Soil Management and Nitrogen Fertilization for Increasing Soybean Yield

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As the returns of soybean cultivation are low in spite of the multifold utility of the crop, the study on soybean cultivation for increasing the yield per unit land area had received limited attention and is less advanced in Asian countries. Recently, in view of the anticipated shortages of agricultural commodities in the future, increasing the yield of soybean and making it stable become to be recognized as an important problem.

Soybean is one of the crops which require a large amount of nitrogen to produce a unit yield[5]. And it has been recognized that the nodule bacteria symbiotic with soybean provide sufficient nitrogen to meet its requirements from the atmosphere[2]. The amount of nitrogen fixed by nodule bacteria under the general condition of soybean cultivation, however, may be estimated at less than 100 kg/ha[1,3,5], which is no more than that corresponding to less than 1.3 t/ha of the yield of soybean. So, the author thought that there may be the way to increase the yield up to an economic level through the use of nitrogen fertilizer and organic nitrogen materials like compost.

Accordingly, studies were conducted to pursue the use of nitrogen fertilizer for soybean cultivation with the financial support from AVRDC at Tainan, Taiwan, during a period from 1973 to 1976. In this paper, results of these studies will be presented[4,5].

Inoculation and nitrogen fertilization[5]

To compare the effects of nitrogen fertilization on nodule formation and growth of soybean with that of inoculation of Rhizobium, an experiment was conducted in wooden box using three soils differing in microorganism population and available nitrogen content. Experimental materials and methods are roughly described as footnotes of Table 1.

As shown in Table 1, under the w/o I condition (without inoculation), nitrogen fertilization (w.N) remarkably reduced the number of nodules only in Soil A where microorganism and available nitrogen were at a high level. But, in other soils, especially in Soil C which was poor in them, the nitrogen fertilization accelerated the formation of nodules and pods to a marked extent. On the other hand, under the w.I condition (with inoculation), nitrogen fertilization had little effect on the number of nodules in Soil A and B. Furthermore, it was observed that the inoculation makes the size of nodule small and nitrogen makes it large, especially in soil C. Nitrogen fertilization increased the dry matter production and the pod number of soybean in all soils used, and inoculation was effective in that respect only in soil C.

These phenomena may suggest that nitrogen supply at a certain level is important to increase not only the yield but also the development of nodules. Furthermore, maintaining the population of Rhizobium in a soil at a high level, nitrogen seems not always to retard the formation and the developemnt of nodules. Besides, in a soil like soil C, inoculation of Rhizobium seems to be effective for accelerating the growth of soybean even under the w.N condition, though its effect is considerably small in comparison with that of

Table 1. Effects of inoculation and nitrogen fertilization on the number of nodules and the growth of soybean in different soils[a] (per box)

Treatments[c]	Soil A[b]			Soil B[b]			Soil C[b]		
	D. W. (g)	Nod. (No.)	Pods (No.)	D. W. (g)	Nod. (No.)	Pods (No.)	D. W. (g)	Nod. (No.)	Pods (No.)
w/o N, w/o I	73	125	205	50	66	121	21	19	55
w/o N, w. I	84	139	197	44	84	101	46	136	83
w. N, w/o I	97	59	233	73	104	185	76	193	116
w. N, w. I	107	152	223	82	96	211	93	429	140

a) Cultivar, Shih-Shih, was planted to different soils in wooden boxes (3 cm depth) at May 8 and harvested at Aug. 13.

b) Soil A: Surface soil treated with rice straw compost (3 : 1 v/v), high soil microorganism population (10^{12}) and high available N. Soil B: Surface soil, middle soil organism (10^{6}) and low available N. Soil C: Sobsoil (below 50 cm depth), low soil microorganism (10^{3}), trace available N.

c) I: Inoculum, 25 mg/12 kg fresh soil/box. Nitragin Soybean Inoculate ("S" Culture) by Nitragin Co., Milwaukee, Wis. 53209, was mixed thoroughly with fresh soil before planting.
N: Ammonium phosphate, 600 mgN/12 kg fresh soil/box, was applied two times at 12 days after germination and at the flowering initiation, respectively.
D. W.: Dry weight of plant, Nod.: Nodule

nitrogen fertilization. In such a soil, nitrogen fertilization with inoculation may be an effective means accelerating the growth of soybean in practice.

Application level of nitrogen and absorption of nitrogen

To know the relation between the level of nitrogen applied to soybean and the amount of nitrogen absorbed by it, a pot experiment was conducted using nitrogen fertilizer labelled with ^{15}N.

