Influence of Sowing Time and Nitrogen Topdressing at the Flowering Stage on the Yield and Pod Character of Green Soybean (*Glycine max* (L.) Merrill)

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Abstract: Basal dressing is generally considered important in the conventional cultivation of green soybean (edamame). In this experiment, we investigated the influence of the sowing time and nitrogen topdressing at the flowering stage on its yield and pod character. Seeds were sown on April 10 (early) and April 20 (late); the total amount of nitrogenous fertilizer applied was maintained constant, and the ratio of nitrogen applied as basal dressing to that applied as topdressing was changed: 10 : 0, 7 : 3, 3 : 7, and 0 : 10. The plant top growth during the early growth stages and its dry weight during the flowering stage increased with the increase in the amount of nitrogen applied as basal dressing, but the length of the main stem, number of branches, and total number of nodes at the time of harvesting did not. The yield, number of pods, and proportion of high-quality 3-grained pods increased with the amount of nitrogen topdressing. The number of pods set and the green soybean yield tended to decrease with the delay in the sowing time. However, in both early and late sowing, the yield tended to be higher when large quantities of nitrogen topdressing were applied. These results suggest that nitrogen topdressing after the flowering stage is effective in improving the yield of green soybean.

Key words: Green soybean, Nitrogen topdressing, Pod character, Pod yield.

The area of soybean (*Glycine max* (L.) Merrill) cultivation has increased in recent years due to the implementation of a policy regarding the reduction of the rice acreage in Japan. Soybean is mainly cultivated in upland fields converted from paddy fields. It is incorporated into crop rotation programs involving paddy rice and wheat, thus enabling efficient utilization of land. However, these fields are often used for soybean monoculture due to the field conditions and climate. Therefore, in order to increase the efficiency and profitability of soybean cultivation, other crops (except wheat) that can be cultivated during the fallow period of soybean cultivation are required.

Soybean is generally sown from late June to mid-July in southwest Japan. Consequently, in a double-cropping system, the preceding crop must be harvested at the latest from mid-June to the first 10 days in July. In previous studies, we have reported the possibility of using green soybean (edamame) as one of the preceding crops in this system (Okumura et al., 1983; Nishioka and Okumura, 2003). Green soybean comprises the fresh fully filled green pods before they turn yellow. This stage corresponds to the R6 stage of soybean development (Fehr et al., 1971). The taste of the grain and the pod traits are extremely important factors for the green soybean (Aoba, 1993; Sasahara, 2004; Takao, 2004). Further, large pods containing many grains are considered to be of good quality. In Japan, the yield (weight of fresh pods sold) of green soybean was 560 g m⁻² in 2004 (Statistics Department, Ministry of Agriculture, Forestry and Fisheries, Government of Japan 2005).

The yielding ability of green soybean in open fields may be affected by its sowing time due to adverse weather conditions (low temperature or rainfall).

As a possible solution to this problem, we considered increasing the yield of green soybean in the double-soybean cropping system by improving the fertilization methods employed. However, limited reports are available regarding appropriate fertilization methods for the cultivation of green soybean.

Basal dressing is generally considered important in the cultivation of green soybean, and nitrogen topdressing is applied in small amounts when necessary, depending on the growth status of the plant (Ishibashi, 1973; Kono, 1989; Kikuchi, 2004). However, in the case of soybean cultivation for grain production, nitrogen top dressing at the flowering stage is considered effective for increasing the yield (Nakano et al., 1982; Watanabe, 1982; Watanabe et al., 1983). Therefore, in this experiment, we investigated the influence of the sowing time and nitrogen top dressing at the flowering stage on the yield and pod character of green soybean.

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Materials and Methods

The experiments were conducted in the experimental field of the Faculty of Agriculture, Kinki University, Nara, Japan (34º67´N, 135º73´E), from April 2004 to July 2004. The Hokueishiroge variety of green soybean was used. Prior to ridging, 1 kg m⁻² leaf mold and 60 g m⁻² magnesium lime as a soil conditioner were applied to the farmland. Each plot comprised a ridge that was 0.7 m in width and 3.0 m in length with 2 replications. The experiment was conducted in 16 ridges.

The chemical fertilizers used were ammonium sulfate (N), superphosphate (P₂O₅), and potassium sulfate (K₂O).

