Efficiency of some modified urea fertilisers for wetland rice grown on a permeable soil

JC KATYAL, BIJAY SINGH, VK SHARMA and ET CRASWELL[1]

All India Co-ordinated Scheme of Micronutrients in Soils and Plants, Punjab Agricultural University, Ludhiana-141004, India, and Agro-Economic Division, International Fertilizer Development Center, Muscle Shoals, Alabama 35660, USA

(Accepted: 10.01.1985)

Key words: leaching, nitrogen losses, supergranules

Abstract. Split broadcast applications of prilled urea, deep point-placed urea supergranules (USG), and broadcast sulfur-coated urea (SCU) were compared as nitrogen sources for wetland rice (*Oryza sativa L.*) in two field experiments on a sandy soil (Typic Ustipsamment) with a high percolation rate (approx. 110 mm/day) in the Punjab, India. The USG was consistently less effective than the split urea and averaged 1 ton ha^{-1} less rice yield at the highest nitrogen rate (116 kg N ha^{-1}). SCU produced the highest grain yields in both experiments; it averaged 1.7 ton ha^{-1} more than did the split urea at the highest N rate.

The fertilisers were then compared in field microplots; percolation was permitted or prevented so that the cause of the poor performance of USG could be elucidated. USG gave higher grain yield and N uptake in microplots that were not leached than in those that were leached. In leached microplots, the grain yields were higher from prilled urea than from USG treatments provided the placement pattern of the USG matched that of the field plots. Yields were not higher from treatments in which the USG were more closely spaced. In microplots in which leaching was prevented, the broadcast prilled urea was less effective than the deep-placed USG, which gave yields approximately 60% greater than those from split urea and the same as those from SCU. Broadcast prilled urea in undrained microplots caused high levels of ammonium (40 ppm) to develop in the floodwater where high pH (8.9) and high alkalinity (4.9 meq l^{-1}) may have led to extensive ammonia volatilisation. The use of USG and SCU in undrained microplots reduced floodwater ammonium levels to less than 3 ppm.

Urea and ammonium leaching losses measured in fallow soil columns in the laboratory were much greater from USG than from prilled urea. Leaching losses from SCU were negligible. The data suggest that SCU is the preferred N source for rice soils having a high percolation rate and that USG is a poor alternative to split applications of prilled urea.

Urea, the major N carrier for rice, is now known to be subject to intensive losses after broadcast application. Innovation of modified urea fertilisers for lowland rice is one approach to solving this problem. Urea briquettes or supergranules (1–3 g size) placed at an 8–10 cm depth are known to minimise N losses due to ammonia volatilisation and denitrification [2]. However, the performance of supergranules has not been consistent. For

[1] Present address: Australian Centre for International Agricultural Research, P O Box 1571, Canberra, A.C.T., Australia.

Fertilizer Research 8: 137–146 (1985)

instance, data from 226 experiments showed that supergranules were significantly inferior to conventionally split application of prilled urea at eight sites [3]. Loss mechanisms other than NH_3 volatilisation were, perhaps, operative at these sites. Vlek et al. [8] from greenhouse work that, in soils with a percolation rate exceeding 5 mm day^{-1}, extensive leaching losses drastically reduced fertiliser N uptake from supergranules.

The aim of this study was to determine the causes of differential efficiency of split applications of prilled urea, urea supergranules (USG), and sulphur-coated urea (SCU) for lowland rice. The efficiency of these fertilisers was evaluated in the field, and N loss mechanisms were investigated either in field microplots or in the laboratory. The highly percolating soil on which these studies were conducted represents an area of 0.5 million ha in the Punjab State of India.

Materials and methods

The stuides were carried out on a Fatephur loamy sand (Typic Ustipsamment) having an average percolation rate of 109 mm/day. Some characteristics of the soil are given in Table 1.

