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REVIEW

Improvement of Soybean Growth and Yield (*Glycine max* L.) by Inter-row Stripe Tillage in Upland Fields Converted from Paddy Fields

Satoshi YOSHINAGA*

Rice Research Division, NARO Institute of Crop Science, National Agriculture and Food Research Organization (NARO) (Tsukuba, Ibaraki 305–0044, Japan)

Abstract

We adopted 'inter-row strip tillage' (IST), which involves conducting tillage between rows and sowing on no-tillage soil, to cultivate soybeans in upland fields converted from paddy fields (UFCP) and examined the effect on soil water content, growth and soybean yield. The three phase of no-tillage soil in IST differs from soil harrowed via conventional tillage, which shows lower solid and liquid phases. No-tillage soil in IST showed a larger water content under drought conditions and less fluctuation of the liquid phase between conditions of drought and excess moisture compared to those of harrowing soil in conventional tillage. The plants in IST had more root nodules and showed higher SPAD values. They were also longer, with more nodes on the main stem, and a larger dry weight at the flowering stage. The IST yield exceeded that in conventional tillage, due to the higher number of pods and 100-kernel-weight. The factors of superior growth and higher IST yield were attributed to the property of the no-tillage soil in IST, which alleviates the fluctuation of the soil water content in UFCP. The relationships between soil permeability and property remain to be evaluated, while there is also a need to improve the IST operational efficiency.

Discipline: Crop production
Additional key words: no-tillage, root nodule, soil moisture

Introduction

By 1994, the land area of cultivated soybeans had decreased by approximately 60,000ha, but has since doubled over the past decade and now covers 150,000ha in Japan, most of which is converted from paddy fields. In upland fields converted from paddy fields (hereafter referred to as UFCP), soybean plants are prone to damage from high soil moisture due to the lower water permeability of the soil. The latter also exacerbates drought damage due to the decrease in the soil pulverization ratio (Sugimoto et al., 1988). Thus, the rapid increase in the area of UFCP in recent years might be a factor behind the lower yield and quality of soybeans.

The main cropping pattern of soybean production in Japan involves drastically fluctuating climate conditions during the plant's growth period, due to the rainy season, followed by a hot and dry mid-summer season. In the north-east, the amounts of precipitation in the seeding season tend to be low and the climate favors seeding. However, the delay of rainfall after the seeding possibly results in a lower rate and less uniform seedling emergence, hence the decrease in initial growth. During the rainy season subsequent to seedling emergence, soybean growth suffers from excessive soil moisture due to heavy rain.

Furthermore, in mid-summer, when the climate is relatively dry and hot, the soybean growth stage would be from flowering to pod setting, whereupon water requirements increase and plants become more susceptible to drought. Low precipitation during this period may mean the soybean plants suffering adverse effects on growth. Soybean is a crop that is relatively sensitive to soil moisture because soybean nodulation and nitrogen fixation are sensitive to excessive moisture and soil drought (Shimada, 2006). Accordingly, improving the cultivation method in order to control soil moisture is key to stabilizing soybean production.

New tillage or planting methods for controlling the

*Corresponding author: e-mail yosinaga@affrc.go.jp
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soil moisture in UFCP have thus been developed and evaluated recently. One of the new methods involves seeding on a ridge row with simultaneous ridge making tillage (Hosokawa, 2004; Takahashi et al., 2006), while another method is a broad-bed planting system with shallow tillage (Watanabe et al., 2004). For the same purpose, we also developed a kind of partial tillering method, called inter-row stripe tillage (hereinafter referred to as IST), which enables partial tillage to be performed with little change in the rotary claw arrangement. In northeastern Japan, the area cultivated by IST has been gradually increasing and exceeded 120 ha in 2010.

In this report, we evaluated the effects of inter-row stripe tillage on soil moisture and soybean growth and yield based on a series of pot and field experiments.

Transformation of machinery for IST and operation efficiency

A rotary seeder consisting of an up-cut rotary 160 cm wide (Kobashi-Kogyo Co., Ltd., 160-T) and a 2 row seeder (Agritecno-YAZAKI Co., Ltd., Clean-seeder) were utilized for the field experiments. In IST, an area about 50 cm wide between rows was tilled, and a gap 22 cm wide under the seeding row was left untilled due to the elimination of 3 rotary claws, and a nick (5 cm deep) was made by attaching one straight short claw as a colter at the center of the seeding row (Fig. 1). Accordingly, the seeds in IST were placed on the nick of the no-tillage soil and covered with tillage soil transferred from the inter-row tillage. Although most of the down-cut rotary can also be utilized for IST, the operational efficiency might be delayed. In IST, tillage and seeding must be operated simultaneously, which has the advantage of shortening the operating hours for tillage and seeding. However, the seeding speed in IST might be slower by half compared with that in conventional tillage (hereinafter referred to as CT), in which seeding is done after tillage operation. For farmers, the seeding speed is important due to the limited number of seeders, and likewise the operating hours, making it also important to improve the IST rate of operation.

