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Effect of algicides on urea fertilizer efficiency in transplanted rice

I. Floodwater chemistry and biota

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Abstract

The effects of the algicides terbutryn and copper sulfate on the potential for reducing the gaseous loss of NH_3 from urea applied to rice were examined in experiments with 2 methods of N fertilizer management, 2 or 3 N rates, and 3 algicide treatments. The experiments were conducted during the 1986 dry and wet seasons in an experimental field at Pila, Laguna, Philippines.

Copper sulfate had little effect as an algicide at the rate used, but terbutryn immediately reduced algal growth. The populations of species resistant to terbutryn probably increased, but terbutryn had no long-term effect on the total number of colony-forming units of algae. There was some evidence that terbutryn reduced photodependent N_2 fixation as estimated by acetylene reduction assay.

Terbutryn, when applied with urea 10 days after transplanting, reduced the maximum floodwater pH by 0.9 units or more for 7 d in the DS and by about 0.5 units for 8 d in the WS. Terbutryn increased the ammoniacal-N (AN) concentration in the floodwater 100% or more in the DS and 60% in the WS. The combined effect of terbutryn on the floodwater pH and AN concentration was reduced photodependent NH_3 partial pressure (ρNH_3), about 25% in the DS and 38% in the WS.

Introduction

Ammonia volatilization is recognized as an important N loss process after urea is applied to the floodwater of rice. The measured losses when urea is broadcast into the floodwater soon after transplanting vary from 11 to 47% of the fertilizer N applied [5, 16]. However the losses from applications around panicle initiation are generally lower (3–15% of the N applied) because (1) the larger canopy reduces wind speed at the water surface, (2) the canopy reduces photosynthetic activity in the floodwater and therefore the maximum value of the floodwater pH, and (3) N uptake by the crop is more rapid.

The loss by NH_3 volatilization is primarily controlled by the concentration of NH_3 gas dissolved in the water, the rate of exchange of gas from the water to the air, and the movement of the gaseous NH_3 away from the air close to the water surface [9]. The concentration of aqueous NH_3 is dependent on the concentration of ammoniacal-N (AN) in the water, and the pH of the water and its temperature. The potential for loss of NH_3 from treatments applied to small plots can be compared using the NH_3 partial pressure (ρNH_3) in the floodwater. The important role of pH in influencing NH_3 emissions is demonstrated by the increase in the ratio of NH_3-N/NH_4^+-N from 0.05 to 5 as the pH of the solution increases from 8.0 to 10.0.

The pH of the floodwater fluctuates diurnally and the maximum reached is controlled by algal photosynthesis. pH values of 9.5 and above are often reached in the field [3, 10, 16]. Bowmer and Muirhead [1] demonstrated that the algicide terbutryn, when applied with urea at panicle initiation to drill-sown rice in a temperate environment, reduced the diurnal fluctuation in floodwater pH for 6 days. They also reported that AN concentration significantly increased but cumulative emission of NH_3 was reduced 43% relative to the control. However, terbutryn did not significantly affect yield or dry matter production of rice.

The objective of this study was to determine the effect of 2 algicides on the processes affecting N-use efficiency of urea applied to transplanted rice in a tropical environment. This paper presents the effect of the treatments on the floodwater chemistry and biota. The second paper in this series deals with rice growth, yield, and weed control.

Materials and methods

We conducted two experiments in an irrigated farmer's field at Pila, Laguna, Philippines, in 1986. The soil, an Andaqueptic Haplaquoll, had a clay texture and was slightly acidic (pH 6.6), with average organic C (13.6 g kg^{-1}) and N (1.4 g kg^{-1}) and no available (Olsen) P in the surface 200 mm.

Dry season experiment

The field was plowed soon after the previous rice crop was harvested. Details of crop management are summarized in Table 1. Irrigation water was applied every other day to maintain a water depth of about 50 mm within each plot during the period of detailed water measurements. Insect control and

Table 1. Details of crop management and treatment applications in DS and WS experiments at Pila, Laguna, Philippines, 1986

Operation	DS	WS
Crop management		
Date previous crop was harvested	n.a.[a]	21 Jun
Date field was plowed	13 Feb	5 Jul
Plot size (m)	4.0 × 4.8	4.8 × 5.6
Date basal fertilizer was applied	10 Mar	22 Jul
Rate of triple superphosphate (kg P ha^{-1})	17	17
Rate of KCl (kg K ha^{-1})	25	25
Rate of $ZnSO_4$ (kg Zn ha^{-1})	5	5
Method of incorporation	power weeder	power weeder
Presence of free water	trace	trace
Date seedlings were transplanted	11 Mar	24 Jul
Variety	IR64	IR64
Seedling age (d)	21	21
Seedlings per hill	2–3	2–3
Spacing (cm)	20 × 20	20 × 20
Date plots were flooded	14 Mar (3 DT)	25 Jul (1 DT)
Treatment management		
Researchers' split		
First urea application	10 Mar (−1 DT)	22 Jul (−2 DT)
First algicide application	15 Mar (4 DT)	25 Jul (1 DT)
Second algicide application	Nil	29 Jul (5 DT)
Farmers' split		
First urea application	21 Mar (10 DT)	4 Aug (11 DT)
First algicide application	22 Mar (11 DT)	4 Aug (11 DT)
Second algicide application	Nil	8 Aug (15 DT)

[a] n.a. = not available.

other cultural practices were optimum and followed standard practices. Visual symptoms of zinc deficiency were observed at 20 d after transplanting (20 DT) and zinc sulfate was applied at 5 kg Zn ha^{-1}.