As shown in Fig. 1, when nitrogen was applied at the levels lower than 50 ppm, absorption of nitrogen derived from soil and N_2 markedly decreased, but accumulation of nitrogen in the plant was hardly affected by nitrogen application, because the plant absorbed nitrogen derived from fertilizer to a great extent. This phenomenon suggests that, particularly when Rhizobium population is comparatively low, nitrogen must be supplied at a considerably high level to accelerate the nitrogen accumulation in soybean plants.

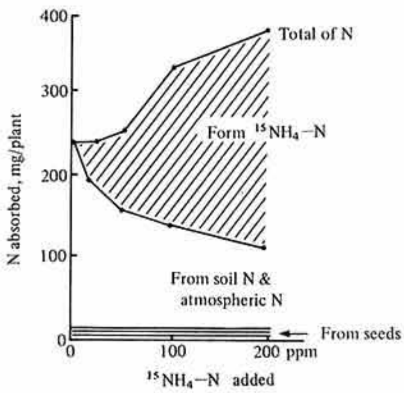


Fig. 1. Effect of application level of nitrogen on nitrogen accumulation in soybean plant at vegetative stage[a]

a) Cultivar, Shih-Shih, was grown in a pot containning 10 kg of fresh soil, clay loam, treated with ammonium sulphate labelled with ^{15}N, for 40 days.

Inferiority of NH_4–N

A solution culture experiment was conducted in green house to investigate the effects of NH_4– and NO_3–N and nitrogen supply intensity on the growth of soybean. Experimental materials and methods are roughly described as footnotes of Table 2.

When soybean was grown in the culture solution with HN_4–N, the ammonium toxicity symptom appeared even on the soybean treated

Table 2. Effects of nitrogen sources on the yield and yield components of soybean in culture solution[a)]

Treatments	Pods per pl.	Seed No. per pod	100-seed (g)	Seeds (g/pot)	N absorbed (g/pot)
No N	4.3	1.05	5.0	0.9	0.2
NH_4-N					
5 ppm	11.8	1.70	11.0	8.8	0.9
10	15.5	1.86	9.1	10.2	1.2
15	20.3	1.80	14.8	21.6	2.3
30	21.8	1.80	18.1	28.2	1.9
50	17.8	1.77	14.4	18.1	2.9
NO_3-N					
15 ppm	27.0	1.83	12.9	25.5	2.3
30	46.0	1.83	15.7	52.8	5.5
50	57.5	1.85	19.2	81.6	6.2
100	53.0	1.77	20.1	75.7	5.8
150	49.3	1.86	21.0	76.7	5.9

[a)] Composition of nutrient solution: CaO 110 ppm, MgO 10 ppm, K_2O 110 ppm, P_2O_5 70 ppm, Fe 35 ppm Mn 0.3 ppm, B 0.06 ppm, Zn 0.09 ppm, Cu 0.009 ppm. Four plants (Cultivar. Shih-Shih), 2 weeks old, were grown in plastic container with 11 litre solution. The pH of the solution was adjusted to 6.0 every morning. The solution was renewed every 4 days at the early stage and every other day later. pl.: Plant, No N: Mineral nitrogen was not supplied.

with 5 ppm N at the young stage. The NO_3-N did not retard the growth of soybean even if supplied at 150 ppm. The optimum concentration of NH_4- and NO_3-N in a culture solution for the yield was 30 ppm (seed wt.: 28 g/pot) and higher than 50 ppm (seed wt.: 82 g/pot), respectively. The NO_3-N was more profitable as nitrogen source for soybean. Especially, pod formation was greatly retarded by NH_4-N, compared with NO_3-N. The number of seeds per pod was little affected by nitrogen sources and the supply intensity, though it was only 1.1 per pod in the plot treated without nitrogen. The 100-seed weight was affected, especially, by supply intensity of nitrogen. The higher the nitrogen supply intensity, the heavier the 100-seed weight, when soybean was grown comparatively healthily.

Total nitrogen concentration of leaves and hulls was higher in NH_4-plant than in NO_3-plant and the accumulation amount of nitrogen in NO_3-plant was more than two times as large as that in NH_4-plant at the harvest time. The nitrogen required to produce 1 g seed was larger in NH_4-plant (106 mg N) than in NO_3-plant (83 mg N).

These phenomena suggest that though nitrogen must be supplied at a considerably high level to increase nitrogen absorption by soybean, NH_4-N supply at a high level must be averted. To make nitrification in a soil active may be important in practice.

