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Technique for Deep Placement of Coated Urea Fertilizer in Soybean Cultivation

Yoshihiko TAKAHASHI*[1] and Takuji OHYAMA*[2]

*[1] Niigata Agricultural Research Institute, Crop Research Center
(Nagakura, Nagaoka, Niigata, 940-0826 Japan)
*[2] Department of Applied Biological Chemistry, Niigata University
(Ikarashi, Niigata, 950-2102 Japan)

Abstract

The objective of this study was to increase the productivity of soybean seeds by the application of controlled release nitrogen fertilizers (coated urea). Based on the results obtained in field experiments carried out for 3 years (1989-1991), deep placement of coated urea consistently enabled to increase the seed yield by about 10-20% over the conventional treatment. Deep placement of coated urea did not depress the N_2 fixation activity throughout the growth stages until maturity, though N from fertilizer was actively absorbed. The basal deep placement of coated urea for soybean cultivation enabled to supply N from the lower part of roots without concomitant depression of N_2 fixation, and consequently seed yield increased. High recovery rate (over 60%) of fertilizer N was also advantageous from economical viewpoints.

Discipline: Soils, fertilizers and plant nutrition/Crop production
Additional key words: N2 fixation, ureide, root growth, Rb uptake

Introduction

Soybean is the most important leguminous grain crop used by human beings and livestock as food or feed, respectively, worldwide. In Japan there are many traditional soybean products, such as 'tofu', 'miso', soy sauce, 'natto' (fermented soybean), etc. Soybean seeds are useful materials for the food industry, because they are very rich in oil and protein with a good nutritive value.

Soybean plants require a continuous supply of a large amount of N for maximum seed yield, and N is generally derived from 3 sources under field conditions; from symbiotic N_2 fixation by root nodules, from N absorbed from soil mineralized N and from fertilizer. In spite of the high demand for N, a large supply of N fertilizer markedly depresses nodule development and N_2 fixation activity, resulting in the reduction of the seed yield.

In Niigata Prefecture, about 80% of the soybean plants are cultivated in upland fields converted from drained rice paddy fields. The fields consist mostly of clayey Gray soil, and adverse soil conditions such as poor water drainage lead to a low average soybean seed yield of 1.3 Mg ha^{-1}. On the other hand, the contribution of N_2 fixation is estimated to be relatively high in soybean plants cultivated in drained paddy fields in Niigata, and about 60–80% of total accumulated N in shoot originates from fixed N_2.

In the present studies, a new technique consisting of deep placement of coated urea fertilizer has been developed to obtain high yield, efficient fertilizer utilization, and high N_2 fixation activity[6,8-14].

Materials and methods

1) Cultivation

Soybean [*Glycine max* (L.) Merr. cv. Enrei] plants were grown in an upland field converted from a drained paddy field of Niigata Agricultural Experiment Station. Seeds were sown on May 31–June 4, in 1989–1991. The seeds were stripe-sown at a density of 8.9 seeds m^{-2} (15×75 cm) by single stem training. Cultivation method was applied according to the guidebook for soybean cultivation published by Niigata Prefecture. Main operation sequence was as follows: fertilization→tillage; harrowing→herbicide application

→seeding-intertillage; earthing up (late in June ~early in July). Agricultural chemicals were spread 2 or 3 times to control the insect pests.

The terminology of the reproductive stages followed that reported by Fehr and Caviness[1]. Corresponding description with the stage numbers was as follows: R1; beginning of bloom, R3; beginning of pod development, R5; beginning seed of development, R7; beginning of maturity, R8; full maturity.

2) Field conditions

The experimental field had been converted from a paddy field in the previous year. The soil was a fine-textured Gray Lowland soil. Chemical properties of the soil were as follows: texture; clay loam, pH (H_2O); 7.1, CEC (cmol(+)kg^{-1}); 31.3, total carbon content (10^{-2} kg kg^{-1}); 1.0, total nitrogen content (10^{-2} kg kg^{-1}); 0.11, C/N; 9.1, amount of mineralized N determined by the incubation of air-dried soil under upland conditions for 4 weeks at 30°C (10^{-7} kg kg^{-1}); 4.8.