Effects of tillage on soybean growth and yield

The effects of tillage on soybean growth and yield were evaluated in comparison with the results of field and pot experiments. The field experiments were conducted from 2003 to 2006 in a field of Gray Lowland soil in the National Agricultural Research Center for the Tohoku Region (Daisen, Akita prefecture) and from 2003 to 2006 in the farmers' field of Andosols in Daisen city (Akita prefecture). Soybean seeds (cv. Ryuhou) were sown from June 3 to 16, with an interval of 75cm left between rows

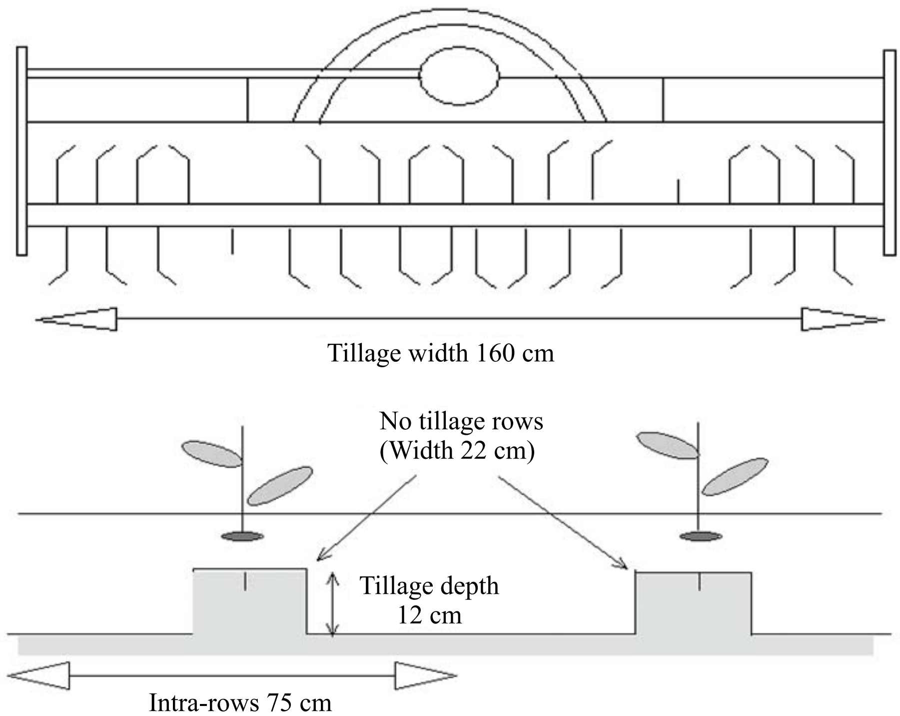

Fig. 1. Schematic diagram of the rotary claw arrangement (upper) and profile of the soil (lower) in the inter-row stripe tillage

and 18cm intra-hill (2 seeds per hill). All the fields were converted from paddy fields and maintained without tillage after the harvesting of rice. Cultivation management was implemented in line with conventional methods in this area, with each plot arranged in a randomized block design with three replications, although the 2003 experiment in the Andosols field had no replication (measurement was practiced at three locations in each plot). Table 1 shows the periodical precipitation and air temperature for each year. The precipitation from seeding to emergence was low and the soil moisture was also low in 2003 and 2005, while the precipitation and soil moisture were greater in 2004. The characteristics of the climate conditions subsequent to seedling emergence were low sunshine hours in 2003, higher rainfall in 2004, low precipitation in 2006 and a relatively normal condition in 2005.

The pot experiment was conducted on 2006 at the National Agricultural Research Center for the Tohoku Region. Puddled soil (Gray lowland soil) was filled in 1/5000-a Wagner pots, which were then left until the soil dried. Subsequently, the soil was tilled and refilled into the pot for CT treatment. For the treatment of IST, 5 cm of surface soil were tilled (lower than 5 cm of soil was considered a no-tillage condition). Three soybean seeds (cv. Ryuho) were sown in a pot on Sep. 8 at a sowing depth of 4 cm and thinned into one plant after seedling establishment. All pots were located in an air-conditioned growth chamber (Koito-Kogyo Co., Ltd., Koitotoron) with a day/night temperature regime of 24/16 ^{o}C under natural sunlight. From 27 days after seeding, pots of both treatments were placed in a container filled with water and the water level was kept at the soil surface for 6 days. Each treatment was arranged in a randomized block design with nine replications.