Relative importance of nitrogen at different growth stages[5)]

A pot experiment was conducted in green house to find the relative importance or the functions of nitrogen when applied at different growth stages of soybean. Experimental materials and methods are roughly described as footnotes of Table 3.

The results shown in Table 3 suggest that a considerable amount of nitrogen applied at any stages can be absorbed by soybean, and a possibility that the activity of Rhizobium, nitrogen fixing, is promoted by the application of nitrogen at an initial growth stage.

Nitrogen applied at an initial growth stage increased mainly the number of pods per plant.

Table 3. Effects of nitrogen application timing on the yield and yield components of soybean in pot culture[a]

(Oven dry basis)

Treatment[b]	D. W.	Seeds wt. (g/pl.)	Pods no. (/pl.)	Seeds no. (/pod.)	100-seed wt. (g)	T-N in top (mg/pl.)	T-N (mg) / Seed (g)
000	17	6.2	24	1.79	14.5	381	61
010	21	8.2	35	1.82	12.9	449	55
020	22	9.4	42	1.72	13.0	587	62
100	32	10.3	32	1.97	16.5	642	62
120	29	12.2	45	1.70	15.9	756	62
121	31	14.2	45	1.86	17.1	920	65
130	26	12.7	49	1.74	15.0	785	62
131	31	14.2	54	1.65	16.0	933	66
200	27	10.6	41	1.79	14.5	658	62
210	27	11.3	45	1.63	15.5	680	60
220	28	13.0	49	1.67	15.7	796	61
230	27	12.5	52	1.62	14.7	835	67

a) Cultivar, Shih-Shih, was planted in pot containning 6 kg soil treated with P_2O_5 and K_2O on Apr. 30 and harvested on July 29.

b) Nitrogen fertilizer, ammonium sulphate, was applied at the initial growth stage, May 9 (first column), the flowering initiation stage, May 30 (second column), and the pod formation stage, June 14 (third column). Application amount of N is denoted as 0, 1, 2 and 3 which represent 0, 150, 300 and 450 mg N/pot, respectively.

When applied at the flowering initiation, it increased the number of pods per plant and the 100-seed weight. Then, the nitrogen applied at the pod formation stage increased only 100-seed weight. Furthermore, nitrogen accelerated the translocation of nitrogen into seeds and when applied at later stages, it raised the N% of seeds.

These phenomena clearly show that nitrogen absorbed at different growth stages of soybean gives different effects on yield components.

Importance of nitrogen at the later growing stage[5]

A solution culture experiment was conducted to confirm the importance of nitrogen supply at the later growing stage. Experimental materials and methods are roughly described as footnotes of Fig. 2.

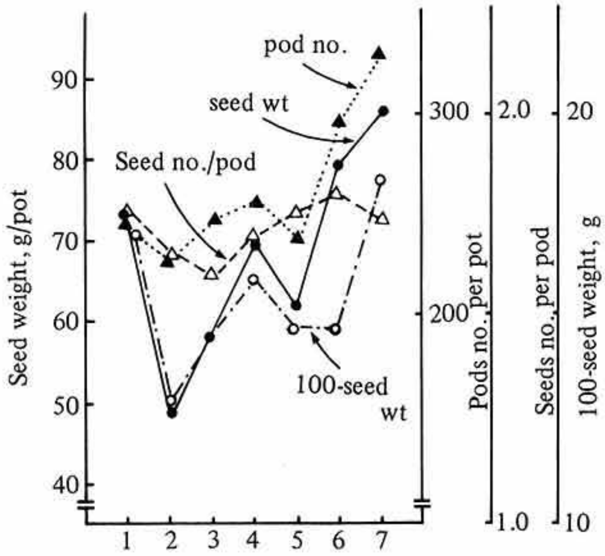
The results shown in Fig. 2 suggest that the supply of nitrogen after flowering initiation is important to increased pod number and 100-seed weight for obtaining high yield.

Demonstration of the response of soybean to nitrogen fertilization in field[4]

To demonstrate soybean plants showing a positive response to nitrogen fertilization, field experiments were conducted in the spring and the summer. Experimental materials and methods are roughly described as footnotes of Table 4.

The pod number per plant increased as a result of nitrogen application, especially when applied at the flowering initiation stage, in both plots treated with or without compost. And the effect was more remarkable in the summer than in the spring. Furthermore, compost application was very effective for increasing the pod number both in the spring and in the summer.