3) Fertilizer application

Fertilizer application is outlined in Table 1. Three treatments were designed as follows: (a) control; basal dressing of ammonium sulfate (16 kg N ha^{-1}), (b) deep placement; basal dressing of ammonium sulfate (16 kg N ha^{-1}) and deep placement of coated urea, 100-day type (100 kg N ha^{-1}), (c) top dressing; basal dressing of ammonium sulfate (16 kg N ha^{-1}) and top dressing of coated urea,70-day type (100 kg N ha^{-1}). In addition, phosphorus and potassium fertilizers were supplied as basal dressing for all the experimental plots (60 kg P_2O_5 ha^{-1}, 80 kg K_2O ha^{-1}), respectively. Each treatment was triplicated in randomized plots.

Two types of coated urea fertilizer were supplied by Chisso-Asahi Co., Ltd., namely the 100-day type of coated urea was used for the deep placement and 70-day type of coated urea for the top dressing treatment, which require 100 days and 70 days to release 80% of N by incubation in water at 25°C, respectively.

The deep placement of coated urea was carried out using the fertilizer injector (Fig. 1a) devised by Shioya (1985)[7] or a fertilization machine (Fig. 1b) produced by Niigata Agric. Exp. Stn. on an experimental basis in 1991. Fertilizers were injected just under the seed-placement lines at a 20 cm depth along the ridges. Top dressing of 70-day type coated urea was carried out just before the flowering stage. In the control treatment, N 16 kg ha^{-1} $(NH_4)_2SO_4$ was supplied as basal application.

Effect of deep placement

The accumulation of dry matter and total N content in shoot were always the highest in the plants with the deep placement treatment at R7 stage (Table 2). On the other hand, in the top dressing treatment, the amount of N accumulated from the R3 to R7 stages was lower than in the deep placement treatment (Table 2). Consequently, the seed yield in the deep placement was 4.17–5.92 Mg ha^{-1}, surpassing that in the control (3.73–4.80 Mg ha^{-1}) and the top dressing (3.59–5.32 Mg ha^{-1}) treatments (Table 3).

The promotive effect of seed yield by the deep placement was analyzed from the characters in the shoots at the R8 stage. Since the number of pods per node of the plants with deep placement

Table 1. Fertilizer application treatments

Treatment	Basal application[a)]			Top dressing		
	Type of N fertilizer	Applied N (kg ha^{-1})	Placement depth (cm)	Type of N fertilizer	Applied N (kg ha^{-1})	Placement depth (cm)
Control	$(NH_4)_2SO_4$	16	0–13			
Deep placement	$(NH_4)_2SO_4$ Coated urea[b)]	16 100	0–13 20			
Top dressing	$(NH_4)_2SO_4$	16	0–13	Coated urea[c)]	100	2–5

a): Fused magnesium phosphate (60 kg P_2O_5 ha^{-1}) and potassium chloride (80 kg K_2O ha^{-1}) fertilizers were used for basal application in all the experimental plots.
b): 100-day type of coated urea which releases 80% of the N in water at 25°C in 100 days.
c): 70-day type of coated urea which releases 80% of the N in water at 25°C in 70 days.