The effects of tillage on soybean growth in the fields of Gray Lowland soils and Andosols are shown in Table 2. At the flowering stage (R2), the length and node number of the main stem in IST increased in addition to the stem diameter and shoot dry weight. At the pod-setting to seed filling stage (R4 – R5) of the plants in IST, the number of main stem nodes and the stem diameter in Gray Lowland soils showed significant increase, as well as the main stem length and shoot dry weight in both soil types. In the pot experiment, photosynthetic activity in IST was significantly higher under different soil water conditions than that in CT (Fig. 2), while the dry weight of the shoot and leaf area in IST exceeded that in CT (Table 2).

As for the yield, despite no significant differences in the ripened pod number between tillage methods, the number in IST exceeded that in CT by 10% (Table 3), while the yield and 100-seed wt. of IST in Gray Lowland soils and the yield of IST in Andosols increased significantly compared with those in CT.

Increased initial growth (until flowering) in IST was observed in the field of different soil types and pot experiment. Since greater fluctuation of the soil water content results in reduced growth and yield (Seko et al., 1987; Shimada et al., 1995), the increased growth in IST in field and pot experiments seemed to be linked with the variation in soil moisture between tillage methods. The high photosynthetic activity in IST, as observed in the pot experiment, might have contributed to the increased shoot dry weight, while during the later growth period, the difference in growth between tillage methods, which was observed at the flowering stage, was maintained.

As for the factors behind the yield increase in IST, it is reported that growth stimulation at the flowering stage resulted in an increase in the number of pods, while drought or excessive soil moisture at flowering decreased the pod setting rate (Matsuzaki et al., 2006; Saito et al., 1999; Yahagi et al., 2002). Thus, the increased IST yield is assumed to have been derived from the stimulation of growth until the flowering stage. Furthermore, the 100 seed weight, which affects processing quality, increased in IST compared with in CT, which suggests that the production of dry matter during the seed filling period might be stimulated in IST, while the stabilization of IST yield

Table 1. Climate condition

Growth stage	Sunshine hours (h/day)					Precipitation (mm/day)				
	Normal	2003	2004	2005	2006	Normal	2003	2004	2005	2006
Seeding - VE	4.5	4.5	5.6	4.8	3.9	3.8	1.1	6.3	0.9	1.5
VE - R2	4.1	3.2	3.3	3.1	2.7	6.0	5.8	7.2	6.9	4.6
R2 - R5	5.5	2.4	5.6	5.2	6.6	5.8	7.0	7.8	5.3	1.7
R5 - R8	4.2	4.2	3.3	4.1	4.9	5.5	4.6	6.8	6.1	3.6

Data in ‘Normal’ is the 30 year average (1971-2000). The growth stage was defined based on Fehr et al. (1971).

might possibly result in high grain quality. Effects on yield stabilization in IST were observed in both the field Gray Lowland soil and Andosols. However, the soil property is related to changes in the soil water status in different soil taxonomies or under different soil water conditions. Thus, further experiments in fields with wider soil properties are required to determine the optimal tillage method to improve soybean growth and yield.

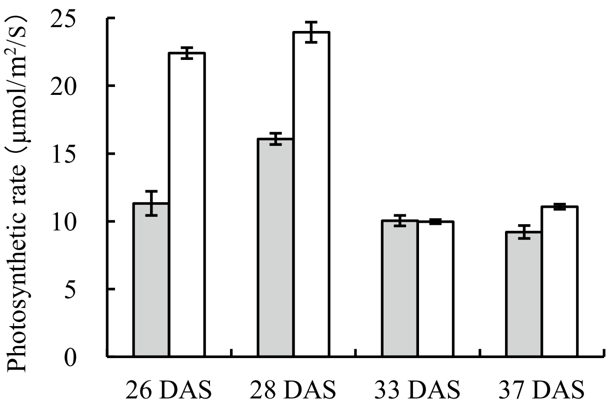

Fig. 2. Effects of the tillage method on the photosynthetic rate under different water conditions (Pot experiment)
Error bars indicate standard error (n=4). Pots were flooded from 27 to 33 days after seeding.
DAS: Days after seeding.
□ : CT, □ : IST.