In all plots, basal dressing comprised of 10 g m⁻² P₂O₅ and K₂O was applied. Nitrogen was applied as follows: (1) plot N10−0, 10 g N m⁻² as basal dressing and no top dressing; (2) plot N7−3, 7 g N m⁻² as basal dressing and 3 g N m⁻² top dressing; (3) plot N3−7, 3 g N m⁻² as basal dressing and 7 g N m⁻² as top dressing; and (4) plot N0−10, 10 g N m⁻² as top dressing and no N as basal dressing (Table 1). The basal dressing was incorporated into the top soil of the ridge prior to sowing. Nitrogen top dressing was applied to the soil surface along the ridge on day 10 after flowering (R3), followed by molding.

The seeds were sown on April 10 (hereafter referred to as early sowing) and April 20 (late sowing). Three seeds were sown 15 cm apart on each hill, and they were thinned to 2 plants per hill when the primary leaves had opened fully (19 plants m⁻²).

Seasonal changes in the plant height, number of nodes, number of branches, and leaf color value (SPAD) were measured. The SPAD value of the fully expanded leaf at the 5th node from the apex was measured by using SPAD-502 (Konica-Minolta Holding, Inc., Osaka, Japan).

In each plot, 2 hills were sampled at the flowering stage (R1) and on day 16 after flowering (R5), and 3 hills per plot were sampled at the time of harvesting (R6), i.e., 33 d after R1. The dry weight of different parts of the plants was measured, and the number of root nodules was counted. The nitrogen fixation activity of the root nodules was measured by using the acetylene reduction method (Hardy et al., 1968). All the root nodules obtained from each plant were incubated at 30ºC for 1 hr in the presence of 10% acetylene, and the amount of ethylene released was determined with an ethylene analyzer (Model GS-2, Kiya Seisakusho Co. Ltd., Tokyo, Japan).

Results

1. Top growth

(1) Early sowing

No significant differences were observed among the plots in the length of the main stem, number of branches, and total number of nodes at the time of harvesting (Table 2).

In all the plots, the SPAD value declined during the growth stage (R1) but gradually increased from R1 to R6 (Fig. 1). During the pod-setting stage (R3−R5), the highest SPAD value was recorded in N0−10; however, no significant difference was observed in the SPAD value among the plots at R6.

At R1, the highest leaf area index (LAI) was recorded in N10−0 (Fig. 2). However, at R6, LAI was highest in N0−10 and the lowest in N10−0. At R1, the top dry weight of the plants was higher in the plots to which a greater amount of nitrogen had

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**Table 1.** Plot and design of fertilization.

| Plot | Basal dressing (g m⁻²) | Top dressing (g m⁻²) |
|------|------------------------|---------------------|
|      | N  | P₂O₅ | K₂O | N  | P₂O₅ | K₂O |
| N10−0| 10 | 10   | 10  | 0  | 0    | 0   |
| N7−3 | 7  | 10   | 10  | 3  | 0    | 0   |
| N3−7 | 3  | 10   | 10  | 7  | 0    | 0   |
| N0−10| 0  | 10   | 10  | 10 | 0    | 0   |

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**Table 2.** Main stem length, number of branches, and number of nodes per plant at the harvest.

| Plot     | Main stem length (cm) | Number of branches | Number of nodes | Main stem | Branch | Total |
|----------|-----------------------|--------------------|-----------------|-----------|--------|-------|
| Early sowing |                       |                    |                 |           |        |       |
| N10−0    | 40.9                  | 1.7                | 9.0             | 4.7       | 13.7   |
| N7−3     | 40.5                  | 2.0                | 8.9             | 6.1       | 15.0   |
| N3−7     | 45.9                  | 1.8                | 9.3             | 5.3       | 14.6   |
| N0−10    | 41.7                  | 1.7                | 9.3             | 4.5       | 13.8   |
| LSD(0.05)| n.s.                  | n.s.               | n.s.            | n.s.      | n.s.   |
| Late sowing |                    |                    |                 |           |        |       |
| N10−0    | 40.8                  | 1.4                | 8.6             | 3.8       | 12.4   |
| N7−3     | 40.9                  | 1.4                | 8.4             | 4.3       | 12.7   |
| N3−7     | 40.5                  | 1.5                | 8.4             | 3.8       | 12.2   |
| N0−10    | 36.8                  | 1.5                | 8.7             | 4.3       | 13.0   |
| LSD(0.05)| 3.8                   | n.s.               | n.s.            | n.s.      | n.s.   |
Fig. 1. Seasonal change in the SPAD value. A is early sowing plots and B late sowing. R1, R3, R5 and R6: flowering stage, 10 days after flowering, 16 days after flowering and harvest time, respectively. The vertical bars indicate standard error of the mean of 2 replicates.

Fig. 2. Seasonal change in the Leaf Area Index (LAI). A is early sowing and B late sowing. R1, R5 and R6: flowering stage, 16 days after flowering and harvest time, respectively. The vertical bars indicate standard error of the mean of 2 replicates.