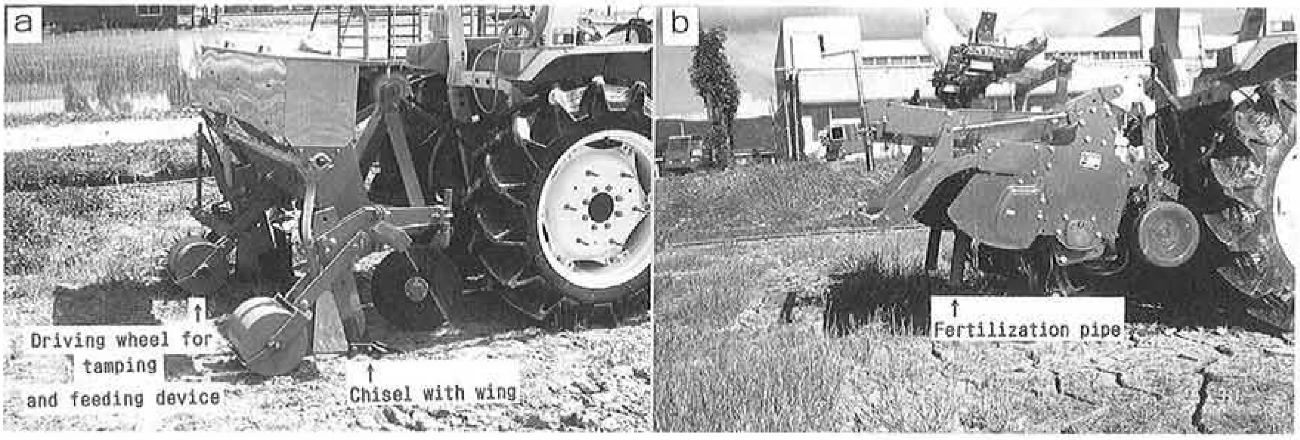

Fig. 1. Fertilizer injector (a) and fertilization machine (b) used
Fertilizer injector was used in 1989–1990.
Fertilization machine was used in 1991.

Table 2. Dry matter production and N accumulation in shoot of soybean plant

Experiment year	Treatment	Dry weight of shoot (Mg ha^{-1})		N accumulation in shoot (g m^{-2})	
		R3	R7	R3	R7
1989	Control	3.16 a	7.40 a	8.33 a	23.56 a
	Deep placement	3.68 a	9.57 b	9.69 a	31.35 b
	Top dressing[1)]	3.94	7.56	10.83	24.45
1990	Control	3.12 a	9.13 a	9.31 a	34.77 a
	Deep placement	3.83 a	10.98 c	11.69 b	42.59 b
	Top dressing	3.21 a	9.85 b	9.88 ab	38.47 ab
1991	Control	2.14 a	6.58 a	5.30 a	24.77 a
	Deep placement	2.29 a	9.11 b	6.30 a	33.33 b

Within a column, means followed by the same letter are not significantly different by 5% level LSD test.
1): These data were considerably different in each block, and thus omitted for statistical calculation.

Table 3. Seed yield and yield components

Experiment year	Treatment	Seed yield (Mg ha^{-1})	Yield components			
			No. of pods (m^{-2})	No. of seeds per pod	No. of seeds (m^{-2})	100-seed weight (g)
1989	Control	3.73 a	523 a	2.06 a	1,080 a	34.6 a
	Deep placement	4.24 b	571 a	2.04 a	1,163 b	36.4 b
	Top dressing	3.59 a	509 a	2.01 a	1,023 a	35.0 a
1990	Control	4.80 a	766 a	1.86 a	1,423 a	33.8 a
	Deep placement	5.92 c	928 b	1.89 ab	1,752 b	33.8 a
	Top dressing	5.32 b	836 ab	1.91 b	1,597 ab	33.8 a
1991	Control	3.79 a	596 a	1.91 a	1,101 a	34.5 a
	Deep placement	4.17 b	631 b	1.89 a	1,193 a	34.9 a

Within a column, means followed by tye same letter are not significantly different by 5% level LSD test.

