High Yield of Soybean and Soil Fertility
— A Case of Seed Yield of 600Kg/10a —

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Soybean is regarded a crop which is difficult to raise yield. Although logics how to increase yield have been known to some extent, it is not easy to materialize them. What is the reason why soybean yield has not shown remarkable increases as shown by rice? In case of rice, increases in the efficiency of solar energy utilization contribute predominantly to the yield increases. However, soybean shows the efficiency as low as only 1/3 of that of rice, due to it's poor light-receiving structure[12]. Namely, the efficiency shows no increase beyond a certain level, even when leaf area is increased by heavy application of fertilizer or by dense planting. This may be a constraint for high yields. Secondly, increases of dry matter production in soybean are not followed by increased yields. In most cases, the maximum yield occurs at a lower level of dry matter production[3], indicating a low rate of distribution of photosynthetic products to seeds. This may be the second constraint.

Tohoku region of Japan is said to be adapted for growing soybean. However, an yield contest, to which each member of our laboratory participated, resulted in a dull result, mostly with about 300 kg/10a of yield, in spite of the fact that each member tried to challenge with his best strategy. This experience has lead us to initiate the study on high-yielding cultivation of soybean in 1979.

Based on the results so far obtained in this study, some problems related to soil fertility and high-yielding of soybean will be discussed in this paper.

Experimental method aiming at high yield

Based on information so far obtained by many researches as well as by surveys of farmers' high-yielding cultivation, it can be said that the basic requirements for high yielding of soybean are (1) promotion of root nodule formation[8], (2) increased soil fertility[7], and (3) appropriate plant growth required for high-yielding[10, 11]. These three aspects were taken into consideration in designing the following experimental method:

1) Promotion of root nodule formation

The role of root nodule is not only to supply nitrogen to plant through biological nitrogen fixation, but also to exert a favourable effect on nitrogen metabolism of plant so as to increase the efficiency of seed protein production (as discussed later). Therefor, the soil condition, whether it is favourable or not for the formation of many root nodules, largely effects the seed production. Factors[8] effecting root nodule formation are (1) rate of nitrogen applicaton, (2) growth amount and growth stage of plant, and (3) soil condition (pH, contents of available phosphorus, organic matter, and bases, and physical properties of soil such as air permeability, soil moisture and temperature, etc.). Therefore, measures specific to a given soil have to be employed. As the soil used in the present experiment is Ando soil (Kuroboku soil), which is poor in phosphorus fertility, 100 kg/10a of fused phosphate (P_2O_5 20%), 4 ton/10a of barnyard manure, and enough quantity of calcium carbonate to adjust pH to 6.5 were applied to improve the soil. In addition, basic dressing of nitrogen was limited to 3 kg/10a with an aim to facilitate root nodule formation.

2) Increase of soil fertility

Soybean is a crop highly dependent on soil fertility, especially on nitrogenous fertility. In the Ando soil, initial growth of soybean is restricted due to phosphorus deficiency, so that heavy application of phosphorus is also effective. Furthermore, as soybean absorbs a substantial amount of phosphorus during the ripening period[2], heavy application of fused phosphate is effective in supplying phosphorus in the later growth period. However, heavy application of phosphorus to the Ando soil of high humus content promotes greatly the mineralizatin of soil nitrogen and tends to induce overgrowth of plants. Therefore, the author considered 100 kg/10a of fused phosphate is optimal. Thus, the fused phosphate has a role of increasing nitrogen supply temporarily by promoting soil nitrogen mineralization[1], and also of supplying additional bases.

It is expected that the organic matter application is effective not only in promoting root nodule formation as mentioned before, but also in supplying nitrogen during the later growth period, when the root nodule activity decreases. The optimal rate of organic matter was shown to be 6–8 ton/10a in the past experiments, in which no fused phosphate was used. But 4 ton/10a of barnyard manure was applied in the present experiment by considering the soil nitrogen mineralization effect of fused phosphate.

3) Optimal vegetative growth for high-yielding

As seed yield is related to vegetative growth per unit land area, it is required to promote vegetative growth by improving plant nutrition for getting high yield. However, the great growth often results in reduced yield due to over-elongation and lodging, depending upon soil and climatic conditions. Therefore, it is necessary to know the optimal growth for high-yielding, and planting density enough to give that growth. Though the optimal growth varies with varieties, plant types, and cultural conditions, leaf area index or stem weight is used as a growth index. The leaf area index for high yielding, i.e. the optimal leaf area index, is about 4–6. When soil fertility is high, it becomes higher, and even in case of the same leaf area index as that in less fertile soils, the productive efficiency of leaves is high, so that higher yield can be expected. The optimal stem weight is regarded to be approximately 200–250 kg/10a in Tohoku region[11]. Greater stem weight than that is said to induce overgrowth with decreased ratio of seeds/stems, and decreased yield.