The treatments were in a split-plot design, with N fertilizer management and N rate as main plots and algicide treatment as the subplots. Each treatment was replicated in four blocks. The actual time the treatments were applied is summarized in Table 1. The 2 systems of fertilizer management studied were the researchers' split (2/3 basal and incorporated with no standing water immediately before transplanting and 1/3 broadcast into the floodwater at panicle initiation (PI)) and the farmers' split (1/2 into the floodwater at 10 DT and 1/2 at 10 d after PI). Three rates of N fertilizer applied as urea— no N (O N), 90 kg N ha^{-1} (90 N), and 150 kg N ha^{-1} (150 N)— and 3 algicide treatments —no algicide (No A), copper sulfate applied at 1.5 kg Cu ha^{-1} (Cu), and terbutryn (2-(*tert*butylamino)-4-(ethylamino)-6-(methylthio)-*s* triazine) at 100 g a.i. ha^{-1} (T)— were compared. The granular formulation of terbutryn, Clarosan, which contained 1% technical terbutryn (95% terbutryn and 5% herbicidally active triazines) and obtained from Ciba-Geigy Ltd., Basle, Switzerland, was used. Because of the small quantity spread, we mixed terbutryn with sand before applying to achieve uniform distribution. Copper sulfate was dissolved in water and applied between the hills with a wash bottle. All treatments were applied from the levees to avoid disturbing the plots. The algicide treatments were applied only with the first N application.

Wet season experiment

An experiment similar to the dry season (DS) experiment was conducted in the wet season (WS). The field was plowed within 2 weeks the previous crop was being harvested. The important cultural practices are summarized in Table 1.

The WS experiment used the same three factors —N fertilizer management, N rate, and algicide —and experimental design. The fertilizer management treatments—researchers' split and farmers' split—were the same. However, only 2 N rate treatments were used: no N (O N) and 87 kg ha^{-1} applied as urea (87 N). The algicide treatments were no algicide (No A), 1 application of terbutryn at 100 g ha^{-1} (T), and 2 applications of 100 g terbutryn ha^{-1} (2 T), the second application at 5 d after the first. Table 1 lists the time the treatments were applied.

Floodwater measurements

Floodwater measurements were taken daily for up to 8 d after the algicide treatment. Water depth was measured on graduated bamboo stakes located at 4 sites in each plot. Floodwater pH, temperature, and O_2 concentration were measured *in situ* at 0730 h referred to as minimum for convenience and 1300 h referred to as maximum for convenience each day. The fluctuation in floodwater pH and O_2 concentration during daylight hours was measured on 1 occasion at 2 h intervals, at 13 DT in the DS experiment. Floodwater samples were collected at 1300 h from 4 sites within each plot and bulked. A 200-ml subsample was acidified with 1 ml of 30% H_3PO_4 to prevent gaseous loss of NH_3. The sample was filtered and where urea analysis was required, a 9-ml aliquot was treated with 1 ml of 50 mg l^{-1} of phenyl mercuric acetate. The samples were frozen and stored until analysis. Urea-N was determined by a colorimetric method and AN by the colorimetric method using alkaline phenol and sodium hypochlorite. Both analyses were carried out on an autoanalyzer. ρNH_3 was calculated using the method described in De Datta et al. [4].

Algae enumeration

Composite soil-water samples were collected at 34 and 40 DT from researchers' split, DS experiment in the O N and 90 N treatments, each receiving either No A or T. Samples were composed of the top 5 mm soil layer and the corresponding floodwater of 10 cores collected with plastic tubes 100 mm long and 30 mm in diameter, along a transect oriented according to the dominant wind. Dilutions of soil suspensions were prepared on a surface basis from 10^{-2} to 10^{-6} and plated in triplicate on agarized BGII medium which allows enumeration of blue-green algae (BGA) (*Cyanophyceae*) and many diatoms (*Bacillariophyceae*) and nonmotile unicellular green algae (*Chlorophyceae*).

The same medium depleted of N was used for enumerating N_2-fixing BGA. The method is described in Roger et al. [13, 14].

Acetylene reduction activity

Composite surface-soil samples of 8 cores each were taken at 20 and 34 DT from the O N and 90 N treatments receiving No A and T in 4 replicates of the DS experiment. The method for ARA assay is described in [12].

Results and discussion

Algal development

Dry season experiment

When the algicide treatments were applied to the researchers' split in the DS, green algae were unevenly distributed over the experimental site. On No A and Cu during the day the treatments were applied, a scum with entrapped bubbles (froth) developed and moved over the water surfaces of the plots in the wind direction. Major algal components of the scum were *Euglena* sp., representatives of the *Lyngbya-Plectonema-Phormidium* group of homocystous BGA, and several diatoms among which *Synedra* sp. and *Navicula* sp. were the most abundant. After several days, scattered benthic algal mats rose to the surface of the water in the mid-afternoon. No scum developed on any T within 7 d of treatment application but the first signs of a green bloom and froth had appeared after 9 d on T with 150 N. Three days after algicides were applied to the farmers' split, the size of the scum in the mid-afternoon on both No A and Cu increased with increasing N rate. However, there was only a light scum on O N.

Wet season experiment

In the WS experiment, no froth formed in any treatment, although algal scums did develop. In the researchers' split, a dense bloom developed in the water on all No A treatments, 2 d after algicide application, while no algal bloom was visible within 7 d in T and 2T. In the farmers' split, a high density of zooplankton (algal grazers) was evident. Again, the density of the algal bloom on No A was higher with added N. After 6 d on No A/87 N, a green film of *Euglena* sp. accumulated on the surface, and on one plot it formed a complete, discrete layer. While deposits similar to paramylon bodies (excess photosynthate) were scattered on the surface. Within 2 d, the film had decomposed. No algal bloom was evident within 7 d on T or 2 T.