Table 4. Characteristics of shoots of soybean plants at R8 stage

Experiment year	Treatment	Main stem length (cm)	No. of nodes in main stem	No. of first branches	Stem diameter (mm)	No. of total nodes (m^{-2})	No. of pods per node
1989	Control	56 a	13.8 a	4.5 a	9.3 a	315 a	1.66 a
	Deep placement	56 a	13.7 a	4.9 a	9.1 a	334 a	1.71 a
	Top dressing	55 a	13.5 a	4.7 a	8.9 a	321 a	1.60 a
1990	Control	53 a	13.5 a	6.5 a	9.4 a	442 a	1.83 a
	Deep placement	53 a	13.8 a	7.0 a	10.0 a	451 a	2.06 b
	Top dressing	53 a	13.6 a	6.5 a	9.7 a	425 a	1.97 b
1991	Control	47 a	12.4 a	4.5 a	9.3 a	281 a	2.05 a
	Deep placement	51 b	12.4 a	4.8 a	9.7 a	287 a	2.20 b

Within a column, means followed by tye same letter are not significantly different by 5% level LSD test.

was higher than in the control ones, total pod and seed number increased by deep placement (Tables 3, 4).

The average seed size expressed as 100-seed weight shown in Table 3 indicates that the seed size in the deep placement was larger than or the same as that of the control or top dressing treatments. The chemical composition of seed, such as protein, oil, carbohydrates, minerals, etc., was almost similar among the treatments[6]. Therefore, the seed quality was not lower in deep placement of coated urea.

Evaluation of N_2 fixation

A modified relative ureide method has been employed for the estimation of the proportion of plant N derived from N_2 fixation by analyzing the N content of ureides, nitrate, and amino N in xylem sap collected from root bleeding xylem sap[3]. We used the relative abundance of ureide-N (ureide-N/(ureide-N + NO_3-N + amide-N) as an indicator for the relative dependence on N_2 fixation, based on the fact that the major part of fixed N_2 is transported in the form of ureides[4], whereas the transport forms of absorbed N from soil and fertilizer N, were mainly nitrate, amino acids, and amides[5]. We compared the "relative ureide-N method" with the conventional "N-balance method" using nodulating (T202) and non-nodulating (T201) isolines grown in the field, and the results suggested that the relative ureide method is a useful technique for estimating the current ratio of N derived from N_2 fixation versus the total N assimilation[9].

By using the relative ureide method we obtained the following results (Fig. 2). Top dressing treatment depressed the N_2 fixation activity during the maturation stage (R5–R7) and the N absorption rate was higher than that of the control plants. On the other hand, deep placement of coated urea did not depress the N_2 fixation activity throughout the growth stages until maturity, although active

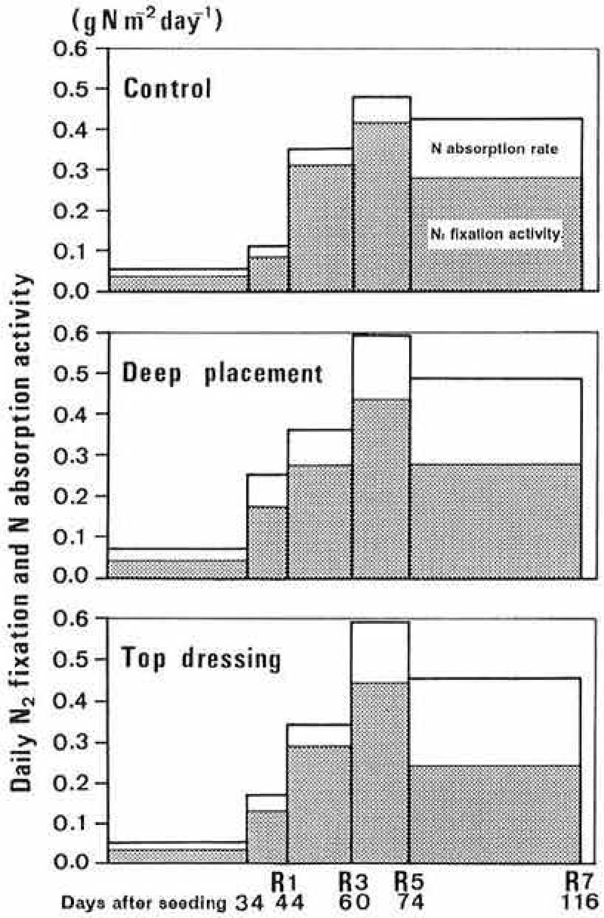

Fig. 2. Daily N_2 fixation activity and N absorption rate (from soil + fertilizer) depending on the plant stages and treatments

