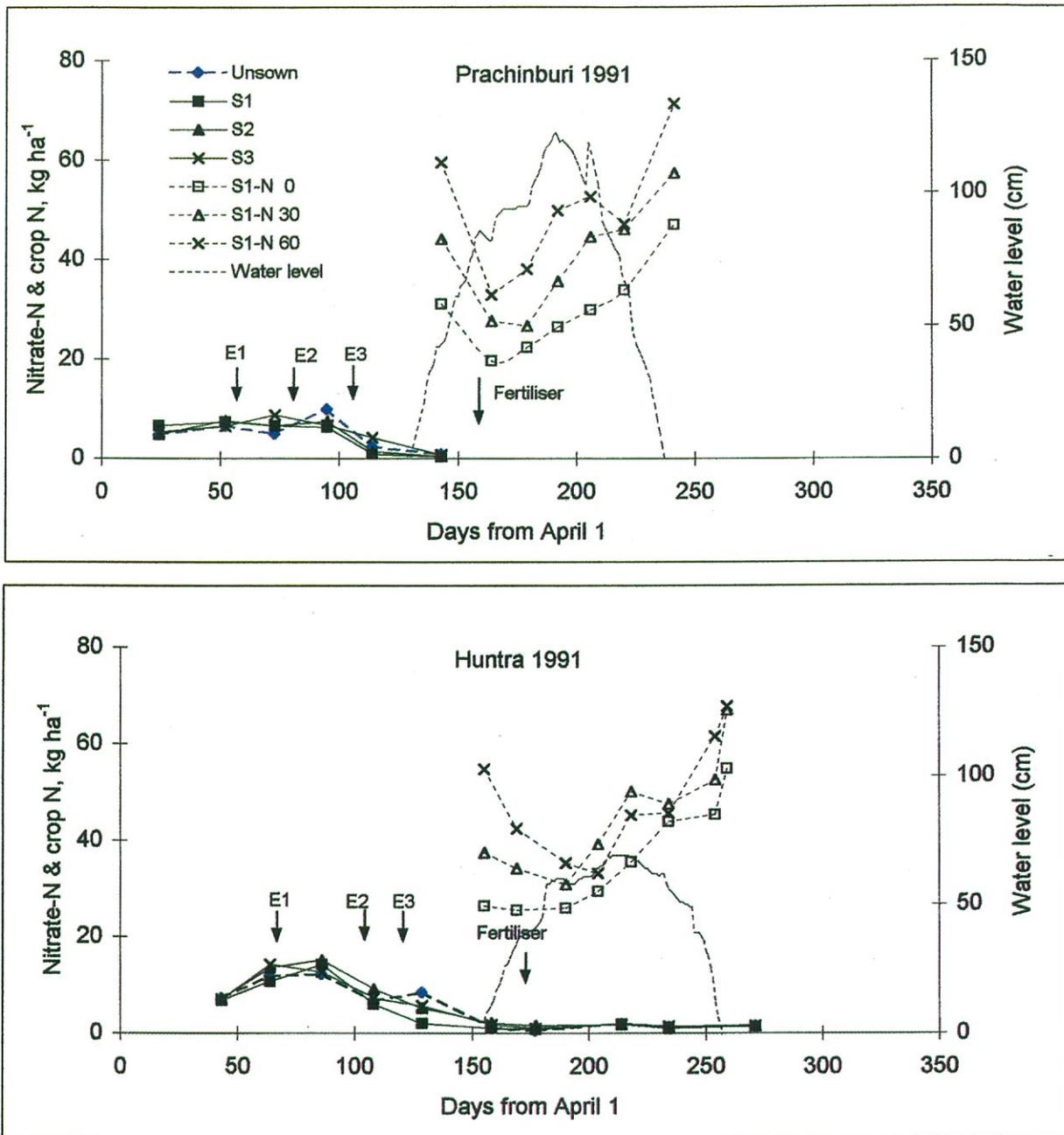


Figure 2. Comparison among soil nitrate-N for each soil layer from plots without fertiliser-N, Prachinburi and Huntra, wet season 1991. (ns=not significant, \*significant at the 5% level, \*\* significant at the 1% level)

depth of floodwater, but these are sources most likely to make a gradual contribution during flooding.

The crop N content was initially very high (Figure 3), decreased markedly during early flooding, and then increased. Most of the fertiliser N appears to have been taken up initially, but then

lost from the plants. The decline during early flooding may be due to death of leaves as floodwaters rise, with leaching of N from plant parts. The losses appear greatest at the high rate of N fertiliser. Similar patterns occurred at both PCR and HTA. Puckridge *et al.* (1991) also found a decrease in N



**Figure 3.** Soil nitrate-N for unsown plots and three times sowing of deepwater rice, crop nitrogen uptake for the first sowing of three fertiliser treatments, and water levels at Prachinburi and Huntra, wet season 1991. (E1, E2, E3 are Emergence date of S1, S2 and S3 respectively)

uptake immediately after flooding at HTA and PCR in two of six crops, with continuing availability of N during the flood period in all crops. In those experiments the total pre-flood N uptake ranged from 7–25 kg ha<sup>-1</sup> for HTA and 6–12.2 kg ha<sup>-1</sup> for PCR, with a mean pre-flood N uptake for unfertilised

plots of 0.27 kg N day<sup>-1</sup> over 67 days at HTA and 0.13 kg N day<sup>-1</sup> over 62 days at PCR. In another study of 85 deepwater rice fields in the central plain of Thailand, Puckridge *et al.* (1994) found 80% of the plant N accumulated during the flood period. The question still not answered is what proportions

of this came from the soil and from other sources, and how can the natural supply of N be sustained.