Algal populations and N-fixing activity

Algae enumerations were done at 34 and 40 DT during the DS to obtain information on the effect of algicide on algal populations. In most cases, algal density was slightly higher in the no-algicide plots than in algicide-treated plots (Table 2). Total algal population averaged 2.2×10^{10} colony-forming units (CFU) m^{-2} in No A and 1.3×10^{10} m^{-2} in T. N_2-fixing BGA averaged 9.0×10^8 CFU m^{-2} in No A and 4.8×10^8 CFU m^{-2} in T.

However, ratios between algal populations in nontreated and treated plots ranged from 1 to 2.3 and averaged 1.7, which does not allow the differences to be considered significant [8]. In addition, when the algal colonies on petri dishes were being counted, no apparent difference in the composition of the algal flora was observed.

At the time of sampling for algal enumeration and ARA measurements, no algal bloom was observed in the field. Average values recorded for total algal flora (1.7×10^{10} CFU m^{-2}) and the N_2-fixing BGA (6.4×10^8 CFU m^{-2}) were very close to the average values recorded in wet soils of the same area when no algal bloom was present (2.1×10^{10} CFU m^{-2} and 8.2×10^8 CFU m^{-2},

Table 2. Effect of N rate and algicide treatment applied in the researchers' split, DS experiment, on the enumeration of benthic and planktonic algae on BG 11 medium (total) and BG 11 medium without N (N_2-fixing blue-green algae)

Algal Florae	Colony-forming units, no. m^{-2}			
	0 N		90 N	
	No A	T	No A	T
	34 DT			
Total	2.7×10^{10}	1.3×10^{10}	3.1×10^{10}	1.6×10^{10}
N_2-fixing	7.7×10^8	4.0×10^8	1.9×10^9	8.3×10^8
	40 DT			
Total	1.3×10^{10}	9.3×10^9	1.6×10^{10}	1.2×10^{10}
N_2-fixing	4.3×10^8	4.3×10^8	5.0×10^8	2.7×10^8

Table 3. Acetylene-reducing activity (μmol C_2H_2 m^{-2} h^{-1}) of the surface soil as affected by terbutryn and N fertilizer applied to the researchers' split, DS experiment

	20 DT	34 DT	59 DT	70 DT	Average
T/90 N	$25^{a}_{(53,13)}$	$2_{(4,1)}$	1	1	$7_{(14,4)}$
T/O N	$5_{(11,3)}$	1	0	1	$2_{(3,1)}$
No A/90 N	$25_{(57,15)}$	$4_{(7,2)}$	0	0	$7_{(11,4)}$
No A/O N	$36_{(98,23)}$	$26_{(51,19)}$	$2_{(4,1)}$	$9_{(17,7)}$	$18_{(30,11)}$
Probability corresponding to F values[a]					
Block	–	–	.061	–	–
Algicide	–	.085	.279	–	.036
Nitrogen	–	–	.064	–	–
Algicide x Nitrogen	–	–	.025	–	.093

[a] Confidence intervals (p = 0.05) indicated within brackets and F values are calculated after log transformation of the data.
[b] Probabilities > 0.3 are not presented.

respectively) [14]. When blooms develop, total algae range from 10^{11} to 10^{12} CFU m^{-2} [12].

One month after T application, there was no significant effect on counts of total algae and N_2-fixing BGA. However, because of the limited algal growth observed in all the plots at the time of algal enumerations, further observations in experiments where algal blooms develop are needed before drawing definite conclusions.

Table 3 shows the effect of the nitrogen and algicide treatments on ARA in the researchers' split in the DS. ARA remained very low in all the plots and large variations were recorded among replicated plots. For comparison, ARA in plots where a N_2-fixing algal bloom develops may range from 200 to 500 μmol C_2H_2 m^{-2} h^{-1} [13].

Highest ARA were recorded in the no-algicide, no-fertilizer plots (36 and 26 μmol C_2H_2 m^{-2} h^{-1}). Variance analysis indicates a significant effect of algicide when the average of four ARA measurements is considered. However, as for algal enumerations, observations in experiments where N_2-fixing algal blooms develop are needed before definite conclusions on the effects of T during the crop cycle can be drawn.

Floodwater pH

Dry season experiment

Cu did not significantly reduce the floodwater pH in either the researchers' split or the farmers' split

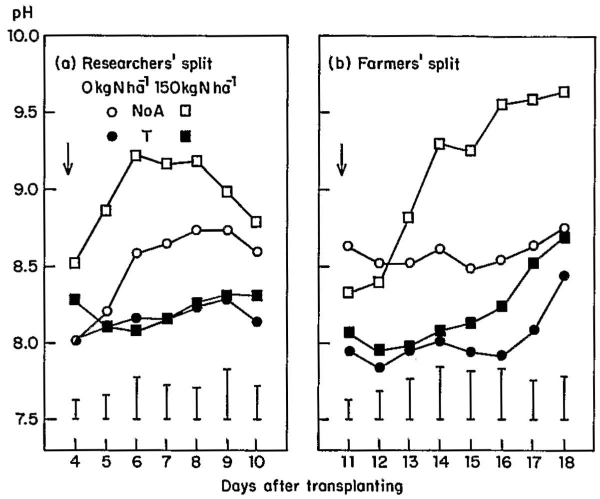

Fig. 1. Floodwater pH at 1300 h in the DS experiment as affected by algicide treatment with 0 N and (a) 100 kg N ha^{-1} (150 N) in the researchers' split and (b) 75 kg N ha^{-1} (150 N) in the farmers' split. Arrows indicate when the treatments were applied and the bars represent least significant difference (P = 0.05) for comparison of algicide treatments at the same N rate.