Table 5. Fertilizer-N recovery rates in the plant shoot

Experiment year	Treatment	R3 stage		R7 stage	
		Absorbed N ($g\ m^{-2}$)	Recovery rate (%)	Absorbed N ($g\ m^{-2}$)	Recovery rate (%)
1989	Control[a]	0.05	3.1	0.15	9.4
	Deep placement[b]	2.10	21.0	4.75	47.5
	Top dressing[c]	0.63	6.3	2.56	25.6
1990	Control[a]	0.13	8.3	0.15	9.2
	Deep placement[b]	1.23	12.3	6.24	62.4
	Top dressing[c]	0.22	2.2	3.26	32.6

a): ^{15}N-$(NH_4)_2SO_4$. b): ^{15}N-Coated urea 100-day type. c): ^{15}N-Coated urea 70-day type.

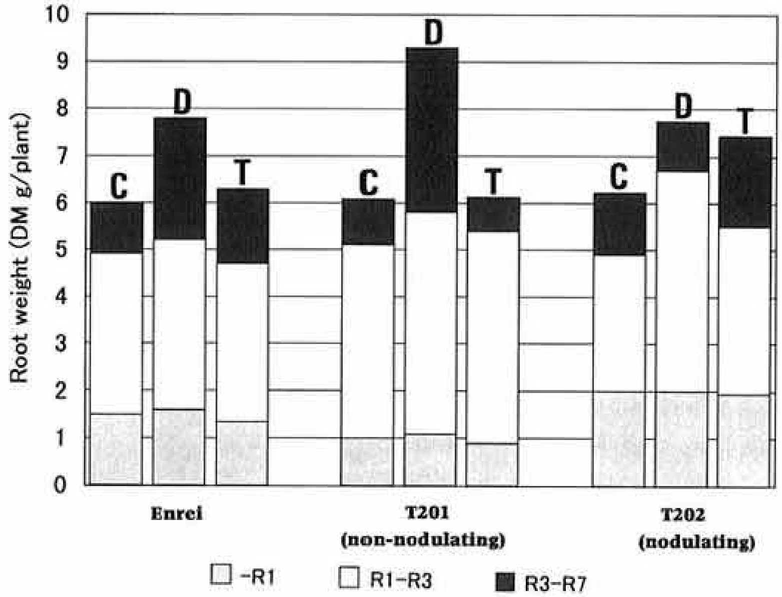

Fig. 3. Amount of roots depending on the plant stages, cultivars, and treatments
C: Control. D: Deep placement. T: Top dressing.

N absorption from fertilizer was confirmed by the ^{15}N tracer experiments. The N recovery rate in the plants with deep placement of coated urea was about 62%, a value much higher than that of the plants with top dressing of coated urea (33%) at the R7 stage (Table 5).

Root growth and activity

The effects of placement of coated urea fertilizer on the root growth and activity were investigated by measuring the root dry weight and Rubidium (Rb) absorption activity (Figs. 3, 4). Alternatively ^{32}P and Eu tracer have been used to study the root activity. However these methods are expensive and require a special equipment for analysis.

Recently Rb has been used in field studies as a convenient tracer and some reports were published[2]. We employed the Rb tracer method to measure the moisture uptake activity and the root density.

The results shown in Fig. 3 suggested that the deep placement of coated urea promotes the growth of roots, especially during the reproductive stages (R1–R7). Also top dressing treatment slightly enhanced the root growth.

When Rb was injected at a 10 cm depth in soil, the total amount of Rb accumulated in the plants was larger in the sequence of control<deep placement<top dressing. On the other hand, the amount of Rb accumulated from an area at a

25 cm depth was always the largest in every variety subjected to deep placement of coated urea followed by the top dressing treatment. Consequently, it was considered that deep placement of coated urea exerts a beneficial effect on the growth of soybean plants, where the extended roots are able to absorb moisture from deeper areas and drought can be avoided. Moreover, it is possible that deep placement of coated urea does not exert a harmful effect on nodule development especially those located near the surface layer.