Fig. 3. Top dry weight and that excluding pod weight. A and B are early sowing plot. C and D are late sowing. The vertical bars indicate standard error of the mean of 2 replicates. The vertical bars indicate standard error of the mean of 2 replicates.

been applied as basal dressing (Fig. 3). However, at R5, the weights of the plants in all the plots were identical, and at R6, the plants in the plots that had been treated with larger quantities of nitrogen top dressing were heavier than those in the other plots.

Thus the top dry weight of the plants, excluding the pod weight during vegetative growth after R1 was increased by nitrogen top dressing as compared with N10–0.
Late sowing
At the time of harvesting, the main stem length of the plants in N0−10 was significantly shorter than in the other plots, but in the number of main stem nodes, number of branches, and total number of nodes per plant were not significantly different from those in the other plots (Table 2). Moreover, the values of all these parameters were lower in the plots with late sowing than with early sowing.

The highest and lowest SPAD values were recorded in the N0−10 and N10−0 plots, respectively, during the growth period (Fig. 1).

The LAI in N10−0 was the highest among the four plots at R1 and the lowest at R6 (Fig. 2).

The top dry weight of the plants at R1 was high in plots wherein large quantities of nitrogen were applied as basal dressing (Fig. 3). However, at R6, the top dry weights of the plants in N7−3 and N0−10 were higher than those of the plants in the other 2 plots.

The increase in the top dry weight of the plants after R1, excluding the pod weight, was greater in the plots to which nitrogen top dressing had been applied.

2. Root nodules and nitrogen fixation
(1) Early sowing
The number of root nodules in N10−0 increased from R1, and the highest number of root nodules was recorded in this plot at R6 (Fig. 4). In contrast, the number of root nodules in N0−10 decreased after R1, and the lowest number of root nodules was recorded in this plot at R6. An intermediate number of root nodules was recorded in N3−7 and N7−3 due to seasonal changes.

The amount of ethylene released due to the root nodule activity at R1 was largest in N3−7, followed by N7−3 (Fig. 4). The amount of ethylene released in N10−0 increased at R6, and the smallest amount of ethylene released was recorded in N0−10.

(2) Late sowing
In general, few differences were observed in the number of root nodules among the 4 plots (Fig. 4). This number increased in all the plots from R1 to R5.

Fig. 4. The number of the root nodule (A) and seasonal change in nitrogen fixation capability of root nodule shown by acetylene reducing activity (B). Acetylene-reducing activity was measured by the method of Hardy et al. (1968). All root nodules in each plant were incubated at 30°C for 1 hr in the presence of 10% acetylene and ethylene released was determined by ethylene analyzer. At the development stage R5 in early sowing, ethylene formation was not measured. The vertical bars indicate standard error of the mean of 2 replicates.

| Plot     | Yield g m⁻² | Number of pod set m⁻² | The ratio of grain pod⁻¹ |
|----------|-------------|-----------------------|-------------------------|
|          |             | One-grained | Two-grained | Three-grained | Empty grained | Total |                      |
| N10−0    | 681.0 c     | 84.1 a      | 215.9 ab    | 128.6 b       | 30.2 a        | 458.7 b | 0.46 b                |
| N7−3     | 813.6 bc    | 93.7 a      | 222.2 ab    | 142.9 ab      | 31.7 a        | 490.5 b | 0.50 ab               |
| N3−7     | 925.3 ab    | 96.8 a      | 231.7 ab    | 173.0 ab      | 33.3 a        | 534.9 ab | 0.51 a               |
| N0−10    | 1053.4 a    | 131.7 a     | 246.0 a     | 203.2 ab      | 23.8 a        | 604.8 a | 0.51 a               |
| N10−0    | 730.8 c     | 73.0 a      | 217.5 ab    | 134.9 b       | 25.4 a        | 450.8 b | 0.51 a               |
| N7−3     | 774.6 bc    | 77.8 a      | 200.0 ab    | 149.2 ab      | 28.6 a        | 455.6 b | 0.51 a               |
| N3−7     | 756.1 bc    | 81.0 a      | 181.0 b     | 146.0 ab      | 46.0 a        | 454.0 b | 0.51 a               |
| N0−10    | 892.4 ab    | 95.2 a      | 192.1 ab    | 188.9 a       | 30.2 a        | 506.3 ab | 0.51 a               |

Mean followed by the same letter in each column are not significantly different at 5% level, as determined by T-test. The ratio of grain pod⁻¹: The ratio of the dry weight of the grain to that of the pod containing the grain. Yield was estimated from the small field, 3 m length of two ridges.
but decreased significantly at the time of harvesting in N7−3.