The effect of nitrogen application on the



Expt. plot	Date of treatment[a]	Growth stage	Duration of treatment
1	May 30—June 6	Vegetative	7 days
2	June 10—June 20	Flowering initiation	10
3	June 20—July 1	Flowering	11
4	July 1—July 11	Pod formation	10
5	July 11—July 26	Pod filling (I)	15
6	July 26—Aug. 5	Pod filling (II)	10
7	Control[b]		

[a] During these period, soybean (cultivar. Shih-Shih) was not supplied with mineral nitrogen.

[b] Mineral nitrogen was supplied from the initial to the last stage (NO_3—N, 100 ppm).

Fig. 2. Effect of nitrogen depletion at diflerent growth stages on yield and yield components of soybean.

100-seed weight was noticeable in the plots without compost, but not significant in the plots with compost in the spring. In the summer, it was effective in the plots with compost as well. Particularly, nitrogen applied at the flowering initiation stage was effective. Compost application was also very effective in that respect in all cases in the spring. However, in the summer, it was effective only when nitrogen was applied at the vegetative and the flowering initiation stages.

The highest yield was observed in the plot where compost had been applied successively, and nitrogen fertilizer was added at the initial stage, the vegetative stage and the flowering initiation stage both in the spring and the summer. However, nitrogen applied at the vegetative stage, 2 weeks before the flowering initiation, seemed to be not effective for the yield in the plots without compost in the spring and the summer. In the spring, it was not effective in the plot with compost, too.

Conclusion

From these results mentioned above, it may be recognized that when nitrogen fertilizer is applied at the initial growth stage and after

Table 4. Response of soybean to nitrogen fertilizer and compost in field experiment[a)]

Treatment[c)]	Without compost			With Compost[b)]		
	Pod no. (/pl.)	100-seed (g)	Yield (t/ha)	Pod no. (/pl.)	100-seed (g)	Yield (t/ha)
	Spring soybean (Feb. 15-May 5)					
0- 0- 0	29.9	15.2	2.03	36.7	17.0	2.74
30- 0- 0	33.8	16.0	2.60	38.2	17.4	3.16
30-30- 0	31.3	16.1	2.54	39.7	17.0	2.98
50-50- 0	31.3	16.1	2.31	44.1	17.4	3.74
30-30-30	36.4	17.2	2.59	47.3	17.6	3.92
	Summer soybean (July 4-Sept. 24)					
0- 0- 0	46.2	13.1	1.75	56.0	12.8	2.07
30- 0- 0	58.9	13.7	2.21	87.4	13.5	2.76
30-30- 0	49.5	12.4	1.78	78.6	14.2	3.09
50-20-30	66.0	14.6	2.54	99.9	15.1	3.81
30-30-30	58.3	13.9	2.22	94.8	15.1	3.48

a) Planting density was 270,000 plants per ha in spring soybean and 150,000 plants per ha in summer soybean (Cul. Shih-Shih). Plants were sprayed 2 times with Dithane (×400) and Diostop (×1000) at vegetative growth stage and 1 time with parathion (×800) at flowering stage. Ammonium sulphate was applied on the surface in the center of the rows and superphosphate (P_2O_5 80 kg/ha) and murate of potash (K_2O 150 kg/ha) were applied in the center of the rows to about 20 cm in depth prior to sowing.

b) This field had been successively treated with about 30 t/ha rice straw compost 3 and 4 times previously in spring and summer soybean, respectively. And just before sowing of each season, 30 t/ha of rice straw compost was applied anew.

c) N kg/ha applied at the initial growth stage, vegetative growth stage and the flowering initiation stage is shown in the first, second and third columns respectively.

the flowering initiation at a reasonable level, nitrogen absorption by soybean is increased and the yield is increased. In order to increase nitrogen absorption by soybean, the roots must be kept healthy. Well matured compost is a good nitrogen source and at the same time, when it is applied successively, it is a good material to make the environmental condition more favourable for the roots of soybean. Water management and insect, disease and weed controls must be carried out in an appropriate way to keep the roots healthy. Using a pertinent variety may also be important to get a good response of soybean to nitrogen fertilization.

Furthermore, creating soils which can supply nitrogen constantly at a considerably high level during the whole growing period, especially, at the later growing stage of soybean, may be important, and maintaining the population of nodule bacteria and the activity of nitrification in a soil at a high level may also be unavoidable to get the yield of soybean at the economic level.

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