Table 1. Some properties of the soil at the experimental site

Depth (cm)	pH[a]	CEC[b] meq 100 g^{-1}	Total N[c] %	Organic carbon[d], %	Sand[e] %	Clay[e] %
0–15	7.7	7.2	0.034	0.21	91	7
15–30	7.7	8.6	0.030	0.17	86	9
30–50	7.6	12.6	0.028	0.15	83	12
50–70	7.8	13.3	0.026	0.12	83	13

[a] At soil:water ratio of 1:2
[b] Sodium saturation method [6]
[c] Modified Kjeldahl method [6]
[d] Walkley and Black [11]
[e] Sand and clay particles are 0.02 and 0.002 mm, respectively.

Experiment 1: Comparative efficiency of split urea, USG, and SCU

In field experiments at the same site in consecutive years, prilled urea was applied in two splits: the SCU (37% N, 7-day dissolution rate 21%) and the USG (1 g) were applied in single doses at rates of 29, 58, and 116 kg N ha^{-1}. Two-thirds of the prilled urea application and the entire application of SCU were broadcast and incorporated into the puddled soil before transplanting. The remaining one-third of the prilled urea was broadcast without incorporation at panicle initiation. The supergranules of urea were placed 1 week after transplanting at a depth of 7–8 cm in the pattern depicted in Figure 1a. The treatments, each replicated four times, were completely randomised. Before the last cultivation, every plot received a uniform application of P (50 kg P_2O_5 ha^{-1}), K (50 kg K_2O ha^{-1}) and Zn (10 kg Zn ha^{-1}) through superphosphate, muriate of potash, and zinc sulphate, respectively. Forty-day-old seedlings of PR 106, an improved rice variety, were transplatned at a spacing of 20 × 20 cm. Apart from the irrigation required for puddling the soil before transplanting, the soil was irrigated to a depth of approximately 50 mm daily for the first 30 days after transplanting and on alternate days thereafter. The water had completely infiltrated the soil within 8–10 hours after each irrigation. The crops were harvested at maturity, and the grain yield was measured.

Experiment 2: Effect of leaching on N losses

Steel oil drums (200 litre capacity) were cut in half and used as microplots (60 cm ID × 44 cm). In 30 of the microplots, the bottom was removed, and in the other 30 it was kept intact. To establish the microplots, the soil was removed in three layers (12-cm thick with a 60-cm diameter); it was then packed into the drums layer by layer. The bottomless microplots, in which leaching occurred freely, simulated field conditions and were designated as leached (L) treatments. In the other drums the bottoms were lined with a polyethylene sheet before the soil was packed into them; these microplots were designed to prevent leaching and were designated as not leached (NL) treatments. The N response of rice to split urea, SCU and USG at 65, 130, and 195 kg N ha^{-1} was compared in leached and not leached microplots. Except for the supergranules placement, the fertilisers were applied in the same way as described for the field experiment. The supergranules were placed at four points as depicted in Figure 1b.

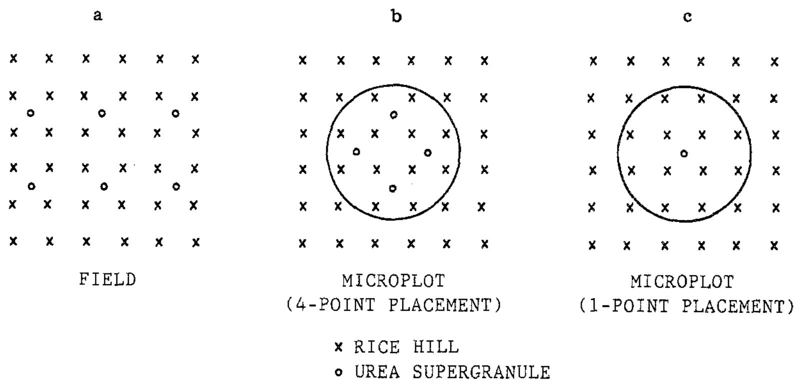

Figure 1. Placement pattern of urea supergranules in the field microplots.

The treatmentments were replicated three times and arranged in a split-plot design with leached (L type) and not leached (NL type) as the main plots and sources at different rates and the control (no N) as subplots. Each microplot was planted with 12 hills of 45-day-old seedlings of PR 106 at a spacing of 15 cm × 15 cm. Two border rows of rice were planted around the microplots.