However, the optimal growth mentioned above is the one which aims at the yield level of 400 kg/10a. This would be insufficient for getting more than 500 kg. As stated above, the optimal growth becomes higher with higher soil fertility, so that it would be possible to raise yield level by improving soil fertility, and denser planting or heavy fertilization. Therefore, in the present experiment, a dense planting at 17,778 plants/10a and a variety, Nanbu-shirome, whic his highly adapted to dense planting (developed in Tohoku National Agricultral Experimental Station) were adopted.

The experimental method discussed above is outlined in Table 1.

High yield attained and yield analysis

1) Seed yield of 600 kg/10a attained

As shown in Table 2, the yield level, as a whole, was high, due to the fused phosphate applied commonly to all plots. In addition, the effects of dense planting and barnyard manure application were apparently recognized. Thus, the average yield as high as nearly 600 kg/10a was obtained in the plots with dense planting +barnyard manure application. The yield

Table 1. Experimental design aiming at high yield

Location	Yield target kg/10a	Variety	Seeding time	Planting density: cm	Planting density: No. of plants per 10a	Fertilizer applied: Barnyard manure (t/10a)	N (kg/10a)	P_2O_5 (kg/10a)	K_2O (kg/10a)	Soil amendment materials	Remarks
Field in Tohoku Nat. Agr. Exp. Sta.	500	Nanbu-shirome	1979 May 24	75×25 75×15 (2 plants/hill)	10, 667 17, 778	4. 0	3	15	10	Fused phosphatic fertilizer: 100 kg/10a $CaCO_3$ to adjust pH to 6. 5	"Kuroboku" soil Exp. plot area: 9. 0 m^2

Table 2. Yields and yield components

	Items	−M S	−M D	+M S	+M D	D/S −M	D/S +M	D/S Average	+M/−M S	+M/−M D	+M/−M Average
	Total top dry weight (kg/10a)	855	1, 026	949	1, 183	120	125	123	111	115	113
	No. of pods/m^2	749	880	829	1, 024	118	124	121	111	116	114
	Stem weight (kg/10a)	227	300	257	335	132	130	131	113	112	113
	Pod weight (kg/10a)	146	168	162	197	115	123	119	111	117	114
	Seed weight (kg/10a)	482	557	530	652	116	123	120	110	117	114
	Seed/stem ratio	2. 1	1. 9	2. 1	1. 9	90	90	90	100	100	100
	No. of seeds/m^2	1, 625	2, 157	2, 023	2, 477	133	122	127	124	115	119
	100-kernel-weight	25. 4	25. 8	26. 1	26. 3	102	101	101	103	102	103
	Seed yield (kg/10a)	466	535	496	599	115	121	118	106	112	109
Per one plant	No. of pods	70	50	78	58	71	74	73	111	116	114
Per one plant	No. of seeds/pod	2. 6	2. 5	2. 5	2. 4	96	96	96	96	96	96
Per one plant	No. of nodes of main stem	15. 3	15. 1	15. 4	15. 2	99	99	99	101	101	101
Per one plant	No. of branches of main stem	5. 9	4. 5	6. 1	4. 7	76	77	77	103	104	104

Note: +M, barnyard manure applied (4 tons/10a) S, sparsely planted
−M, not applied D, densely planted
D/S and +M/−M, ratio in percentage

analysis reveals that the dense planting and barnyard manure application were apparently effective in increasing number of pods produced per unit area, but not on number of seeds per pods and 100-kernel weight. It shows that the factor contributing high yield is the increase of pods per unit area.

2) Vegetative growth in relation to high yield

Fig. 1 shows relationships between total top dry weight (X) at the stage when it reaches the maximum (maximum top weight stage) and No. of pods/m^2 of area at the maximum top weight stage (Y') or that of harvesting time (Y). A linear relationship observed between X and Y' indicates that the greater the vegetative growth the more pods are produced, suggesting a high possibility of high yielding. On the other hand, the relationship between X and Y indicates that the number of pods at the harvesting time was not increased in proportion to the increase of vegetative growth after the number of pods reached the level corresponding to seed yield of 500 kg/10a. From this result, it can be understood that it is not so much difficult to obtain enough number of pods by increasing vegetative growth up to the yield level of 500 kg, but it is not easy to overcome the yield ceiling at 500 kg.

