Nutrio-Physiological Characteristics of Azuki-bean and Methods of Fertilizer Application

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Introduction

Azuki-bean is one of the important field crops in Hokkaido, but its yield is low and unstable. The crop is sensitive to climatic conditions, especially low temperature causes low yields[7,8,10]. In addition to its high sensitivity to weather, the optimum cultivation methods for the crop have not been determined. Particularly it is considered another main cause of unstable yields that the method of fertilizer application has not been established yet.

In the cultivation of azuki-bean, only soil fertility improvement has been stressed[6,16,17], while nutrio-physiological characteristics of the crop and fertilizer application methods have not been fully investigated. In practical cultivation, there is a marked tendency of heavy, but in many cases inefficient fertilization.

With the purpose of improving the yield of azuki-bean, nutrio-physiological characteristics and fertilizer response of the crop were investigated to find out efficient methods of fertilizer application[12].

Nitrogen and carbohydrate accumulation and growth stage determination

The growth period of azuki-bean was about 120 days, and the growth was very slow in the first half of the period, until the beginning of flowering, which occurred at about the middle of the whole growth period. After the beginning of flowering plant dry weight increased rapidly, and vegetative growth and reproductive growth progressed simultaneously for about 30 days (Fig. 1). The accumulation of nitrogen also increased rapidly after the beginning of flowering and the daily rate of increase in nitrogen reached a maximum about the beginning of pod-filling about 80 days after sowing (Fig. 2). After this point more nitrogen accumu-

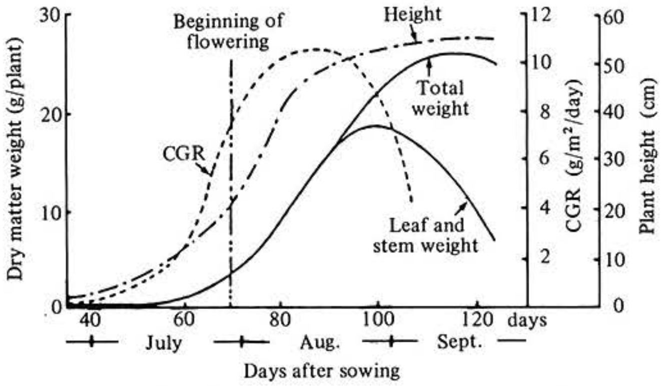


Fig. 1. Dry matter, plant height and growth rate of azuki-bean plant (cultivar Sakaeshozu) at successive stages of growth

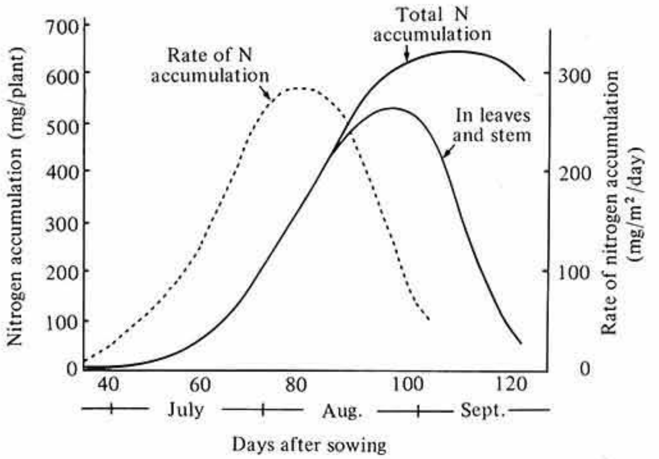


Fig. 2. Total nitrogen accumulation and rate of nitrogen accumulation in azuki-bean plant at successive stages of growth

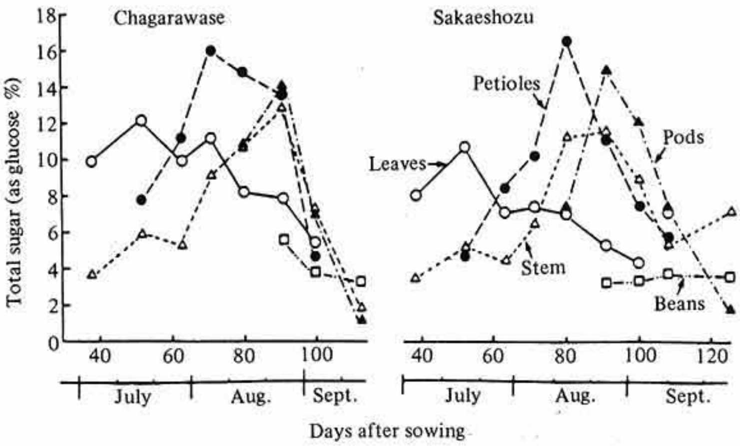


Fig. 3. Changes in total sugar content in each organ of azuki-bean plant

lated in pods and beans than in leaves and the stem.