Regardless of leaching treatment, standing water was maintained to a depth of approximately 50 mm at the time of each irrigation. To maintain standing water for at least 10 hours, it was necessary to irrigate the leached microplots daily. Correspondingly, the NL microplots needed irrigation every third day. Overall, 2.8 times more water was applied to the L microplots than to the NL microplots.

At maturity, the 12 hills from each microplot were harvested. Grain and straw yields were determined on an oven-dry basis. The plant samples were finely ground and seperately analysed for total N by the Kjeldahl method.

Floodwater analysis. The irrigation water had a pH of 7.7, a titratable alkalinity of 4.2 meq l^{-1}, and an NH_4-N content of 0.4 ppm. Floodwater samples were collected from the microplots treated with 130 kg N ha^{-1} at 13:00 h on 0, 1, 2, and 3 days after fertiliser application. Further sampling was disrupted by heavy rains.

Within 2 hours after the collection, floodwater samples were filtered through Whatman No. 1 filter paper and analysed for pH, alkalinity (by titration with 0.01 N H_2SO_4 to pH 4.65), and NH_4-N (by steam distillation with MgO according to Bremner and Edwards [1]).

Experiment 3. Efficiency of USG as influenced by placement pattern

An experiment was conducted to determine whether the different placement patterns of USG used in the main field experiment and that in the microplots contributed to variation in the USG efficiency. In one treatment, USG was concentrated at the centre of the microplots (Figure 1c). This placement pattern was similar to that used in the main field (Figure 1a), in which four hills surrounded each USG. For the other treatment USG was palced as in Experiment 2 (Figure 1b). Fertiliser rates and other details followed in this study were similar to those of Experiment 2.

Experiment 4: Fertiliser N loss through leaching

This experiment was conducted using fallow soil in porcelain pots (20 cm ID × 22 cm) fitted on the side near the bottom with leaching outlets (5 cm ID × 25 cm) made of glass tubing. The opening of the glass tube inside the pot was covered with glass wool. On the other end of the glass tubing, a polyethylene tube was fixed. Six kilograms of soil from the 0 to 15 cm layer (site of Experiment 1) was placed in each pot to a depth of approximately 15 cm. Water was applied, and the soil was puddled to a depth of 7–8 cm. Pots were then leached with 150–200 mm of water, and the leaching rate was adjusted by a screw-type pinch clamp fixed on the tubing so that 50 mm of water leached through the soil in 9–10 hours. This rate was chosen to simulate the rate of water infiltration in the field.

Irrespective of the source, each pot received 460 mg of N. Prilled urea and SCU were evenly broadcast on the surface and incorporated with a spatula to a depth of about 5 cm. In the case of USG treatments, one supergranule (1-g size) was placed at a depth of 5 cm in the centre of the pot. Water equivalent to 50 mm was added to each pot every day. Leachates were collected daily, and the volume was measured; then the leachates were analysed for urea-N [4] and NH_4-N [1].

Results and discussion

Comparitive efficiency of different N fertilisers

The yield response to applied N in the field (Experiment 1) was very marked in both years (Table 2). Grain yields from split urea, USG, and SCU treatments differed significantly and consistently in both years. At all rates of application, USG produced the least grain, and SCU yielded the most. The yields of the USG treatments were about 20% less than those of the split applications of urea. On the other hand, SCU produced about 25% more grain than did the split application of urea. Thus, USG was a poor alternative to split applications of urea for lowland rice grown on this light-textured, highly percolating soil. This result is in marked contrast to the superior performance of USG over split applications often reported previously [2, 5, 3].

In the field microplots (Experiment 2) the modified urea materials – SCU and USG – produced significantly more rice than did the split urea application in both leached and nonleached series (Table 3). Preventing leaching increased the mean yield from SCU by 31 g/microplot and that from the USG by 53 g/microplot. In contrast, the mean yield from microplot receiving split urea was reduced by 34 g/microplot when leaching was prevented. This reduction is even more marked when the data for mean grain yield response (treatment yield-control yield) of the leached split urea treatment – 131 g/microplot – is compared with that from the corresponding nonleached treatment – 86 g/microplot. The variation in grain yield shown in Table 3 is closely matched by the effects of the treatments on N uptake by the crop (Table 4). This suggests that the prevention of leaching affected crop yield primarily by reducing the leaching losses of applied N, particularly in the case of USG.