(data not presented). In the researchers' split, T reduced the mean pH for 7 d at 1300 h by about 0.7 units with 150 N and 0.35 units with O N (Fig. 1). The smaller reduction in pH with O N was attributed to the lower maximum pH reached with O N (8.50) compared with 150 N (8.94), and reflected the lower algal growth without N fertilizer. The minimum pH with T with 90 N and 150 N was also significantly reduced for several days after application.

In the farmers' split, the reduction in maximum pH with T was larger than that recorded in the researchers' split (Fig. 1). This difference was attributed to increased algal growth on No A, particularly with 90 N and 150 N. The reduction in mean maximum pH for 8 d was 0.59 units for O N, 1.01 for 90 N, and 0.90 for 150 N. In the 150 N with No A treatment in the farmers' split, the maximum pH was significantly lower at 11 DT than in O N with No A. The pH with 150 N and T showed no diurnal fluctuation for several days probably because a weak NH_4HCO_3 solution formed which buffered the pH at about 8.0.

Wet season experiment

The addition of N in the WS generally did not significantly affect the maximum pH and increased

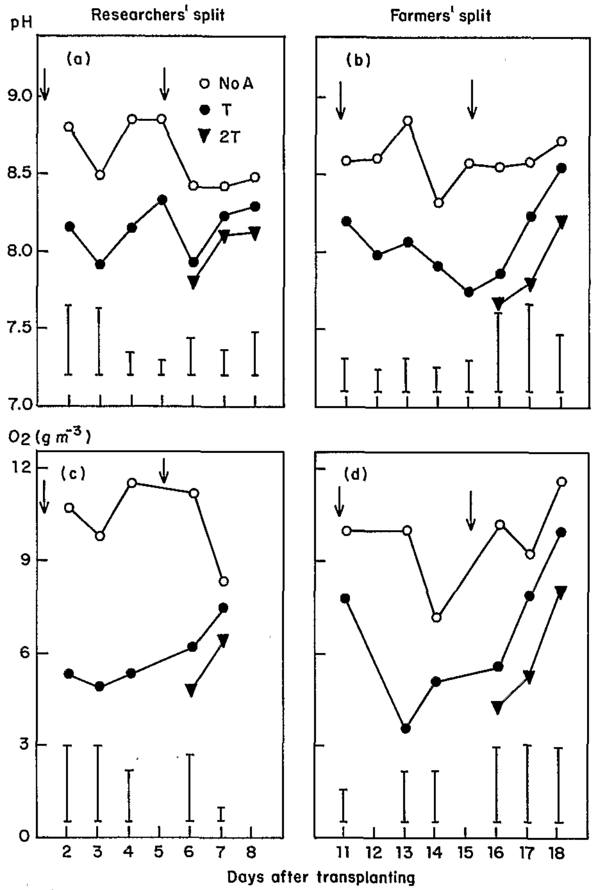

Fig. 2. Effect of algicide treatment in the WS experiment on the floodwater pH at 1300h averaged over N treatments in the researchers' split (a) and the farmers' split (b), and on the floodwater O_2 levels at 1300 h averaged over N treatments in the researchers' split (c) and the farmers' split (d). Arrows indicate when the treatments were applied and the bars represent least significant difference (P = 0.05) for comparison of algicide treatments on the same day.

the minimum pH only slightly for 2 d in the researchers' split but not in the farmers' split. Combining the data over N treatments (Fig. 2a, b), we found that algicide had a similar effect on the maximum pH in both the researchers' split and the farmers' split. Terbutryn (T) significantly reduced the maximum pH for 6 d and 2 T for at least 8 d. The mean reduction in maximum pH for 8 d was 0.42 units with T and 0.51 units with 2 T in the researchers' split and 0.53 and 0.67 units, respectively, in the farmers' split.

The pH on plots that received 87 N and No A in the farmers' split varied from 7.83 to 9.49 on 16 DT; 1 d later a similar range occurred but on different plots. The low values were caused by the complete surface film of algae described earlier which prevented light penetrating to the benthic algae. Algae floating on the floodwater surface may obtain a significant part of their CO_2 from the air and therefore have less effect on floodwater pH. The maximum pH values recorded on the shaded plots were similar to the maximum values measured in the T and 2 T plots.

Floodwater O_2

Dry season experiment

T significantly lowered the maximum O_2 concentration below No A for at least 6 d after the treatments were applied to all N rates in both the researchers' and farmers' split (Fig. 3). Cu did not significantly affect O_2 concentration during the period of measurement in the researchers' split but significantly reduced the maximum O_2 concentration for 1 d in the farmers' split (results not shown). The minimum O_2 concentration was consistently lower on T than on No A, the difference significant on some days, particularly where N fertilizer was applied. The difference was caused by lower O_2 concentrations on T, rather than increasing O_2 levels on No A. Presumably, O_2 consumed by the respiration of soil micro-organisms as well as in biological and chemical oxidation was greater than O_2 diffusing from the air to the water on T whereas on No A, algal photosynthesis replenished O_2 levels. The mean daily O_2 concentration in the researchers' split was reduced from 6.9 $g\,m^{-3}$ in No A to 3.8 $g\,m^{-3}$ with T and in the farmers' split from 7.6 to 3.0 $g\,m^{-3}$.

