The Joint Effect of Nitrogen Fertilizer and Organic Matter Application on Soybean Yields in Warm Regions of Japan

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Introduction

The majority of nitrogen absorbed by soybean plants is nitrogen fixed in root nodules. Therefore, from the technological standpoint of crop management, the soybean crop has an advantage of saving nitrogen fertilizer, but it has a disadvantage of low response to nitrogen fertilizer, and hence difficulty in getting increased yields. This characteristic of soybean makes it difficult to break through the stagnant yield level of soybean.

Soybean requires a large amount of nitrogen. Therefore, to get markedly increased yields, it is necessary to make soybean plants absorb a large amount of nitrogen. However, the cultural method depending merely upon root nodules, which has been employed so far, has limitations. It seems that the increased nitrogenous fertility of soil, and positive application of nitrogen fertilizer are the essential factors for high-yielding production of soybean.

In recent years, as a countermeasure of rice overproduction, the cultivation of upland crops, especially soybean, on dry fields converted from paddy fields is recommended. As the country-average of soybean yields is very low (171 kg dry seeds/10 a in 1985)[5], the remarkable yield-increase is strongly desired.

In view of such a situation, the author studied the method of nitrogen fertilizer application for increasing yields and the effectiveness of successive application of a large amount of organic matter to increase soil fertility under the condition of a warm region of Japan.

Experimental method

The experimental field was selected from the area where the successive rice cropping had been continued. After the conversion to the dry field, soybean and wheat have been grown as a summer crop and a winter crop, respectively. The experimental field is well-drained, because it has under-drains at the depth of 80 cm at intervals of 4 m.

The soil offered to the experiment belongs to marine alluvium, fine textured Gray Lowland soil. The properties of plow layer are as follows: soil texture is LiC, pH(H_2O) 6.7, content of total carbon 1.05%, that of total nitrogen 0.099% and CEC 11.7 me.

The soybean variety used was Tamahomare, a typical variety in the Kinki-Chugoku region. It was sown in late June at the planting density of 70 cm inter-rows, and 20 cm inter hills with two plants/hill (i.e. 14,300 plants/10 a) and harvested in early November. Flowering occurred on about August 5, as in usual years.

As organic matter, 800 kg of wheat straw or 5 t of compost was applied per 10 a every year. Basal dressing of nitrogen was made at the rate of 2 or 4 kg/10 a, and top dressing of nitrogen (5 or 10 kg/10 a) at the flowering stage. P_2O_5 and K_2O were applied as basal dressing at the rate of 10 kg/10 a. The experimental design is shown in Table 1.

Table 1. Experimental design

Method of nitrogen application[a)]	No organic matter applied		0.8 t of wheat straw[b)] applied		5 t of compost[c)] applied	
	Basal dressing	Top dressing	Basal dressing	Top dressing	Basal dressing	Top dressing
No nitrogen	0	0	0	0	0	0
Basal dressing 2 kg	2	0	2	0	2	0
Basal dressing 4 kg	4	0	4	0	4	0
Top dressing 5 kg	0	5	0	5	0	5
Top dressing 10 kg	0	10	0	10	0	10

a): The values are expressed in terms of kg per 10 a. Nitrogen was applied in the form ammonium sulfate. 10 kg of P_2O_5 in the form of super phosphate and K_2O in the form of potassium chloride were applied as basal dressing to all the plots in the experimental field. Top dressing was done at the beginning of the flowering stage.

b): The straw was applied in June every year.

c): Rice straw compost with 60% moisture content was applied in June every year.

Experimental results

1) *Effect of application of nitrogen and organic matter on plant growth and root nodule formation*

Table 2 shows the weight of top and root nodules at the pod-setting stage and seed-thickening stage.

The observation over the whole growth period indicated the followings. In the plot without organic matter application and the plot with 5 t of organic matter, plants without nitrogen fertilizer applied were smaller than those with nitrogen applied until the seed thickening stage. On the contrary, in the plot with 800 kg of wheat straw the growth difference between plants with and without nitrogen application was observed, but the difference almost disappeared at the seed-thickening stage.