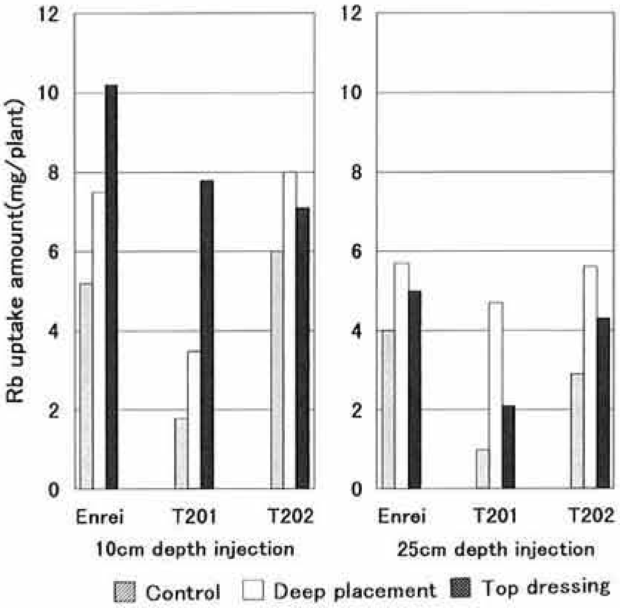

Fig. 4. Amount of Rb uptake depending on the cultivars, treatments, and depth of Rb injection

Behavior of fertilizer-N in soil

The behavior of fertilizer-N in soil was investigated in order to analyze the effect of deep placement of coated urea. At the same time, the deep placement technique was evaluated to prevent groundwater pollution by NO_3^- originating from fertilizer-N.

Theoretically, more than half of the amount of N should be released from deep placement of coated urea during the first half of the growth period in soybean plants (Fig. 5). Fertilizer-N was mainly absorbed during the latter half of the growth period as revealed by the ^{15}N tracer experiment (Table 5). The time lag of the absorption was due to ammonium adsorption and accumulation in soil released from fertilizer N[14] (data not shown). Although the eluted urea was rapidly hydrolyzed to ammonia by urease activity in soil, the NH_4^+-N could not be easily nitrified owing to the low activity of nitrification in the deep layers of soil (Fig. 6). And the adsorbed NH_4^+-N on the negative electric charge of clayey soil was absorbed effectively by the roots in deep layers. As a result, soybean plants could absorb N during the maturation stage when soybean required a large