Wet season experiment

In the WS experiment, T significantly reduced the maximum O_2 concentration for 5 d in both the researchers' and the farmers' split (Fig. 2c, d). Although 2 T significantly reduced the maximum O_2 concentration for several days in both the researchers' and the farmers' split, the extra reduction was not as large as that achieved with the first application. Populations of either algal species or ecotypes tolerant of the algicide or organisms able to break it down may have increased after the first application and reduced the effectiveness of 2 T. Algal species are known to vary from very susceptible to very resistant in their toxicity to an algicide

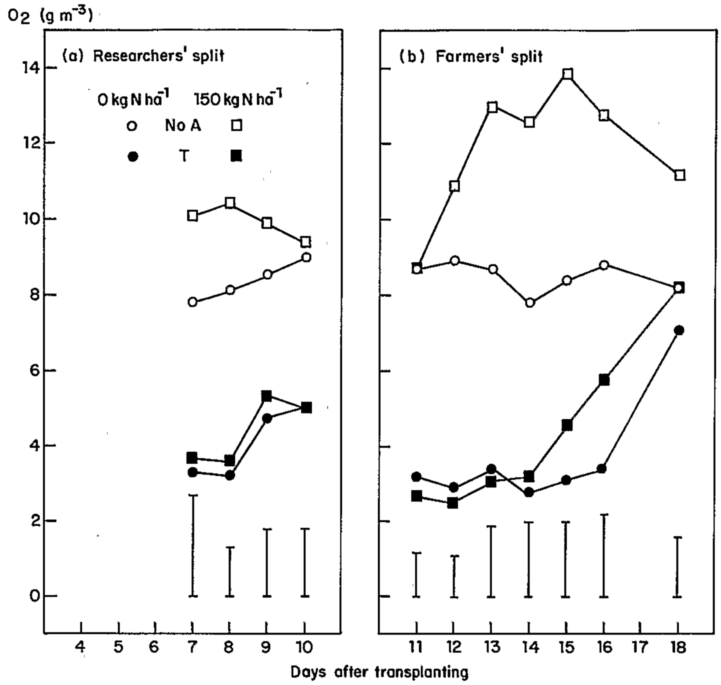

Fig. 3. Floodwater O_2 at 1300 h in the DS experiment as affected by algicide treatment with 0 N and (a) 100 kg N ha^{-1} (150 N) in the researchers' split and (b) 75 kg N ha^{-1} (150 N) in the farmers' split. Arrows indicate when the treatments were applied and the bars represent least significant difference (P = 0.05) for comparison of algicide treatments at the same N rate.

such as copper sulfate [11]. In the researchers' split, the mean daily O_2 concentration was reduced from 7.8 g m^{-3} to 4.9 (T) and 4.5 g m^{-3} (2 T). Similar reductions from 7.3 g m^{-3} to 5.0 (T) and 4.3 g m^{-3} (2 T) occurred in the farmers' split.

Fluctuation in floodwater pH and O_2 concentration during daylight

The maximum value for floodwater pH occurred later (1600 h or later) than for O_2 concentration (1400 h) at 13 DT in the farmers' split in the DS (Fig. 4). O_2 concentration fell more rapidly with 0 N than with 150 N. With T, there was little change during daylight hours in pH and O_2 levels. These data suggest that the pH may have increased slightly after the routine measurements taken daily at 1300 h but O_2 concentration reached a maximum at this time.

Floodwater urea (dry season experiment only)

The half-life of urea in the floodwater averaged 12 h during the period 11 to 14 DT on the farmers' split in the DS, considerably shorter than the 36 h reported in Bowmer and Muirhead [1]. In our experiment, the shallower depth of water (less than 50 mm compared with 100 mm in [1], higher mean temperature, and possibly higher urease activity in the soil probably contributed to the more rapid disappearance of urea. Terbutryn and Cu significantly increased urea concentration in the floodwater 1 d after fertilizer application, and a similar trend existed on the second day (Table 4). In contrast, Bowmer and Muirhead [1] reported that terbutryn increased the rate of urea disappearance whereas Vlek et al. [19] found that simazine, a related triazine, had no effect.

Floodwater ammoniacal-N concentration (AN)

Effect of algicide without N fertilizer (0 N)
Terbutryn applied at the time of the researchers' and farmers' split in both experiments increased AN significantly where no fertilizer N was applied (Fig. 5). Cu had no effect on AN. Ammoniacal-N

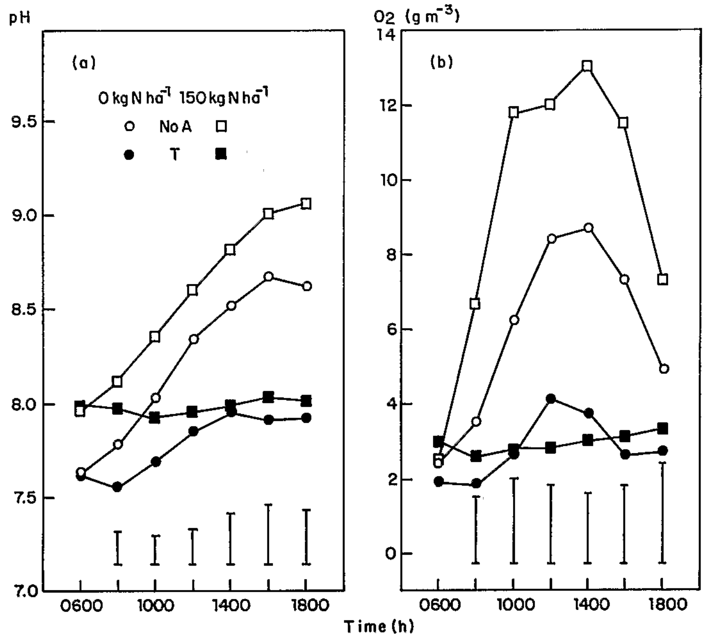

Fig. 4. Effect of algicide treatment during daylight hours at 13 DT in the DS with the farmers' split receiving 0 N and 75 kg N ha^{-1} (150 N) on (a) floodwater pH and (b) floodwater dissolved O_2. Bars represent least significant difference (P = 0.05) for comparison of algicide treatments at the same N rate.