The average of yields for all fertilizer application treatments showed no difference between the plot without organic matter application and the plot with 800 kg of wheat straw, but the plot with 5 t of compost gave the higher value.

In the plot without organic matter application, the weight of root nodules at the pod-setting stage showed that nitrogen application treatments reduced the weight. In the plot with wheat straw application, the weight of root nodules was increased by basal dressing of nitrogen, but reduced by top dressing of nitrogen. In case of 5 t of compost, basal dressing of nitrogen caused no appreciable change in the weight of root nodules, while top dressing of 10 kg of nitrogen reduced the weight.

The weight of root nodules at the seed thickening stage showed a tendency to increase by nitrogen application treatments in the plot without organic matter application, while appreciable effect of nitrogen application was not observed in the plot with organic matter application. The top dressing of 10 kg of N apparently reduced the weight of root nodules in both plots.

The average of weight of root nodules was highest in the plot with wheat straw application followed by the plot without organic matter application, and the plot with 5 t of compost in that order at the pod setting stage. The order of the average at the seed thickening stage was the plot without organic matter > that with wheat straw > that with 5 t of compost.

2) *Effect of nitrogen fertilizer and organic matter application on grain yields*

Regarding the effect on yields, a consistent

Table 2. Weight of top and root nodules during pod setting and seed thickening stage

Organic matter application	Nitrogen application		Weight of top[a)] (kg/10 a)		Weight of root nodules[a)] (kg/10 a)	
	Basal	Top	Pod setting stage	Seed thickening stage	Pod setting stage	Seed thickening stage
None	0	0	319	726	4.85	4.00
	2	0	373	760	3.00	4.45
	4	0	369	831	3.24	4.62
	0	5	381	784	3.33	5.47
	0	10	348	850	2.88	2.44
	Average		358	790	3.52	4.20
Wheat straw	0	0	300	790	4.00	3.90
	2	0	348	767	5.31	—
	4	0	391	802	4.74	4.19
	0	5	400	800	3.85	4.10
	0	10	313	768	3.42	3.56
	Average		350	786	4.27	3.94
Compost	0	0	383	756	2.94	3.55
	2	0	422	843	3.44	3.29
	4	0	397	796	2.67	3.71
	0	5	370	828	1.60	2.49
	0	10	426	833	2.05	1.78
	Average		400	811	2.54	2.96

a) : Values indicated for pod setting stage represent the avarage values for 3 years, while those for seed thickening stage represent the average values for 4 years.

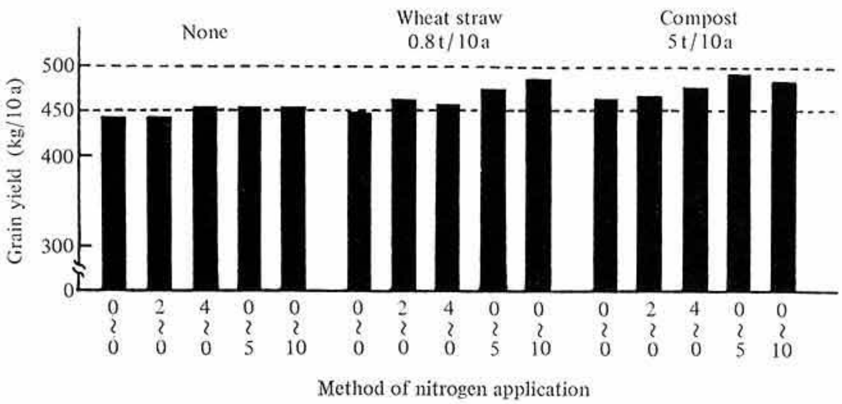

Fig. 1. The effect of nitrogen and organic matter application on soybean yields (average values for 4 years)

tendency was not shown in some years. It was conceived that such variation in yields was caused by yearly differences of climatic conditions, gradual alteration of soil condition due to successive application of organic matter, in addition to the variation associated with the size of plot area and the number of repetition in the experiment. Therefore, in order to decide the effect of each treatment on yields on the long term basis, the average yield for four years was compared (Fig. 1).