Total top dry weight at the flowering stage

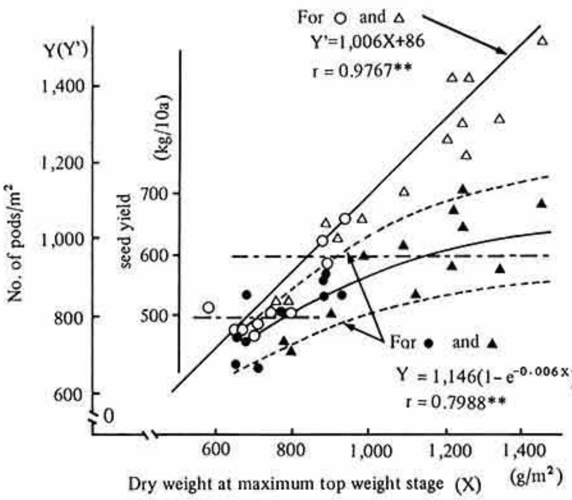

Fig. 1. Relation between total dry weight at the maximum top weight stage and number of pods produced/m².
●S ▲D {No. of pods at harvesting timee
○S △D {No. of pods at maximum top weight stage
S : Sparsely planted, D : Densely planted

also showed a correlation with number of pods at the maximum top weight stage, suggesting that the vegetative growth at the flowering stage determines number of pods at the maximum top weight stage, and hence that of harvesting time. Importance of promoting the early growth is thus demonstrated. The period of 4–5 weeks from the flowering stage to the maximum top weight stage is very important, because during this period plants grow very rapidly by 4 times and vegetative growth as well as reproductive growth proceeds in parallel by a complicated process. Vegetative growth and reproductive growth of soybean are influenced by composition of nitrogenous components of plants[4,5,9], but it is impossible to control freely the concentration of components, which are effective to vegetative growth (such as amino acids) or to reproductive growth (such as allantoin)[6]. Only thing we can do in the field is to promote root nodule formation and increase the quantity of fixed nitrogen which is effective to promote reproductive growth. Quantity of fixed nitrogen is most abundant during the period from the flowering stage to the maximum top weight stage, and the extent of root nodule formation during this period exerts a great influence on seed production. Excellent root nodule formation at the flowering stage is shown in Table 3. Presumably, it might have given very favourable effects on the supply and metabolism of nitrogen in the plants.

Table 3. Root nodule formation

Plot	No. of root nodules/m²	Weight of root nodules (g/m²)	Average weight of root nodules (mg/nodule)
−M. S	2, 834	6. 10	2. 15

Note: Observed at flowering stage (July 25, 1979)

3) *Nutrient contents and absorption*

As shown in Table 4, contents of three nutrients at the flowering stage and the maximum top weight stage were apparently increased by the application of barnyard manure. These contents are close to the standard of nutrition diagnosis of soybean proposed by Ōba et al.[11]. Improved soil fertility and promoted root nodule formation in the present experiment must have caused

Table 4. Content of nutrients in different parts of plant

(a) Flowering stage (July 25)

Nutrient	Leaf				Stem			
	−M		+M		−M		+M	
	S	D	S	D	S	D	S	D
N	5.15	5.17	5.35	5.38	1.59	1.58	1.77	1.61
P	0.35	0.35	0.40	0.38	0.21	0.20	0.25	0.23
K	2.09	2.08	2.27	2.18	3.53	3.49	4.11	4.00
Ca	1.60	1.57	1.52	1.49	1.01	0.99	0.99	0.98
Mg	0.42	0.39	0.43	0.42	0.33	0.34	0.34	0.36

(b) Maximum top weight stage (Aug. 30)

Nutrient	Leaf				Stem				Pod			
	−M		+M		−M		+M		−M		+M	
	S	D	S	D	S	D	S	D	S	D	S	D
N	5.24	5.18	5.42	5.38	1.56	1.56	1.54	1.61	4.32	4.33	4.32	4.25
P	0.31	0.31	0.32	0.32	0.17	0.17	0.21	0.22	0.42	0.43	0.46	0.45
K	1.55	1.59	1.76	1.72	1.66	1.87	2.05	1.88	2.57	2.56	2.72	2.77
Ca	1.91	1.99	1.82	1.85	0.85	0.91	0.79	0.90	0.69	0.66	0.62	0.59
Mg	0.29	0.31	0.30	0.29	0.28	0.30	0.24	0.26	0.34	0.34	0.33	0.33

(c) Harvesting time (Oct. 13)

Nutrient	Seed				Stem				Pod			
	−M		+M		−M		+M		−M		+M	
	S	D	S	D	S	D	S	D	S	D	S	D
N	6.56	6.61	6.53	6.71	0.48	0.46	0.50	0.49	0.82	0.82	0.81	0.81
P	0.61	0.61	0.66	0.64	0.03	0.04	0.04	0.03	0.05	0.05	0.07	0.07
K	1.60	1.60	1.64	1.63	0.61	0.59	0.98	0.87	2.03	2.03	2.66	2.66
Ca	0.26	0.26	0.24	0.24	0.61	0.59	0.54	0.54	0.83	0.83	0.76	0.76
Mg	0.25	0.26	0.27	0.27	0.18	0.17	0.14	0.14	0.51	0.51	0.47	0.47

Notes: +M, −M, S, and D: Same as in Table 2.

a good nutritional condition of plants at those stages, and hence good growth. Soybean is known to absorb nitrogen and phosphorus even during the ripening stage[1,3]. Nitrogen and phosphorus absorbed during the ripening stage accounted for as much as 12–36% and 12–40%, respectively, of the total quantities absorbed, indicating that the nitrogen and phosphorus supply in the later growth stage exerts a great influence on seed development.