Table 4. Effect of rate of N fertilizer and algicide treatment on urea-N concentration in the floodwater, farmers' split, DS experiment. Urea applied 10 DT

Treatment	Urea-N concentration, g m^{-3}			
	11 DT	12 DT	13 DT	14 DT
Nitrogen				
0 N	0	0	0.2	0.06
90 N	48.0	8.2	2.3	0.63
150 N	80.8	16.6	3.8	1.31
LSD (P = 0.05)	7.3	7.8	2.4	0.73
Algicide				
No A	38.4	5.7	1.4	0.48
Cu	46.3	9.4	3.3	1.08
T	44.1	9.7	1.7	0.44
LSD (P = 0.05)	5.5	NS^{+}	1.4	NS

$^{+}$ NS indicates that the analysis of variance showed no significant difference (P > 0.05).

on No A was always less than 0.5 g m^{-3} in the DS and less than 1 g m^{-3} in the WS. With T, the concentrations approached 2 g m^{-3} in the DS and 1.5 g m^{-3} in the WS. The difference in AN concentration between No A and a single application of terbutryn generally increased for several days after reaching a maximum, and then declined. In the WS, the second application of terbutryn (2 T) maintained significantly higher AN levels longer than the single application. The higher AN levels with terbutryn can be partly attributed to diffusion of NH_4^+ ions from the soil into the floodwater where it remained, whereas AN was either lost as NH_3 or immobilized in the algal biomass on No A. Part of the AN in T also resulted from excretion by and mineralization of algae and water and soil biota after the algicide was applied, especially in the farmers' split during the DS where longer submersion and higher light availability favoured algal growth.

Effect of algicide with N fertilizer

When urea was incorporated at various rates in the soil in the researchers' split in both the DS and WS experiments, terbutryn significantly increased the AN levels in the floodwater for 3 to 6 d (Fig. 6). The average AN concentration was increased by 1.0 and 2.4 g m^{-3} with 90 N and 150 N and terbutryn in the DS and 1.5 g m^{-3} with 87 N in the WS.

Much higher AN concentrations were reached when urea was applied to the floodwater in the farmers' split in both experiments (Fig. 6). On the

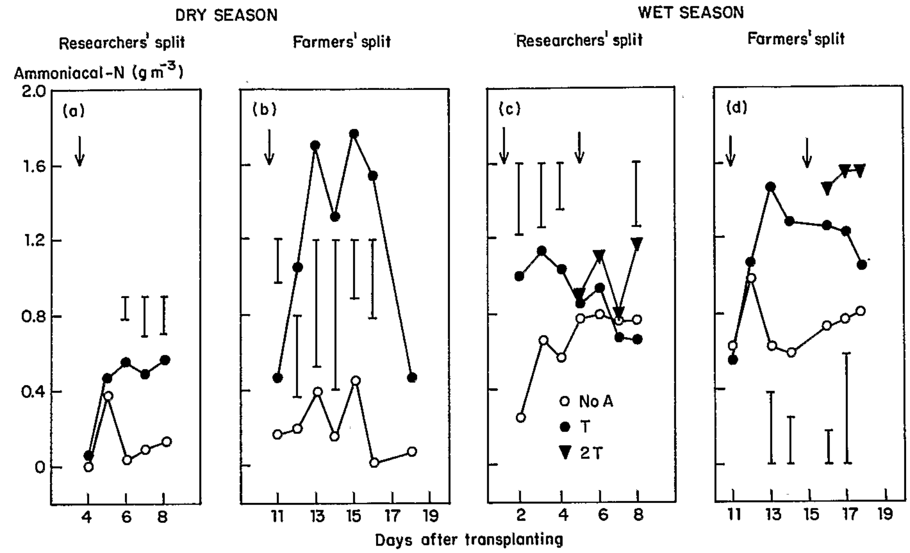

Fig. 5. Effect of algicide treatment on the AN concentration in the floodwater where 0 N was applied in the researchers' split and the farmers' split in the DS (a and b) and researchers' split and farmers' split in the WS (c and d). Arrows indicate when the treatment were applied and the bars represent least significant difference (P = 0.05) for comparison of algicide treatment on the same day.

No A treatments, the AN levels fell rapidly after reaching a peak within 2 d of application. After the maximum AN was reached, the levels on the algicide treatment were invariably significantly higher than on No A for at least 5 d. In the DS, T increased the average AN concentration from 3.8 to 10.5 $g\,m^{-3}$ with 90 N and from 9.8 to 20.9 $g\,m^{-3}$ with 150 N while in the WS, T increased the AN level from 4.8 $g\,m^{-3}$ to 7.7 $g\,m^{-3}$.

Ammonia partial pressure (ρNH_3)

The algicide treatments applied with the researchers' split did not significantly affect ρNH_3 in the DS and WS experiments except at 5 DT in the WS when T applied with 87 N significantly increased ρNH_3 when compared with No A. The maximum ρNH_3 averaged over algicide treatments in both the DS and WS experiments was generally less than 0.1 Pa (Fig. 7). The incorporation of 90 N in the DS and 87 N in the WS experiment more than doubled the ρNH_3 relative to No A for most of the period measurements were made.

In both seasons, the maximum ρNH_3 in the farmers' split with O N remained less than 0.1 Pa and was not significantly affected by the algicide treatment. The maximum ρNH_3 on all N with No A treatments exceeded 0.8 Pa on the day after the treatments were applied (Fig. 8). However, the decline in ρNH_3 was more rapid on No A in both seasons and within 4 d in the DS and 5 d in the WS, the ρNH_3 on the algicide treatments was higher than No A. When compared with T, 2 T significantly reduced the ρNH_3 for 2 d after the second application. ρNH_3 in 2 T remained higher than in No A for this period but all values were less than 0.2 Pa. The reduction in the mean maximum ρNH_3 for the measurement period was 26% for 90 N and 25% for 150 N with T in the DS, and 40% for T and 37% for 2 T with 87 N in the WS.