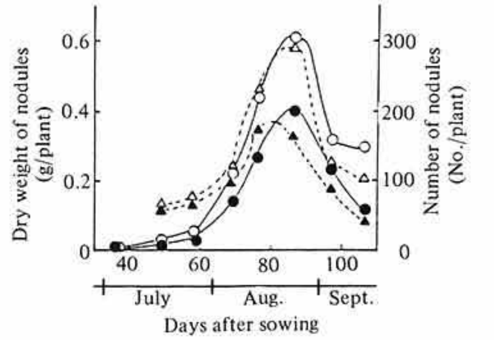
The place of accumulation of carbohydrate (total sugar) varied with the stage of growth (Fig. 3). Early in the growth period, the total sugar accumulated in leaf blades, and during the period when the vegetative growth progressed most rapidly after the beginning of flowering, it accumulated at a high concentration in petioles, showing as high as more than 15%. From the beginning of the pod-filling stage to the maximum growth stage that occurred at the end of vegetative growth (about 90 days after sowing), the carbohydrate accumulated chiefly in the stem, and later during the maturing stage, it accumulated successively in pods and beans.

From the relation observed between the accumulation of carbohydrate and the growth, the stage when the third trifoliate leaf is completely unrolled (about 50 days after sowing), the beginning of flowering (about 60 days after sowing), the beginning of pod-filling, and the maximum growth stage were considered nutrio-physiologically most important. Based on these four critical stages, the whole growth period can be divided into five growth stages[11].

Ecology of root nodules and movement of nitrogen

1) *Root nodule development and the form of fixed nitrogen*

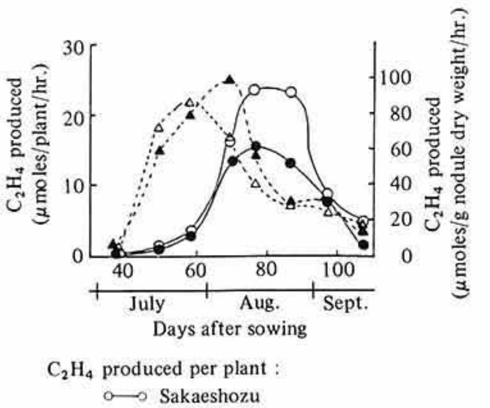
The number and dry weight of root nodules increased until nearly the maximum growth stage and then decreased gradually (Fig. 4). The nitrogen fixation (the amount of acetylene reduction per plant[4]) reached a maximum at the beginning of pod-filling and then decreased rapidly with increasing consumption of carbohydrates in pods and beans (Fig. 5), which reduced carbohydrate supply to the root nodules. This trend of nitrogen fixation is very similar to that of soybean. It has been reported, however, that nitrogen fixation in azuki-bean is lower than that in soybean[5]; Nishimune[9] reported nitrogen fixation in azuki-bean in the range of 1–60 kg N/ha. From trial calculations made in this investigation, the amount of the fixed nitrogen was estimated at 30–50 kg N/ha, accounting for 1/3–1/2 of the total amount of accumulated nitrogen in the plants.



Dry weight of nodules: ○—○ Sakaeshozu, ●—● Chagarawase
Number of nodules: △---△ Sakaeshozu, ▲---▲ Chagarawase

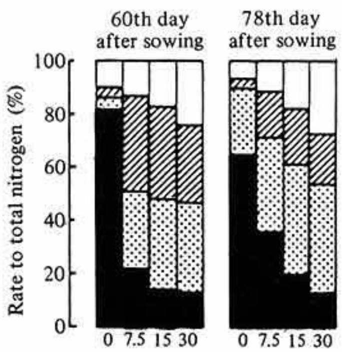
Fig. 4. Changes of number and dry weight of root nodules during the growth of azuki-bean plant

An increase in the amount of nitrogen applied resulted in a rapid decrease in the amount of root nodules. Allantoin (including allantoic acid) was generally contained in the xylem sap, and its ratio to the total nitrogen in the xylem sap increased to more than 80% when nitrogen was not applied and hence the amount of root nodules was the greatest (Fig. 6). This result indicates that the principal form of fixed nitrogen in transportation in the plants is allantoin. The content of allantoin in the stem was relatively high at the early stage of the growth period and for a short time again at the beginning of pod-filling. The amount of allantoin accumulation was small, as the ratio of allantoin to total nitrogen was lower than that of amino acid