In the plot without organic matter application, nitrogen fertilizer application increased grain yields by 2%, irrespective of basal or top dressing, and of the rate of nitrogen application, except 2 kg of nitrogen application. In the plot with wheat straw application, nitrogen basal dressing increased yields by 2–4%, and nitrogen top dressing by 6–8%. Different rates of application resulted in a small yield difference. In the compost plot, yield increase by 1–3%, and 4–6% was obtained by nitrogen basal dressing and nitrogen top dressing, respectively.

As shown above, nitrogen fertilizer application was effective in increasing grain yields, irrespective of with or without organic matter application. However, the rate of yield increase was low, and no difference between basal dressing and top dressing was recognized in the plot without organic matter application. On the contrary, in the straw plot and the compost plot, the rate of yield increase was high, particularly the top dressing made at the flowering stage gave very high rates of yield increase.

As to the kind of organic matter, 5 t of compost gave the highest yield, followed by 800 kg of wheat straw, and the lowest yield was obtained in the plot without organic matter application. Thus it was confirmed that compost is more effective in increasing soybean yields than wheat straw.

Discussion

1) Top weight and grain yields

As shown in Fig. 2, a close positive correlation was found between the weight of top at the maturing stage and grain yields. Sugihara[7] reported that in aiming at high yield of soybean, the most important indicator is the total weight of plants, and when the yield target is 500 kg/10 a, the total weight of plants is needed to reach 1,200 kg. In growing the variety, Tamahomare, in warm regions of Japan, it will be necessary to ensure nearly 850–900 kg/10 a of the total weight of plants (excluding the weight of fallen leaves) at the maturing stage, in order to attain the grain yield target of 500 kg/10 a.

2) Formation of root nodules and grain yields

Many reports[3,4] on the role of root nodules and their importance have already been published, suggesting that the biological nitrogen fixation by root nodules exerts an extremely great effect on growth and yields of soybean.

As already shown above, the application of nitrogen fertilizer and organic matter obviously exerts a great influence to the forma-