In Table 4 the maximum estimated soil nitrate-N plus fertiliser-N is compared with the crop N uptake for each of the sowing treatments. The ratios calculated from plant uptake divided by (soil nitrate-N plus fertiliser-N) show rapidly decreasing efficiency as fertiliser levels increase. For plots without N fertiliser the plant uptake at HTA is 3.7 times the nitrate-N, and up to 4.6 times at PCR. There was no effect of N fertiliser on yield. The first and the second time of sowing at HTA gave higher yield than the third sowing.

Soil nitrate-N for 1992 is given in Table 5. Measured soil nitrate-N was less than one kg ha<sup>-1</sup> at PCR and the maximum at HTA was only 9.6 kg ha<sup>-1</sup>. A main reason for the low nitrate-N at PCR could have been heavy weed growth on all plots in that season. Buresh *et al.* (1989) and George *et al.* (1993) reported that nitrate build-up is reduced when the soil was left to native weed growth or another crop is grown prior to the wet season lowland rice crop, but that N may be returned to the soil through plant residues. Sowing in 1992 was delayed due to unfavourable conditions and establishment of rice plants was very poor at HTA. Subsequently most of the rice plants were destroyed by the flood.

**Table 4.** Uptake of nitrogen by deepwater rice relative to sum of fertiliser-N plus soil nitrate-N . At low fertiliser rate there is apparently an alternative source of N. Huntra and Prachinburi, wet season 1991.

N rate (kg/ha)	Huntra				Prachinburi			
	Nitrate-N+ fertiliser-N kg ha <sup>-1</sup>	N uptake by crop kg ha <sup>-1</sup>	Relative uptake of N	Grain yield (t ha <sup>-1</sup> )	Nitrate-N+ fertiliser-N kg ha <sup>-1</sup>	N uptake by crop kg ha <sup>-1</sup>	Relative uptake of N	Grain yield (t ha <sup>-1</sup> )
<b>Sowing 1</b>								
0	12.2	45.3 a	3.7	3.03	6.4	29.7	4.6	2.22
30	42.2	52.5 a	1.2	3.28	36.4	40.0	1.1	2.09
60	72.2	61.6 a	0.9	3.53	66.4	45.8	0.7	2.46
<b>Mean</b>		53.1		3.28 a				2.25
<b>Sowing 2</b>								
0	12.2	49.4 b	4.0	3.34	6.4	21.2	3.3	1.70
30	42.2	61.7 ab	1.5	3.26	36.4	27.7	0.8	1.93
60	72.2	75.5 a	1.0	3.73	66.4	31.9	0.5	1.95
<b>Mean</b>		62.2		3.44 a				1.86
<b>Sowing 3</b>								
0	12.2	44.4 a	3.6	2.43	6.4	0	0	0
30	42.2	43.8 a	1.0	2.82	36.4	0	0	0
60	72.2	34.5 a	0.5	2.58	66.4	33	0.5	0
<b>Mean</b>		40.9		2.61 b		11		0
CV (%) Sowing		23.4		12.3		-		-
CV (%) Nitrogen		24.6		15.1		31.7*		1.5*

Mean in a column for each sowing followed by a common letter are not significantly different at the 5% level by DMRT. Sowing 3 at Prachinburi was destroyed by flood water and error df is insufficient for a reliable F-test.

\*CV does not include sowing 3.

Table 5. soil nitrate-N (kg ha<sup>-1</sup>) at Huntra and Prachinburi, wet season 1992

Soil depth (cm)	Huntra						Prachinburi		
	19 Jun	7 Jul	28 Jul	18 Aug	15 Sep	6 Oct	29 May	5 Jun	16 Jul
0-20	1.5 a	2.3 a	5.1 a	4.6 a	2.8 a	0.8 b	0.8 a	0.5 a	0.2 a
20-40	0.8 ab	1.1 b	1.7 b	3.2 b	3.1 a	1.7 a	0.3 b	0.4 a	0.1 a
40-60	0.3 b	0.4 b	0.5 c	0.6 c	3.6 a	1.5 a	0.2 b	0.1 b	0.1 a
Total	2.6	3.8	7.4	8.4	9.6	3.9	1.3	0.9	0.4
CV(%)	76.2	42.3	16.7	24.0	47.4	32.3	21.5	41.2	65.3

Means in a column followed by a common letter are not significantly different at the 5% level by DMRT.

### Conclusion

The importance of N losses due to nitrification during non-flooded periods of deepwater and rainfed lowland rice crops and subsequent denitrification remains largely unknown. Understanding NO<sub>3</sub> dynamics of rainfed lowlands is important not only from the perspective of nitrate loss and its probable negative impacts on the environment, but also from the point of retaining this N on land and using it effectively. The development of management practices to prevent loss of accumulated

nitrate might offer an opportunity to reduce the N fertiliser requirements for the subsequent rice crop, but further research is necessary.

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