Table 2. Effects of split urea, SCU, and USG on the grain yield (ton ha^{-1}) of rice during two consecutive years

Source	N application rates in 1980 (kg N ha^{-1})				N application rates in 1981 (kg N ha^{-1})			
	29	58	116	Mean	29	58	116	Mean
Split urea	3.9	5.5	7.0	5.5	2.9	3.8	5.5	4.1
SCU	5.7	7.7	9.0	7.5	3.7	5.0	7.0	5.2
USG	3.5	3.5	5.8	4.3	2.6	2.9	4.5	3.3
Control (No N)				3.4				2.0

Least significant differences at 5% probability level for comparing sources at same N level were 0.9 ton ha^{-1} in 1980 and 0.6 ton ha^{-1} in 1981.

Table 3. Rice response (g/12 hills) to a different nitrogen applications in leached and unleached field microplots

	Leached N application rate (kg N ha^{-1})				Not leached N application rate (kg N ha^{-1})			
Fertiliser	65	130	195	Mean[a]	65	130	195	Mean[a]
Split urea	135	196	246	192b	130	168	176	158b
SCU	178	230	254	221c	184	265	307	252c
USG	148	230	285	221c	216	265	340	274c
Control (No N)				72a				61a

[a]Mean values with a common letter (a, b, or c) within a column are not different at P = 0.05. The least significant difference (P = 0.05) for comparing individual fertiliser means as affected by leaching is 30 g/microplot.

Table 4. Effect of leaching on nitrogen uptake by rice in microplots (g N/12 hills) from different urea materials. Data in parentheses are apparent N recovery, i.e.,

$$\frac{\text{N uptake by fertilized plants} - \text{N uptake by control}}{\text{N applied}} \times 100$$

	Leached N application rate (kg N ha^{-1})				Not leached N application rate (kg N ha^{-1})			
Fertiliser	65	130	195	Mean[a]	65	130	195	Mean[a]
Split urea	2.09 (74)	3.58 (74)	4.58 (66)	3.42b	1.94 (60)	2.64 (47)	3.31 (44)	2.63b
SCU	2.19 (77)	3.51 (72)	4.30 (62)	3.33b	2.25 (73)	3.60 (73)	5.08 (76)	3.64c
USG	1.90 (67)	3.38 (68)	3.87 (54)	3.05b	2.57 (90)	3.50 (70)	5.41 (82)	3.83c
Control				0.88b				0.91a

[a]Mean values with a common letter (a, b, or c) within a column are not different at P = 0.05. The least significant difference (P = 0.05) for comparing indiviudal fertiliser means as affected by leaching is 0.71 g/microplot.

Split urea was inferior to the modified urea sources under both leached and nonleached conditions in the microplots, whereas in the adjoining field plots split urea far excelled the USG (Table 2). This inconsistency may be related to the different patterns of USG placement in the two experiments. In the microplots, the roots of the four central rice hills could contact and adsorb fertiliser-N from two urea supergranules (Figure 1b), whereas in the field plots each hill could contact directly only one supergranules (Figure 1a). The effect of the placement pattern on the rice growth was therefore investigated in a further microplot study in which one-point (Figure 1c) and four-point (Figure 1b) placements of USG were compared (Experiment 3). The data on grain yield and N uptake show that four-point placement was superior to one-point placement (Table 5). In this microplot experiment, a split application of 130 kg N ha^{-1} as prilled urea produced more rice grain

Table 5. Effect of USG placement pattern on grain yield and N uptake by rice in microplots

USG	Leached				Not leached			
	N application rate (kg N ha^{-1})				N application rate (kg N ha^{-1})			
Placement	65	130	195	Mean[a]	65	130	195	Mean[a]
				Grain yield (g/microplot)				
1 point	62	141	155	119a	132	166	176	158a
4 points	79	161	179	140b	159	194	213	189b
				N-uptake (g N/microplot)				
1 point	0.92	1.97	2.58	1.82a	1.70	2.77	3.26	2.58a
4 points	1.10	2.55	3.11	2.25b	2.02	3.13	3.88	3.01b

Grain yield for broadcast and incorporated prilled urea at 130 kg N ha^{-1} was 159 g/microplot (leaching allowed) and 134 g/microplot (leaching prevented).

