Effects of High Ground-Water Level on the Growth and Yield of Supernodulating Soybean Cultivar, Sakukei 4
II. Effects of High Ground-Water Level on Nitrogen Absorption

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The area of rice paddy field converted to upland field for soybean cultivation has been increasing recently in Japan, and reached approximately 85% of the total soybean cultivation area in 2003. Since most of the soybean fields were originally used as paddy fields, they occasionally suffer damage by the high ground-water level such as poor growth of plants and reduced grain yield due to the decrease of the pod number and also of the 1,000-grain weight (Fukui et al., 1951; Mochizuki and Matsumoto, 1991; Sugimoto, 1994). Therefore, an essential issue for the improvement of soybean yield in Japan, is to mitigate the damages of high ground-water level in the converted upland fields.

Soybean plants require a large amount of nitrogen for growth. The plants in the converted upland fields suffer from anoxia in the root zone due to the high ground-water level, which reduces the respiration in the roots and also in the root nodules, leading to a remarkable decrease of total nitrogen absorption (Fukui et al., 1963; Sallam et al., 1987; Sugimoto, 1994). There are two channels for total nitrogen absorption in soybean plants: one is the direct absorption of soil or fertilizer nitrogen via the roots (soil nitrogen), and the other is the indirect absorption of the atmospheric nitrogen fixed by the rhizobia (symbiotically fixed nitrogen) (Haper, 1974). Sprent (1971) and Bacanamwo and Purcell (1999) reported that the roots and the nodules of soybean plants are different in their sensitivity to high ground-water level in the soil. Sugimoto (1994) examined the effect of excessive soil moisture on the growth of nodulating and non-nodulating lines of soybean plants. He found that root nodules played an important role in reducing excessive soil moisture injury. This suggests that nodule development can mitigate the negative effects of high ground-water level on total nitrogen absorption and growth of the plant. A soybean variety, Sakukei 4 (currently Kanto 100) which is a supernodulating genotype derived from Enrei and Tamahomare (Yamamoto et al., 2004), can develop a large number of nodules. This variety has a markedly high rate of nitrogen fixation, and a high photosynthetic rate during the growth period (Maekawa et al., 2003; Takahashi et al., 2003). Sakukei 4 also has a higher grain yield than Enrei (Takahashi et al., 2003).

In the present study, we examined the contribution of nodule development in the mitigation of high ground-water level on total nitrogen absorption; growth and grain yield of soybean plants, Sakukei 4 and Enrei.

Materials and Methods

1. Cultivation of the plant materials

This experiment was conducted at the experiment farm of Nihon University in Fujisawa, Kanagawa Prefecture of Japan. The seeds of soybean plants (Glycine max (L.) Merr. cv. Enrei and Sakukei 4) were sown on May 30, 2005 at the rate of 5 seeds per pot in 1/5000 Wagner pots packed with 3 kg Andosol type soil fertilized with 3.5 g of compound fertilizer (N-P₂O₅-K₂O = 14-14-14%, respectively), and 0.75 g of potassium chloride. The plants were thinned to one plant per pot at the time of the expanding of the first trifoliate leaves. The soil surface was protected from drying by proper application of water with a sprinkler. The pots were put separately with the distance of 20 cm, so that the leaves of the neighboring pots were not overlapped.

2. Rising of ground-water level

At the four trifoliate leaf stage, the ground-water level was high. The pots for the control plant were placed in the field continuously during the sowing to the end of experiment. The pots for the treated plants were submerged in a pool 18 cm in depth, which matched to 0 cm of the ground-water level. The
high ground-water treatment was given from the floral differentiation stage to the flowering stage (Enrei: July 4–19, Sakukei 4: July 7–24), and then the pots were returned to the field condition.

3. Determination of amount of absorbed and fixed nitrogen

The shoots of the soybean plants were cut off at the cotyledon node at the flowering stage (Enrei: July 19, Sakukei 4: July 24), and a silicon tube was installed on the cut section to collect the xylem sap that accumulated from 10 AM to 1 PM. The total nitrogen in the xylem sap was measured by the alkalinity peroxonium disulfuric acid potassium method, and the allantoin nitrogen (allantion + allantoic acid) content was measured by the Young-Conway method. On the same day, the roots were dug up, and were divided into roots and root nodules. All root nodules over 1.0 mm in diameter were collected. Roots without nodules and root nodules were dried at 80°C for 48 hours, and their plants in each group, treatment and control.

Results and Discussion

The total nitrogen absorption by Enrei and Sakukei 4 was significantly lower in the high ground-water level plot than in the control at the 1% level. However, the total nitrogen absorption rate in the high ground-water level plot was 44% of that in the control plot for Enrei, and 38% in Sakukei 4. Thus, total nitrogen absorption was reduced by the high ground-water level in Sakukei 4 than Enrei in (Fig. 1). Because nodules generally show a high level of respiration and demand a very large amount of oxygen, it has been hypothesized that the nodule is more liable for growth suppression by excessive ground-water (Sprent, 1971; Kuwahara, 1988). Hence, the larger decrease in the total nitrogen absorption by the high ground-water level in Sakukei 4 than in Enrei is believed to be due to the suppression of root nodule formation and reduced nitrogen fixation in the nodules. In fact, the high ground-water level reduced the content of allantoin nitrogen, which is an indicator of nitrogen fixation by the nodule in both varieties. In the high ground-water level plot, the allantoin nitrogen content in Enrei was 57% of the control plot, while in Sakukei 4 it was 38% of the control plot. Thus, the allantoin nitrogen content was reduced by the treatment more greatly in Sakukei 4 than in Enrei (Fig. 1). Because Sakukei 4 develops more nodules than Enrei, Sakukei 4 is capable of fixing more nitrogen, resulting in a higher nitrogen content of leaf, and a higher photosynthetic
rate than in Enrei (Maekawa et al., 2003; Takahashi et al., 2003). However, the results of this experiment indicated that a high ground-water level markedly decreases nitrogen fixation by root nodules and the total nitrogen absorption more greatly in Sakukei 4 than in Enrei. Sugimoto (1994) showed that root nodules played an important role in reducing excess moisture injury. He examined the nitrogen uptake of a soybean under an excess moisture condition in root nodulating and non-nodulating lines. However, we examined the nitrogen uptake in a root nodulating line and the super nodulating. Thus, Sugimoto’s result (1994) differs from our result. It is considered that the difference of the comparative material (nodulating line and non-nodulating line, nodulating line and super nodulating line) led to the difference of results. Therefore, it is necessary to repeat the research in the future.

Fig. 2 shows dry weight of roots and nodules. Both the root and the nodule dry weight decreased in the high ground-water level plot compared with the control plot in both varieties. The decrease of dry weight was greater in Enrei than in Sakukei 4. However, Sakukei 4 showed greater decrease in total nitrogen absorption and in allantoin nitrogen content than Enrei did in the high ground-water level plot (Fig. 1). Thus, it may be stated that a decrease in allantoin nitrogen per content of nodule caused by a high ground-water level is greater in Sakukei 4 than in Enrei. In other words, a high ground-water level decreases the activities of root nodules more greatly in Sakukei 4 than in Enrei. However, in this study only the effects of a high ground-water level during the growth period from flower bud differentiation to flowering were examined. It is necessary to conduct similar experiments on the effect of a high ground-water level in other growth stages of soybean plants.

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* In Japanese.