C_2H_4 produced per plant :
○—○ Sakaeshozu
●—● Chagarawase
C_2H_4 produced per g (dry weight) of nodule :
△---△ Sakaeshozu
▲---▲ Chagarawase

Fig. 5. Changes of N-fixing activity during the growth of azuki-bean plant



Allantoin-N (allantoic acid included)
Amino acid-N (α-amino acid and amide)
Nitrate-N
Ammonium-N and residual-N

Fig. 6. Composition of nitrogen compounds in xylem sap as influenced by nitrogen applied

or nitrate nitrogen. This result indicates that the supply of nitrogen to the plants by the fixed nitrogen alone can not meet the rapidly increasing demand for nitrogen after the beginning of flowering.

2) *Changes in nitrogen compounds with fertilization*

Nitrogen compounds in the xylem sap of azuki-bean heavily fertilized with nitrogen were mainly amino acids (including amide) and nitric acids, and more than 60% of the amino acids was asparagin[13].

The increase in the amount of nitrogen application reduced the production of root nodules, but at the beginning of flowering the content of allantoin in the stem showed an increase. It was also shown that during the early growth period even nitrogen compounds, which were produced from nitrogen absorbed from fertilizer heavily applied, were accumulated in the form of allantoin. It was reported for soybeans[1,3] that there is almost no difference between the fixed nitrogen and nitrogen compounds derived from absorbed nitrogen in the efficiency of bean production. This seems to be true for azuki-bean too[2,14,15].

The increase in the amount of nitrogen application resulted in an increased content of nitrogen in each organ. The content of nitrate nitrogen in petioles of the plants which received heavy nitrogen application was high (about 1%) even at the beginning of pod-filling (the ratio to the total nitrogen was more than 30%). It suggests that a part of the absorbed nitrogen accumulated in the petioles as nitrate nitrogen.

Response to fertilization and correlation among growth, seed yield, and nutrient accumulation

Significant correlations were found out between CGR (crop growth rate) at each growth stage and seed yield. The higher correlation coefficients were observed in earlier stages (Table 1). This result indicates that to improve seed yield, it is essential to promote plant growth in the early

Table 1. Correlation between CGR at each growth stage and seed yield

Growth stage	Correlation coefficients
I~II	0.854**
II~III	0.888**
III~IV	0.876**
IV~V	0.823**
V~VI	0.177

I: Seedling emergence (June 7)
II: The third trifolilate leaf is completely unrolled (July 14)
III: The beginning of flowering (July 28)
IV: The beginning of pod-filling (Aug. 11)
V: The maximum growth stage (Aug. 26)
VI: The middle ripening stage (Sept. 8)
**: Significant at 0.01

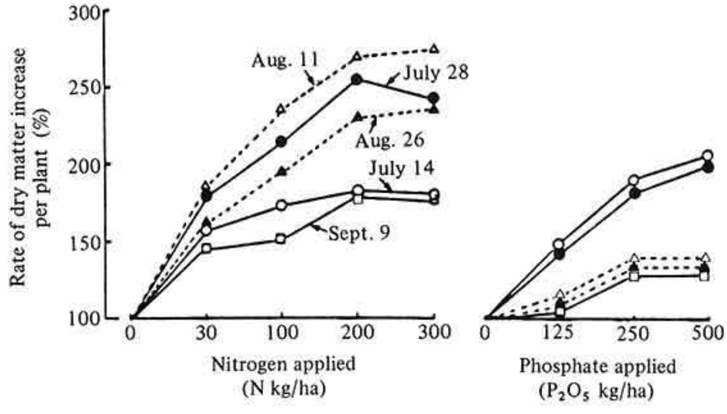


Fig. 7. Effect of nitrogen or phosphate application on the rate of dry matter increase at different growth stages

stage as well as in the later growth stage after the beginning of flowering.

The growth increments at each of the growth stages were compared at different amounts of nitrogen and phosphate fertilizer application (Fig. 7). At the stage prior to flowering the increased phosphate application promoted growth more effectively than nitrogen, while after the beginning of flowering an increase in nitrogen was more efficient in promoting growth than phosphate. Significant correlations were found out among the amount of accumulated nitrogen and phosphate at each stage, crop growth rate (CGR) and seed yield. The correlation between the content of nitrogen compounds in each organ at each stage and CGR after that stage was also investigated. As a result, it was found that the content of nitrate nitrogen in the petioles showed high correlation until the beginning of pod-filling. Considering this result together with the particularly high accumulation of nitrate nitrogen in the petioles, it is suggested that nitrate nitrogen would be a useful diagnostic index of the nutritional status of the plants.