[a]Mean values in the same column with a common letter (a or b) are not significantly different (P = 0.05).

than did one-point placement of supergranules, a result which agrees with that of the conventional field experiment. One-point placement of USG in drained microplots therefore appears to simulate large plot-field conditions better than does the four-point pattern used in Experiment 2. The apparently anomalous superiority of USG over split urea in the leached microplots of Experiment 2 was probably caused by the high density of USG placement in the microplots.

Nitrogen loss mechanisms

As mentioned above, the low efficiency of USG under leached conditions suggests that N losses due to leaching were extensive. In contrast, the reduced efficiency of broadcast and incorporated prilled urea when leaching was prevented indicates that some other loss mechanism such as ammonia volatilisation was operating. These loss mechanisms were investigated further by measuring the concentration of urea-N and NH_4-N in the leachates in laboratory columns and by studying the kinetics of ammonia in the floodwater of field microplots.

The results of Experiment 4 show that a substantial proportion of the USG-N could be recovered in the leachates as urea within 2 days after application (Figure 2). In contrast, the urea and NH_4-N contents of the leachates from the SCU treatment were negligible. In the case of prilled urea, the leaching loss of urea was intermediate between those of SCU and USG, which agrees with the results of Vlek et al [8]. Because of the low CEC and light texture of the experimental soil, a significant amount of N was also lost by leaching as NH_4-N. The fact that slightly more NH_4-N was lost from prilled urea than from USG or SCU (Figure 2) suggests that the broadcast

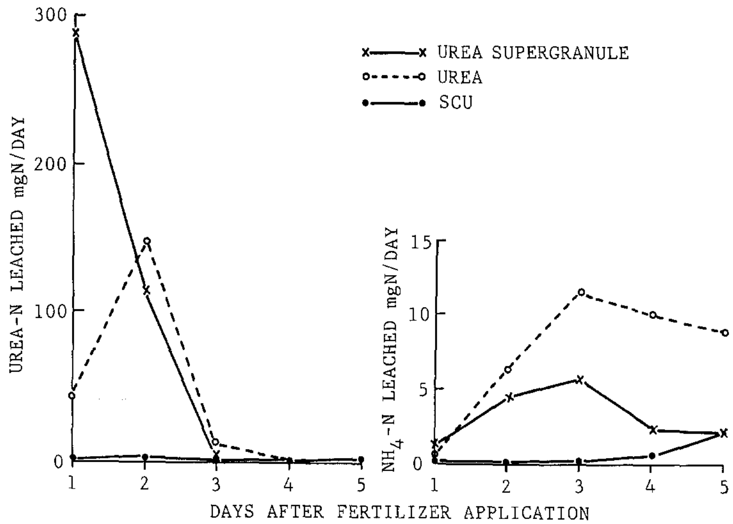

Figure 2. Leaching losses of urea and NH_4-N from uncropped pots.

prilled urea was hydrolysed more quickly than the USG or SCU was. Mahli and Nyborg [7] have shown that USG is hydrolysed more slowly than is broadcast urea under upland soil conditions. The small volume of soil and the high concentration of urea at USG placement site probably retarded hydrolysis and made the USG more vulnerable to leaching losses than was the broadcast prilled urea. Hydrolysis to the less mobile and more strongly adsorbed NH_4-N form would have reduced the USG leaching losses. These findings confirm the results reported by Vlek et al [8].