At R1, a larger amount of ethylene was released in the N0−10 and N3−7 plots than in the other plots due to the high root nodule activity; however, at R5, the largest amounts of ethylene released were recorded in N7−3 and N10−0. Further, in all the plots, the amount of ethylene released decreased at R6; however, this amount was relatively larger in N10−0 and N7−3 than in the other 2 plots.

3. Yield and pod character
   (1) Early sowing
   The fresh pod yield in N0−10 tended to be significantly higher than that of N7−3 and N10−0, and the fresh pod yield of N3−7 did significantly higher than that in N10−0 (Table 3). Moreover, the number of pods recorded was significantly higher in N0−10 than in N7−3 and N10−0.

   The number of pods having 3 grains was the highest in N0−10, followed by N3−7. The proportion of 3-grained pods tended to increase with the amount of top dressing applied (Fig. 5). The ratio of the grain dry weight to the pod dry weight was significantly higher in N0−10 and N3−7 than in N10−0 (Table 3).

   (2) Late sowing
   The fresh pod yield tended to be the highest in N0−10 and the lowest in N10−0 (Table 3). In general, the yield of plots with late sowing, except for N10−0, was less than that of plots with early sowing under the same system of N fertilization. However, the yield in N0−10 with late sowing was similar to that in N0−10 and N3−7 with early sowing.

   The number of pods set was the highest in N0−10. The ratio of 3-grained pods increased with the increase in the amount of nitrogen top dressing applied (Fig. 5). The ratio of the grain dry weight to the pod dry weight did not differ significantly among the plots (Table 3).

4. Relationship between Relative Growth Rate and Pod Number
   The relationship between the relative growth rate (RGR) from R1 to R6 and the number of pods per plant was investigated (Fig. 6). In both plots with early and late sowing, a positive correlation was observed between the RGR and the number of pods and also between the RGR and the proportion of the number of 3-grained pods to the total number of pods.

Discussion
In Japan, the demand for green soybean peaks in summer. Moreover, since green soybean is not harvested in large quantities from the end of June to...
After the flowering season, and the LAI did not decrease when compared with the plots applied large amounts of basal dressing. Thus, vigorous growth was maintained until harvesting.

At the time of harvesting, the number of pods and the green soybean yield increased with the increase in the amount of nitrogen top dressing applied. Saitoh et al. (1999) reported that delayed flowering at the flowering stage resulted in reduced pod setting due to the competition for assimilates between the vegetative and reproductive stages of growth. However, in this experiment, top dressing was applied 10 d after flowering. Therefore, the enough nutrient supply was maintained even after the flowering stage, thus reducing the competition for assimilates between the vegetative and reproductive stages; This improved flower setting during the later stages of flowering and increased the number of pods. In addition, when a large quantity of top dressing was applied to the plots with early sowing, the ratio of 3-grained pods to the total number of pods set increased, as did the ratio of grain weight to pod weight. The plants were considered to effectively absorb the nitrogen fertilizer applied during the flowering stage because, as mentioned above, the time period from flowering to harvesting was short.

The total number of nodes per plant was higher in the plots with early sowing than in those with late sowing. In addition, the number of pods set per plant and the green soybean yield were higher in the former than in the latter. Hokueishiroge used in this experiment is an early maturing type. Flowering in this variety is greatly influenced by temperature. Therefore, in the plot with late sowing, the total number of nodes and the number of pods set decreased because the plants began to flower before they attained full growth. However, the yield tended to be high both with early sowing and late sowing when an appropriate quantity of nitrogen top dressing was applied during the flowering stage.

In addition, a positive correlation was observed among the RGR from R1 to R6, the number of pods, and the proportion of the number of 3-grained pods to the total number of pods. This indicates that the soybean yield can be increased by controlling the growth of the plant up to the flowering stage and accelerating the growth thereafter.

In conclusion, the application of a small amount of nitrogen basal dressing and a large amount of nitrogen top dressing was observed to increase the yield of green soybean. In addition, even if the same amount of nitrogen fertilizer was applied, the number of 3-grained pods increased with increasing amount of nitrogen top dressing. Thus, the yield of high-quality green soybean can be increased even at the same fertilizer cost, making it possible to raise the value of this commodity and improve the profitability of green soybean cultivation.
Future studies are needed to determine the appropriate amount of nitrogen top dressing required for the cultivation of other varieties of green soybean and on the influence of applying large quantities of nitrogen top dressing on the subsequent crop.

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* In Japanese with English abstract.
** In Japanese with English summary.
*** In Japanese with English title.
**** In Japanese. The present authors translated the title from Japanese.