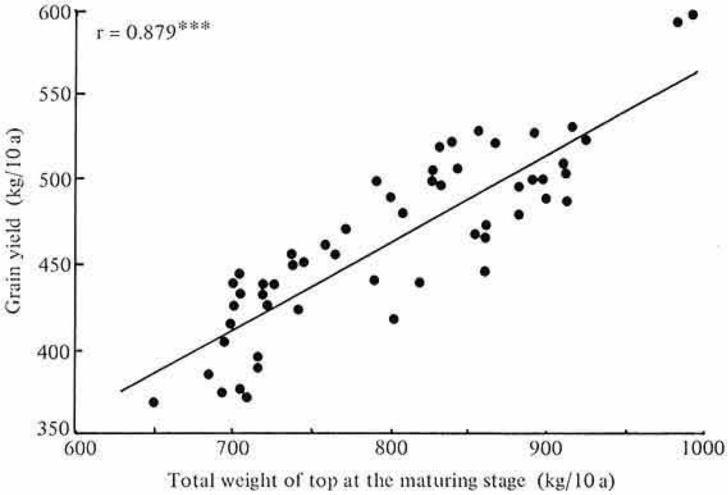

Fig. 2. Relationship between total weight of top and grain yields

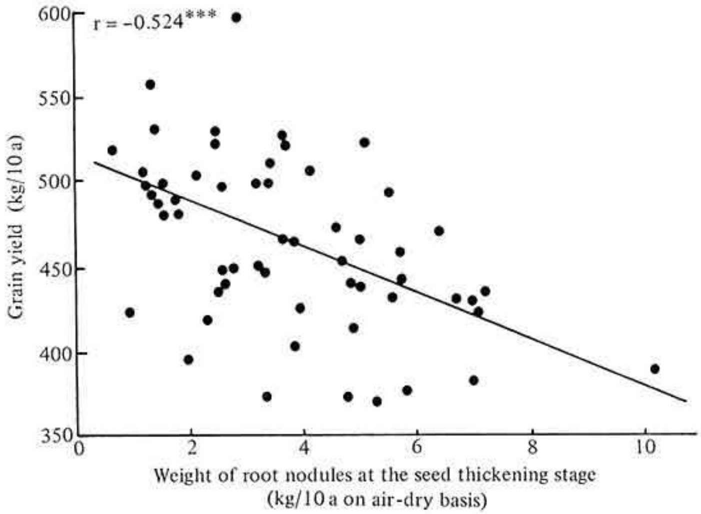

Fig. 3. Relationship between the amount of root nodules and grain yields

tion of root nodules. However, how is the relationship between the amount of root nodules produced and grain yields? Fig. 3 shows a weak negative correlation between them. Namely, it shows a trend of higher yields with less amount of root nodules. This result is seemingly in contradiction to our knowledge so far obtained. The fact that the application of nitrogen fertilizer and a large amount of organic matter was positively adopted in the present study may be the reason for such a result. The analysis of this result, however, suggests that the positive utilization of nitrogen fertilizer and a large amount of organic matter of good quality like compost can serve as a powerful measure to attain high yielding production of soybean even under the condition suppressing root nodule formation.

3) Effectiveness of nitrogen application and significance of organic matter application

Many studies[9,10] have been conducted on the effect of nitrogen fertilizer application to soybean regardless of cold areas or warm areas. Their results show that the effect was diverse according to conditions, such as regions, the number of years of cropping soybean, etc. However, it can be said in general that when environmental conditions, such as climatic and edaphic, are not unfavorable, the effectiveness of nitrogen application can hardly be expected.

The result of the present study indicates that the yield-increasing effect of nitrogen fertilizer is hardly expected under the condition without organic matter application. However, this effect is enhanced by the use of wheat straw or compost. It seems possible to get the yield increase of about 10% by combining nitrogen top dressing at the flowering time with organic matter application. Thus, it may be concluded that the yield-increasing effect of nitrogen application can be manifested in combination with the use of organic matter.

A high positive correlation was recognized between the total amount of nitrogen absorbed by plants and grain yields up to 600 kg/10 a (Fig. 4). It is of vital importance to increase nitrogen uptake of soybean plants for getting high yields.

Hashimoto[1] and Yoshida[8] recognized that the application of organic matter like compost promoted the formation and development of root nodules and enabled the continuance of active function of root nodules. In the present study, application of 5 t (fresh wt.) of