The substantial reduction in the efficiency of prilled urea (Table 3) when leaching was prevented indicates that ammonia volatilisation may have been occurring. Applied urea is liable to volatilisation from the floodwater if the total ammoniacal nitrogen, pH, alkalinity, and temperature are high [9, 10]. The results in Table 6 show that a high concentration of ammoniacal N occurred only in those microplots where leaching was prevented and in which prilled urea was the source of nitrogen. Since the floodwater temperature was high (37°–40°), the floodwater was alkaline, and the pH was high, the potential for ammonia losses was very high in these nonleached urea treatments. This would explain the decrease in the efficiency of prilled urea when leaching was prevented in Experiment 2.

The advantage of USG in curbing the ammonia volatilisation losses is evident from the data in Table 6. The concentration of NH_4-N in the floodwater even from nonleached microplots was severalfold lower than in the prilled urea-treated microplots. These data explain the improved efficiency of USG-N split urea-N when leaching was prevented (Table 3).

Table 6. Alkalinity, pH, and NH_4-N concentration in the floodwater of leached (L) and unleached (NL) microplots

	Days after transplanting					
	pH	Alkalinity (meq l^{-1})	NH_4-N (mg l^{-1})			
Fertiliser	1	1	0	1	2	3
Urea-L	8.0	4.2	3	3	1	1
Urea-NL	8.9	4.3	2	21	30	40
SCU-L	8.9	4.2	2	2	1	1
SCU-NL	9.0	2.7	3	3	2	1
USG-L (4-point)	9.0	4.1	1	2	1	1
USG-NL (4-point)	9.0	2.5	1	2	1	1
Control-L	8.7	4.2	1	4	0	1
Control-NL	9.0	2.3	2	1	0	1

Conclusions

These results show that on a light-textured soil with a high percolation rate the efficiency of different N sources for lowland rice depends upon their susceptibility to leaching losses. Urea supergranules are particularly prone to such losses and their use should be discouraged. Although the deep-point placement appears inadequate under these conditions, our data show that slow-release fertilisers such as SCU minimise N losses and are very effective agronomically. An economically viable slow-release fertiliser would be an excellent source of N for wetland rice grown on permeable soils. Frequent split applications of prilled urea would be an efficient alternative in areas with cheap labour.

Acknowledgments

We thank ICAR (New Delhi, India) and IFDC (Muscle Shoals, Alabama, USA) for financial support, and PAU, Ludhiana (Punjab, India) for providing the necessary facilities for field experiments. We also appreciate the input of Dr P.L.G. Vlek, IFDC, in the planning of this research.

References

1. Bremner JM and Edwards AP (1965) Determination and isotope ratio analysis of different forms of nitrogen in soil: I. Apparatus and procedure for distillation and determination of ammonium. Soil Sci Soc Amer Proc 29, 504–507
2. Craswell ET and Vlek PLG (1979) Greenhouse evaluation of nitrogen fertilisers for rice. Soil Sci Soc Amer J 43, 1184–1188
3. Craswell ET and Vlek PLG (1982) Nitrogen management for submerged rice soils. 12th Intern Congr Soil Sci 11, 158–181
4. Douglas LA and Bremner JM (1970) Extraction and colorimetric determinations of urea in soils. Soil Sci Soc Am Proc 34, 859–862

5. International Rice Research Institute (IRRI) (1979) Preliminary report on the first and second trial on nitrogen fertiliser efficiency in rice (1978/79), IRRI, Los Banos, Philippines
6. Jackson ML (1967) Soil chemical analysis. Prentice-Hall of India, Ltd., New Delhi, India
7. Mahli SS and Nyborg M (1979) Rate of hydrolysis as influenced by thiourea and pellet size. Plant Soil 51, 177–186
8. Vlek PLG, Byrnes BH and Craswell ET (1980) Effect of urea placement on leaching losses of nitrogen from flooded rice soils. Plant Soil 54, 441–449
9. Vlek, PLG and Craswell ET (1979) Effect of nitrogen source and management of ammonia volatilisation losses from flood rice soil systems. Soil Sci Soc Am J 43, 352–358
10. Vlek PLG and Stumpe JM (1978) Effects of solution chemistry and environmental conditions on ammonia volatilisation losses from aqueous systems. Soil Sci Soc Am J 42, 416–421
11. Walkley A and Black IA (1934) An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Sci 37, 29–38