General discussion

Our studies have shown that terbutryn applied with urea in the farmers' split reduced floodwater pH for up to 7 d after application. The reduction coincided with the period when AN levels in the floodwater were high and favouring loss by NH_3 volatilization. However, the AN concentration in the floodwater more than doubled with the terbutryn treatment in the DS and increased 60% in the WS. Consequently, there was only a modest reduction in the ρNH_3 at 1300 h, about 25% in the DS and about 38% in the WS.

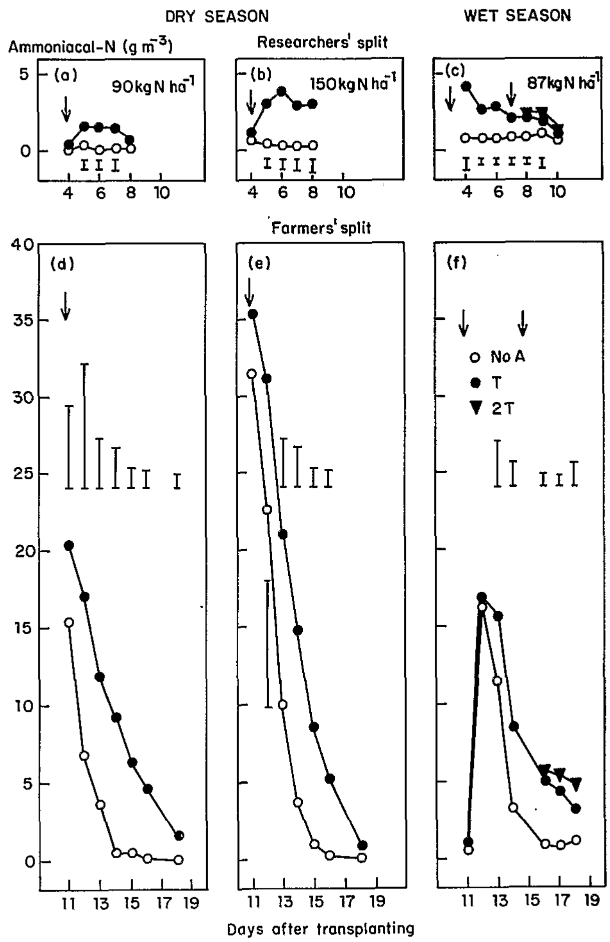

Fig. 6. Effect of algicide treatment on the AN concentration in the floodwater in the researchers' split where (a) 60 kg N ha^{-1} (90 N) and (b) 100 kg N ha^{-1} (150 N) were applied in the DS and (c) 58 kg N ha^{-1} (87 N) in the WS; and in the farmers' split where (d) 45 kg N ha^{-1} (90 N) and (e) 75 kg N ha^{-1} (150 N) were applied in the DS and (f) 43 kg N ha^{-1} (87 N) in the WS. Arrows indicate when the treatments were applied and the bars represent least significant difference (P = 0.05) for comparison of algicide treatments on the same day.

The substantial increase in AN concentration with terbutryn has been attributed to an increased rate of urea hydrolysis and reductions in NH_4^+ adsorption, immobilization in the soil, NH_3 volatilization, and denitrification losses [1]. We did not detect any differences in the rate of urea disappearance in the DS experiment which, however, was more rapid than reported in [1]. The higher rate of urea disappearance in our study is consistent with higher rates of disappearance with shallower water [7].

In the DS experiment, the quantity of N (AN + urea N) in the floodwater 1 d after the algicide treatments was applied represented about 23% of the fertilizer N used. It is likely that the remaining fertilizer N had moved into the soil. The AN in the floodwater declined more rapidly during the 2 d after it reached a maximum on No A (1.7 and 2.8 kg N ha^{-1} d^{-1} with 90 N and 150 N, respect ively) than with terbutryn (0.9 and 1.9 kg N ha^{-1} d^{-1}, respectively). We have shown that terbutryn lowered the ρNH_3 during this period and a reduced rate of NH_3 loss would follow. Consequently, the reduced rate of NH_3 loss with terbutryn would result in a higher AN concentration in the floodwater. This is consistent with the results obtained by Simpson et al. [17] who showed that the AN concentration in the floodwater in-

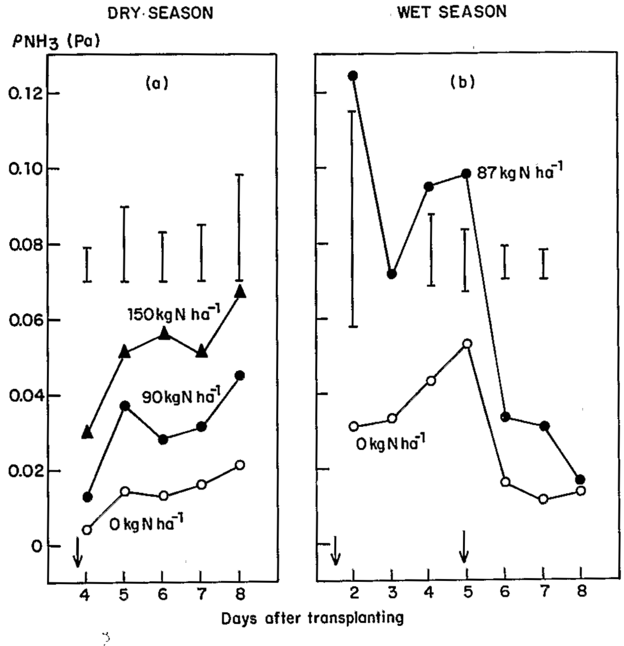

Fig. 7. Effect of N rates averaged over algicide treatments on ρNH_3 in the researchers' split in the DS (a) and the WS (b). Arrows indicate when the treatments were applied and the bars represent least significant difference (P = 0.05) for comparison of N rates on the same day.