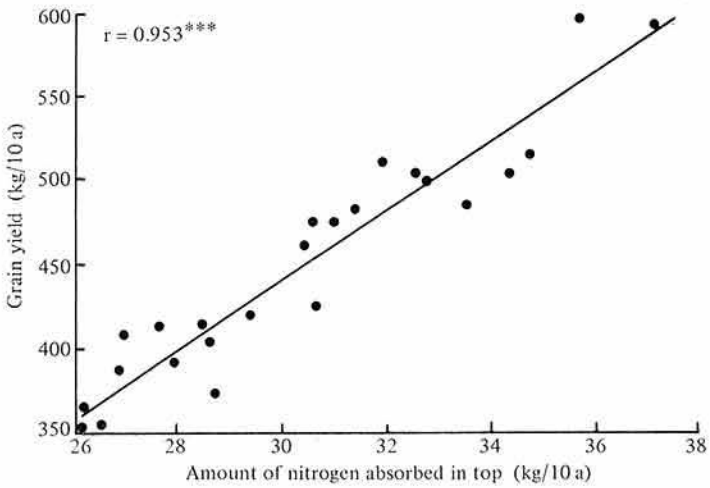

Fig. 4. Relationship between the amount of nitrogen absorbed and grain yields

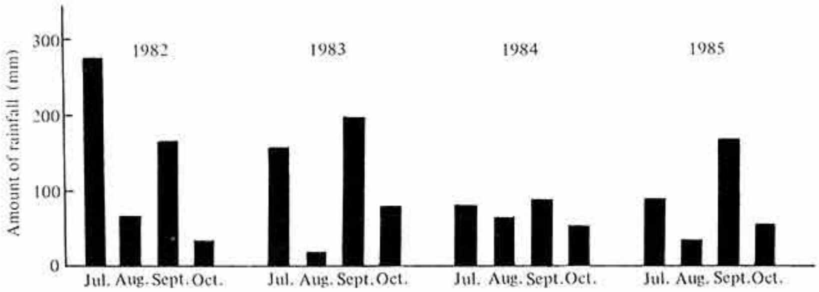

Fig. 5. The amount of rainfall in the seasons of soybean cultivation

compost rather retarded the root nodule formation, nevertheless it improved rhizospheric environment, and, as a result, increased the absorption efficiency of nitrogen. This is conceived as the reason for the yield increase caused by organic matter application.

Recently, the use of compost is decreased due to a labor problem, though the value of compost is recognized. However, compost is considered as a useful measure for high-yielding culture of soybean. Its effectiveness is gradually increased by successive application, and it prevents yield decrease in bad harvest years whereas it gives high yield-increasing effect in good harvest years. It shows many advantages for the stable production of soybean.

4) Soil moisture content and grain yields

Figs. 5 and 6 show rainfalls during the soybean growing seasons in four years of the experiment and yearly changes of grain yields. The third year (1984) after converted from paddy field was a year of low yield. This year was characterized by the least rainfall during the soybean season. Soil moisture at the flowering stage and pod-setting stage is liable to affect the number of pods set. Yield components in this year clearly showed a small number of pods (data omitted). Probably, the reduced pod number due to lack of soil moisture may be the main factor for the yield reduction. In areas or years with lack of soil moisture occurring in summer, water

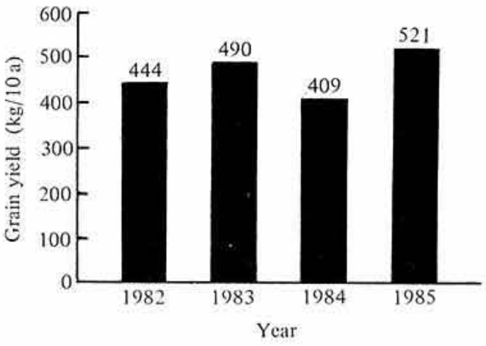

Fig. 6. Yearly variation of soybean yields

supply by furrow irrigation etc. will contribute a great deal to the stable production of soybean.

5) *Effect of organic matter application on soil physical and chemical properties and absorption of soil nitrogen*

Table 3 shows changes in physical and chemical properties of soil caused by successive application of organic matter. The increase of porosity, water-holding capacity, and the total nitrogen content is clearly recognized. Particularly, the effect of compost is remarkable. The amount of soil nitrogen absorbed by plants was measured by using a variety (Lee), which is unable to form root nodules. The result (Table 4) shows that in spite of plenty of available nitrogen in soil, the amount of absorbed nitrogen is small. How to increase the rate of utilization of soil nitrogen by plants is one of the future problems to be investigated.

6) *Characteristics of soybean plants which obtained high yields*

Cases of high yields of soybean so far recorded indicate that the highest yield (the first rank) was 786 kg/10 a, and the yields

Table 3. The effect of organic matter application on physical and chemical properties of soil

Organic matter application	Physical property						Chemical property				
	After 1st harvest			After 3rd harvest			Total nitrogen content[a]				
	Porosity (%)	Moisture content (%)	Bulk density	Porosity (%)	Moisture content (%)	Bulk density	Beginning	After 1st harvest	After 2nd harvest	After 3rd harvest	After 4th harvest
None	56.5	21.1	1.130	51.2	15.9	1.268	0.115	0.126	0.112	0.104	0.106
Wheat straw	55.9	21.7	1.146	52.1	17.6	1.246	0.115	0.120	0.126	0.132	0.132
Compost	58.5	23.2	1.081	55.2	18.4	1.166	0.115	0.160	0.143	0.160	0.157

a) : On oven-dry basis.