Effects of tillage on soil moisture and adnation of root nodules

In the field experiment, three phases of the sampled soils at different growth periods and under different soil moisture conditions were calculated by measuring the actual volume using a three phase analyzer (Daiki Rika Kogyo Co., Ltd., DIK-1121) and weighing pre- and post-oven drying at 105 °C for 2 days. In this comparison of the phases between the tillage and no-tillage soils in CT and

Table 3. Effects of tillage method on the soybean growth (Pot experiment)

Measuring time	Tillage Method	Leaf area (cm^2/plant)	Dry Wt. (g/plant)	Root nodule (no./plant)
27 days after seeding (before flooding)	CT	136	0.68	22
	IST	188	0.92	47
	Significance	*	ns	*
36 days after seeding (after flooding)	CT	200	1.39	31
	IST	312	2.18	54
	Significance	*	**	**

* and ** indicate significance at the 0.05 and 0.01 probability levels, respectively (ANOVA, n=3 for upper measurement time, n=6 for lower measurement time). ns: not significant at the 0.05 level.

Table 2. Effects of tillage method on the growth and yield in different soil type fields

Soil type	Tillage method	R2 Main stem length (cm)	R2 Main stem node number (/plant)	R2 Branch number (/plant)	R2 Stem diameter (mm)	R2 Shoot dry wt. (g/m^2)	R4 - R5 Main stem length (cm)	R4 - R5 Main stem node number (/plant)	R4 - R5 Branch number (/plant)	R4 - R5 Stem diameter (mm)	R4 - R5 Shoot dry wt. (g/m^2)	Grain yield Ripened pod number (/m^2)	Grain yield 100-seed wt. (g)	Grain yield Yield (g/m^2)
Gray Lowland soils	CT	39.0	10.8	1.7	6.1	112	55.4	13.6	3.8	8.0	492	565	30.6	330
	IST	42.1	11.2	1.9	6.5	129	58.5	13.9	4.2	8.4	524	623	31.5	349
	Significance	*	*	ns	*	*	*	*	ns	*	**	ns	*	*
Andosols	CT	29.7	10.1	1.3	5.6	78	44.5	13.3	7.5	3.4	335	557	32.2	286
	IST	32.7	10.6	1.9	6.2	97	49.3	13.4	7.8	3.5	383	623	32.0	306
	Significance	**	**	*	**	**	**	ns	ns	ns	*	ns	ns	*

Average of 4 years in Gray lowland soil and 3 years in Andosols. * and ** indicate significance at the 0.05 and 0.01 probability levels, respectively (paired-sample t-test, n=12 for Gray lowland soil and n=9 for Andosols). ns: not significant at the 0.05 level.
The growth stage was defined based on Fehr et al. (1971).

IST respectively, it was shown that the solid and liquid phases in IST were relatively high, and the property was maintained, even at the flowering stage (approximately 50 days after seeding), although the value of the solid phase decreased slightly at the flowering stage (Table 4). Another comparison of the three phases between CT and IST under drought and wet conditions showed little difference in the liquid phase of the lower soil layer in IST, which was the no-tillage condition, although the tilled soil in CT and IST showed significantly greater changes in the liquid phase, which could be derived from the high solid phase in the no-tillage soil in IST (Fig. 3).

Previous reports suggest that excessive soil moisture might result in a decrease in root nodule activity (Kuwahara, 1988) and the reduced soybean growth and yield (Matsuzaki et al., 2006; Sugimoto et al., 1988; Yahagi et al., 2002). In UFCP, which shows lower soil permeability, excessive soil moisture might be the main factor limiting soybean growth and yield. Measures to counter excessive moisture damage in soybean cultivation involving tillage include 1) the stimulation of soil surface drainage, and 2) seeding at a relatively higher position to expand root system distribution. For 1), no-tillage cultivation (Hamaguchi et al., 2004) and shallow tillage cultivation (Watanabe et al., 2004) are effective, while ridge-making cultivation (Hosokawa, 2004) is an effective method for 2). The no-tillage seed bed in IST showed a high solid phase and large actual volume, and seemed to have less water exchange capacity under wet conditions, as shown in Fig. 3. It is thus assumed that the adverse effect of excessive soil moisture on the soybean root system might be alleviated by IST. Furthermore, the variation in water permeability between no-tillage and tillage soil might stimulate the drainage between rows and boost growth and IST yield.