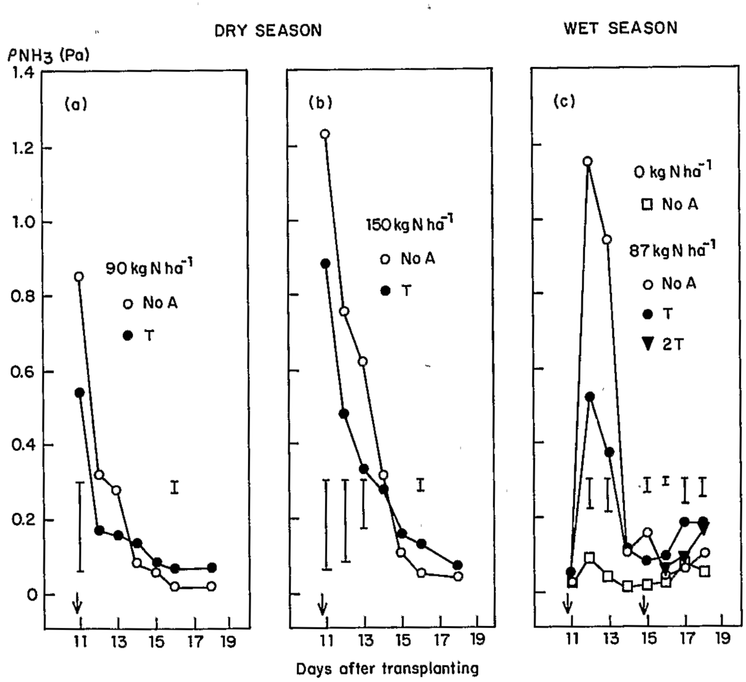

Fig. 8. ρNH_3 in the farmers' split as affected by terbutryn treatment with (a) $45\,kg\,N\,ha^{-1}$ (90 N) and (b) $75\,kg\,N\,ha^{-1}$ (150 N) in the DS and (c) $43\,kg\,N\,ha^{-1}$ (87 N) in the WS. Arrows indicate when the treatments were applied and the bars represent least significant difference (P = 0.05) for comparison of algicide treatments on the same day.

creased for 8 d when floodwater pH was maintained around pH 7 with acid and terbutryn. Cai et al. [2] also demonstrated the same effect with a surface film. Although N immobilization rates in the algal biomass equivalent to 1.5 and 3.3 kg N ha^{-1} d^{-1} have been reported for glasshouse and controlled environment studies [18, 19], the average N content of the total algal biomass in rice fields is estimated to be only 5 kg N ha^{-1} [20]. Consequently, algal immobilization of AN is unlikely to be an important process in reducing AN concentration during the period of maximum loss. We conclude that the AN concentration in the floodwater is primarily controlled by NH_3 loss and the equilibrium between NH_4^+ ions in the soil and floodwater.

Terbutryn reduced the average daily O_2 concentration about 50% in the DS and 40% in the WS. Focht [6] concluded that the effective depth of the aerobic zone is dependent on the O_2 concentration at the soil-water interface. Consequently, the fall in the O_2 concentration produced by the algicide may reduce the depth of the aerobic zone and this could affect both N processes and rice growth in several ways. A smaller aerobic zone could reduce denitrification loss by reducing the number of sites for nitrification. However, Simpson et al. [17] showed no reduction in denitrification loss with terbutryn 10 d after application, although the impact of the algicide on O_2 concentration, which was not measured, may have been less with the deeper water they used. The more reduced conditions produced with terbutryn could also release manganese and ferrous ions, displacing exchangeable NH_4^+ ions which would enter the soil solution and floodwater. Toxins, including organic acids, produced under the more reduced conditions, may accumulate in the root zone, and the higher CO_2 levels could reduce the availability of Zn and Cu and restrict rice growth. The higher CO_2 concentrations with terbutryn could benefit photosynthesis in submerged rice leaves [15]. However, these effects are likely to be short-lived, unless applications are repeated, because the algal activity increases after a week and the higher O_2 levels in the floodwater will expand the aerobic zone.

Terbutryn may have affected the composition of the algal population because the first application in the WS caused a reduction of 0.5 pH units for 5 d or more when compared with No A, but the effect of the second application lasted for 3 d or less. Similar trends were apparent in O_2 concentration. It is likely that algal species resistant to terbutryn dominated the algal population after the first application and developed with little competition so they were not greatly affected by the second application. Terbutryn without N fertilizer did appear to reduce the acetylene-reducing activity of the surface soil for up to 34 d. However, it had no long-term effect on the total number of benthic algae or N_2-fixing flora.

Conclusions

Our study has demonstrated that terbutryn effectively reduced the floodwater pH during the critical period when AN concentration was high after urea was applied to the floodwater of rice. However, AN concentration during this period was higher with terbutryn. The reduction in ρNH_3 was estimated to be 25% (in the DS experiment) and 38% (in the WS experiment) of the levels on the control treatment. Although terbutryn reduced O_2 concentration about 50%, the likely impact on N processes and rice growth was considered minor, mainly because of the relatively short period the floodwater environment was affected.

Terbutryn, in the formulation used in these experiments is registered for the control of algae in fresh water environments overseas [1]. It was not very persistent in our experiments as algal blooms developed after about 10 days. As N_2-fixing algal blooms did not develop in these experiments, it is difficult to reach a definite conclusion on the longer-term effects of terbutryn on N_2 fixation. We believe that terbutryn has the potential to be acceptable in the rice environment.

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