Table 4. The effect of organic matter application on the chemical properties of soil and absorption of soil nitrogen by soybean

Organic matter application	Total nitrogen of soil (%)	Available nitrogen of soil (mg/100 g)	The amount of soil nitrogen absorbed by Lee (kg/10 a)
None	0.118	6.02	2.23
Wheat straw	0.123	8.59	3.18
Compost	0.162	10.84	6.48

The amount of nitrogen absorbed by Lee (a variety which does not fix nitrogen, even when it is grown without nitrogen application) was considered to represent the amount of soil nitrogen absorbed by the soybean plant.

Table 5. Yield component of the soybean which gave the highest yield and the amount of nitrogen absorbed

Organic matter application	Nitrogen application (kg/10 a)		Total weight of top (kg/10 a)	Grain yield (kg/10 a)	Number of grains (/m²)	Weight of 100 grains (g)	Number of ripened pods (/m²)	Culm length (cm)	Amount of nitrogen absorbed (kg/10 a)
	Basal	Top							
Compost (5 t/10 a)	0	0	1133	499	1729	28.8	1057	62.4	31.00
	0	5	1308	597	2004	29.8	1200	64.9	35.62
	0	15	1341	594	1973	30.1	1200	60.5	37.06

Total weight of top includes the weight of fallen leaves and petioles at the maturing stage.
The total amount of absorbed nitrogen includes the amount of nitrogen in the fallen leaves and petioles.

down to the 5th rank were all higher than 600 kg/10 a. The common feature is the compost application, and most of them were obtained on the fields converted from paddy fields. In the present experiment too, the high yield of about 600 kg was obtained with compost application in the 4th year after conversion. Some characteristics of those plants which gave the highest yield in the experiment are shown in Table 5. The total top weight was 1,300 kg/10 a, the total number of grains was 2,000/m^2, the weight of 100 grains was 30 g, and the amount of nitrogen absorbed was 36 kg/10 a. The amount of nitrogen required for producing 100 kg of grains was calculated to be 6–7 kg. According to the past cases, about 9 kg of nitrogen is required for producing 100 kg of grains[2]. Therefore, the grain-producing efficiency of absorbed nitrogen is considered to be high.

There are many problems to be solved in future, such as techniques to increase nitrogen absorption, development of varieties with high grain-producing efficiency of absorbed nitrogen, adequate methods of soil moisture management, etc.

Summary

Effects of application of nitrogen fertilizer and of organic matter on soybean growing in dry fields which were converted from paddy fields were examined.

1) When organic matter was not applied, the yield-increasing effect of basal or top dressing of nitrogen could hardly be expected. However, when wheat straw or compost was successively applied, the yield-increasing effect of nitrogen applied by basal or top dressing was markedly increased. Particularly, top dressing of 5–10 kg of nitrogen at the flowering stage caused a high rate of yield increase. It seemed to get the yield increase by about 10%.

2) High positive correlation was observed between grain yields and the total top weight or the total amount of nitrogen absorbed by plants.

3) Application of nitrogen fertilizer and of organic matter influenced root nodule formation. Application of top dressing of 10 kg nitrogen apparently inhibited the root nodule formation, and 5 t/10 a of compost also inhibited root nodule formation.

4) Weak negative correlation was observed between the root nodule formation (expressed in weight of nodules) and grain yields. Although the positive application of nitrogen and organic matter tends to inhibit root nodule formation, it was pointed out that the positive applicable of nitrogen and organic matter could be a powerful measure to attain high yields of soybean grains.

5) Since soil moisture at the flowering stage and pod-setting stage greatly influences grain yields, it was pointed out that the furrow irrigation was useful in preventing the yield decrease when soil moisture was very deficient.

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