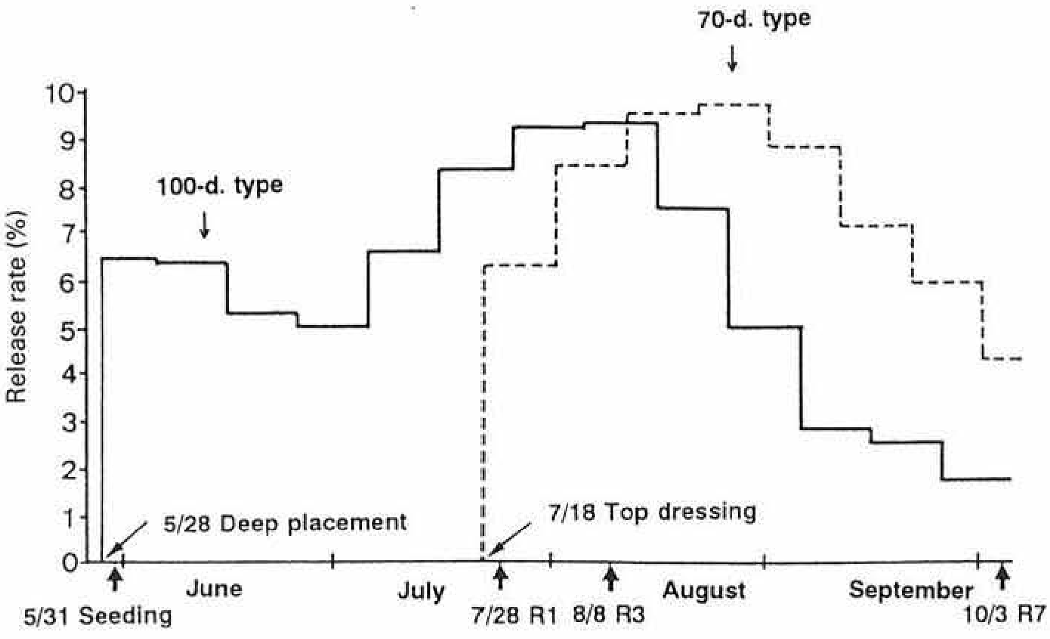

Fig. 5. Theoretical N releasing pattern from coated urea (pattern based on soil temperature in 1990)

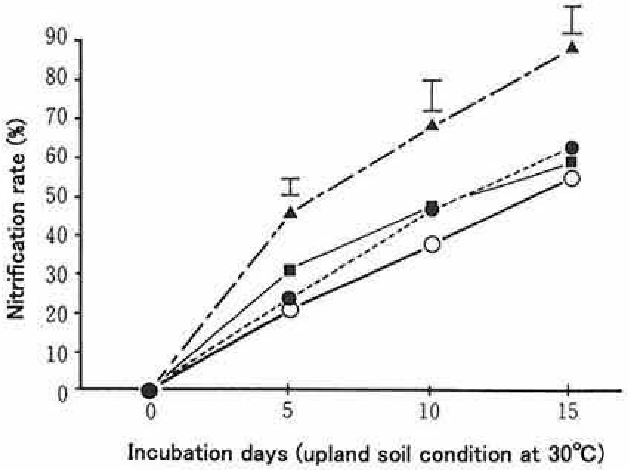

Fig. 6. Nitrification activity of soil depending on the sampling time and soil depth
○: 5/22 0~10 cm depth. ●: 5/22 15~25 cm depth. ▲: 7/9 0~10 cm depth. ■: 7/9 15~25 cm depth. Bars indicate LSD at 5% level.

amount of N for seed production. Then, the absorbed N contributed effectively to the increase of soybean yield.

When the 70-day type of coated urea was applied in surface layers, the fertilizer-N was easily converted to NO_3^--N due to the high activity of nitrification in the surface soil, and eluviated from the rhizosphere soil in the NO_3^- form[8] (data not shown).

Several advantages of deep placement of coated urea include the high recovery rate of fertilizer-N by crop plants and prevention of groundwater pollution originating from fertilizer-N.

Application in farmer's field

The deep placement technique was applied in a farmer's field. In 1993 soybean plants sustained damage from extremely cold weather and wet injury. However the seed yield in the case of deep placement of coated urea increased by 22% over that in the conventional treatment. As a result, due to deep placement of coated urea, the farmer's income increased by 43% compared with conventional fertilization. The increased income associated with a higher seed yield compensated for the cost of coated urea and fertilization machine.

Conclusion

Deep placement of coated urea with whole layer basal dressing of ammonium sulfate enabled to increase the soybean seed yield by about 10–20% over that by the conventional whole layer basal dressing of ammonium sulfate. The promotive effect of deep placement on seed yield was due to the lack of depression of N_2 fixation throughout the growth stages, and to the active absorption of fertilizer-N. The N recovery rate in the plants with deep placement of coated urea was about 62%, a value much higher than that of the plants with top dressing (33%) at the R7 stage. We confirmed that the deep placement of coated urea exerted a beneficial effect on the growth of deeper roots based on the Rb tracer experiment. Although the urea released from coated urea was rapidly hydrolyzed to ammonia, NH_4^+-N could not be easily nitrified owing to the low activity of nitrification in the deep soil layers. As a result, soybean plants could absorb the N during the maturation stage when soybean requires a large amount of N for seed production.

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