Quantities of three nutrients absorbed for yielding 500 kg, were 46.5 kg of N, 9.6 kg of P_2O_5 and 25.7 kg of K_2O, as compared to 24.3, 4.4, and 16.4 kg, respectively, required for yielding 250 kg (in an other field). A great amount of nutrients is needed to get high yield. More fertilization, except nitrogen, is required. Based on the estimation of quantity of nitrogen derived from root nodules and from barnyard manure, it was calculated that the nitrogen derived from root nodules accounts for 24.8 kg/10a, i.e. 53.3% of the total nitrogen absorbed. This value is considerably higher than what it has been regarded so far, suggesting how important is the root nodule activity as a nitrogen source for high yielding.

In conclusion, the experiment aimed at the promotion of root nodule formation and the increase of soil fertility in terms of nitrogen and phosphorus (application of barnyard manure, fused phosphate and calcium carbonate fertilizer) has resulted in the seed yield as high as about 600 kg/10a. By the yield analysis, it was confirmed how important are the soil fertility and root nodule activity for obtaining high yield of soybean. Challenge for stable high yielding of soybean will be continued by analizing more in detail the effect of soil fertility factor and the important role of root nodule activity.

References

1) Hirai, Y.: Inorganic nutrition of soybean plants, 1, Change of inorganic nutrient absorption in growing stage, *Bull. Hokkaido Pref. Agr. Exp. Sta.*, No. 7, 47–57 (1961) [In Japanese].
2) Hirai, Y.: Uptake of different fractions of soil inorganic phosphorous and its significance in phosphate application in soybeans, *Bull. Hokkaido Pref. Agr. Exp. Sta.*, No. 14, 81–89 (1964) [In Japanese].
3) Ishizuka, J.: Studies on nitrogen nutrition of soybean plants. 1. The relation between growth and components of plant materials, *Res. Bull. Hokkaido Nat. Agr. Exp. Sta.*, No. 98, 27–37 (1971) [In Japanese].
4) Ishizuka, J., Okino, F., & Hoshi, S.: Physiological studies on the nutrition of soybean plants. 3. The relation between the contents of nitrogenous components in stems and vegetative growth, *J. Sci. Soil and Manure, Japan*, **41**, (2), 78–82 (1970) [In Japanese].
5) Ishizuka, J.: Nitrogen metabolism of soybean plants, *Agr. and Hort. Japan*, **45**, 1053–1057 (1970) [In Japanese].
6) Ishizuka, J.: Physiological roles of soluble nitrogenous components on vegetative growth and seed protein formation of soybean plants in Hokkaido, *Res. Bull. Hokkaido Nat. Agr. Exp. Sta.*, No. 101, 51–121 (1972) [In Japanese].
7) Konno, T.: A challenge to high yielding of soybean. 3. Effects of nodulation on yield 1, *Nogyo to Kagaku*, No. 1, 2–5 (1980) [In Japanese].
8) Kushizaki, M., Ishizuka, J. & Akamatsu, F.: Physiological studies on the nutrition of soybean. 1. Effect of nodulation on the growth, yield and nitrogen contents of soybean, *J. Sci. Soil and Manure, Japan*, **35**, (9) 319–322 (1964) [In Japanese].
9) Kushizaki, M., Ishizuka, J. & Akamatsu, F.: Physiological studies on the nutrition of soybean. 2. Effects of nodulation on nitrogenous constituents of soybean, *J. Sci. Soil and Manure, Japan*, **35**, (9) 323–327 (1964) [In Japanese].
10) Ōba, T. & Okubo, T.: Growth analytical studies on soybean in Tohoku district. 3. Optimum leaf area index and plant population in four different soils, *Tohoku-Nogyoshikenjo Kenkyusokuho*, No. 15, 77–79 (1973) [In Japanese].
11) Ōba, T.: Fundamental theories on high yielding of soybean, Nogyogijitsutaikei, **6**, 99–116, Nosangyosonbunkakyokai, Tokyo (1976) [In Japanese].
12) Tsunoda, J.: High yielding varieties of rice, judged from morphology and its function. *In* Morphology and Its Function of Rice, 180–195, Nogyogijitsukyokai, Tokyo (1967) [In Japanese].

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