In a word, as a step to achieve yield increase it is necessary to assure better growth until the maximum growth stage. Regarding the fertilizer application it is recommended to supply an adequate amount of phosphate in the early growth stage before flowering and that of nitrogen in the middle and late growth stage after flowering.

Effect of phosphate fertilizer and application method

Of the various phosphate fertilizers such as water-soluble phosphate, citric acid-soluble phosphate and their mixtures (1:1), water-soluble phosphate was the most effective in promoting growth in the early stage. With increased application of water-soluble phosphate (P_2O_5 more than 300 kg/ha) the plant growth was promoted not only in the early stage but also after the beginning of flowering resulting in the yield increase.

Among the methods of fertilizer application, row application, chiefly centering around roots, was more economical and effective than broadcasting and whole layer application. Under low temperature conditions the yield-increasing effect of phosphate was more remarkable, and the broadcasting followed by the whole layer application was also

Table 2. Influence of nitrogen top-dressed at different dates on growth, nitrogen accumulation and seed yield of azuki-bean in 1979 and 1980

Year	Time of top dressing	Dry matter weight (g/plant)		Nitrogen accumulation (mg/plant)		Seed yield (kg/ha)	Index[c] (%)
		Late of July[a]	Late of Aug.[b]	Late of July[a]	Late of Aug.[b]		
1979	No top dressing	2.6	24.5	89	595	2634	100
	July 3	2.9	30.2	99	776	2675	102
	July 12	2.9	28.3	102	686	2756	105
	July 26	—	22.0	—	515	2643	100
1980	No top dressing	2.3	14.0	77	447	1961	100
	July 1	2.5	18.2	98	562	2232	114
	July 15	2.6	16.4	95	542	2246	115
	July 30	—	15.8	—	501	2360	120

a) July 24 in 1979, July 21 in 1980.
b) Aug. 27 in 1979, Aug. 28 in 1980.
c) $\frac{\text{Seed yield with top dressing}}{\text{Seed yield without top dressing}} \times 100$

Nitrogen basal dressing: 30 kg N/ha.
Nitrogen top dressing (ammonium sulfate): 100 kg N/ha.

highly effective. In cooler districts, therefore it is advantageous to apply phosphate by combining the whole layer application with row application to raise the level of phosphate in the whole rhizosphere.

Application methods for nitrogen fertilizer

Under field conditions, a large amount of nitrogen, more than 50 kg of N/ha, given by the row application method inhibits seed germination and initial growth of seedlings. Such adverse effects obviously reduce the seed yield. The amount of nitrogen fertilizer to be used for basal dressing should not exceed 30–40 kg N/ha.

To avoid the damage to germination and initial growth and to supply a sufficient amount of nitrogen after the beginning of flowering, three different methods of nitrogen application were examined; top dressing, foliar fertilization, and the use of slow-release nitrogen fertilizer.

As given in Table 2, the top dressing of nitrogen promoted nitrogen accumulation and plant growth after the flowering, and increased seed yield. As to the time of top dressing, a trend that the later the top dressing the higher the harvest index was observed. However, the top dressing given at the developmental stage of the third trifoliate leaf was fairly effective in increasing yield.

When the top dressing of nitrogen is to be done, the amount of the basal dressing should be 30–40 kg N/ha, and a sufficient amount of phosphate should be applied to enhance the effect of the top dressing.

The top dressing was more effective when the growth was retarded due to low temperature, although it delayed the maturing stage only one or two days.

For the foliar application of nitrogen after the beginning of flowering, 2% urea solution was applied at the rate of 1000 *l*/ha two times every other day, and this treatment was repeated more than three times at the interval of 7–10 days. The result showed that the foliar fertilization was also effective in increasing nitrogen content of plants and increasing seed yield. It was shown that urea was a superior material to be used but its concentration should be less than 2%.

Slow-release nitrogen fertilizer was also found effective. CDU-N (crotonylidene diurea) was applied as basal dressing at the rate of 40 kg N/ha, in addition to 30 kg N/ha of quick-acting nitrogen fertilizer (ammonium nitrogen). The result was the promoted growth and increased yield.

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