In pot and field experiments, the root nodules and growth were influenced by the tillage method, while the number and weight of root nodules were larger in IST than in CT (Tables 3 and 5). In IST, stimulation of nodule adnation was observed at the border of tilled and no-tilled soil (no data shown). It is assumed that the border soil has two kinds of advantages. One might be the high oxygen content from the tilled surface soil layer and the other

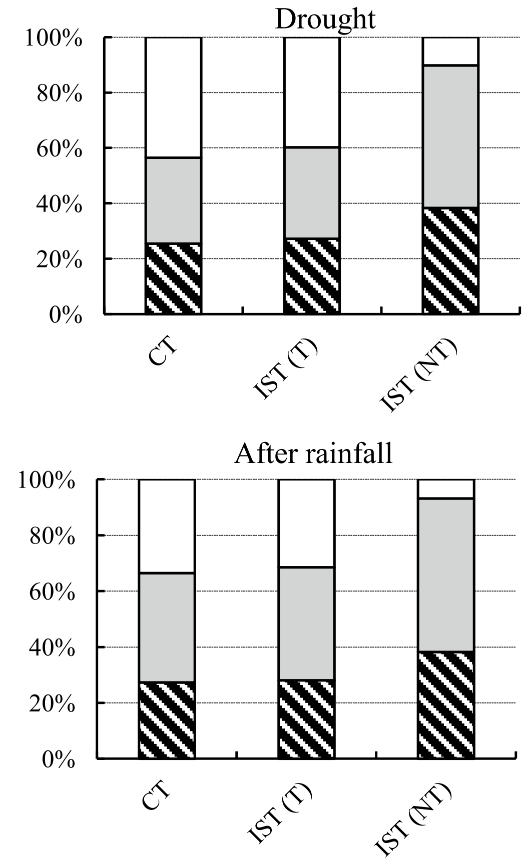

Fig. 3. Effects of tillage method on three phases of soils under different soil conditions
IST (T); tillage soil in IST,
IST (NT); no-tillage soil in IST.
□ : Gas, ▨ : Liquid, ◼ : Solid.

Table 4. Effects of tillage method on three phases of soils at different growth stages

Soil type	Tillage Method	Soil Condition	After Seeding			Flowering		
			Solid (%)	Liquid (%)	Gas (%)	Solid (%)	Liquid (%)	Gas (%)
Gray Lowland soil	CT	Tillage	28.2	28.3	43.5	25.5	34.1	40.3
	IST	No-Tillage	37.2	45.1	17.7	32.0	48.1	19.8
	Significance		**	**	**	*	**	*
Andosols	CT	Tillage	29.5	35.2	35.3	30.7	31.3	38.0
	IST	No-Tillage	40.3	49.3	10.4	35.2	41.5	23.3
	Significance		*	*	*	**	*	*

100cm^3 soil samples of CT and IST were collected based on the no-tillage soil surface. * and ** indicate significance at the 0.05 and 0.01 probability levels, respectively (ANOVA, n=3).

might be reduced moisture fluctuation in the no-tillage soil. The SPAD value of the expanded leaf in IST exceeded that in CT from about 30 days after seeding to flowering (Fig. 4), which suggests the effect of adnation of root nodules in IST on the high SPAD value. It is reported that the plant nitrogen derived from nitrogen fixation highly correlates to relative ureide-nitrogen (Herridge et al., 1990). The results evaluated following the method by Takahashi et al. (1992) indicated no difference in relative ureide-nitrogen between CT and IST (Fig. 5). From these results, the change in SPAD value is attributed to the increase in root nodules in IST and not to the increase in root nodule activity.

General discussion

Although excessive soil moisture is the main constraint in UFCP, drought affects soybean growth, especially during the periods from seeding to seedling emergence and flowering to pod setting. In this experiment, soil moisture in IST was maintained, even under drought

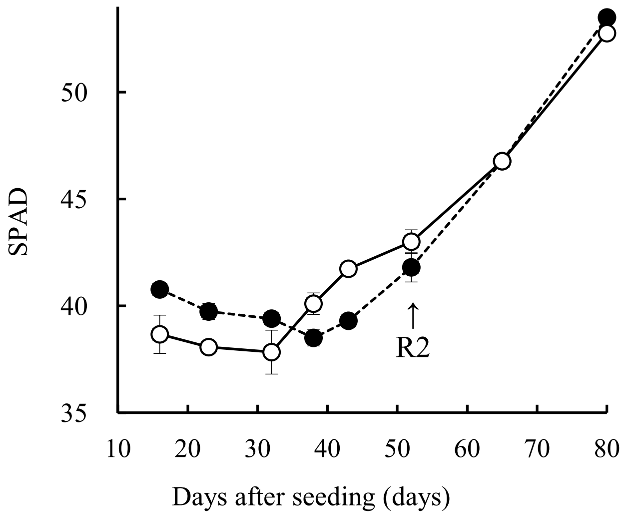

Fig. 4. Effects of tillage method on SPAD
Error bars indicate standard error (n=5). The growth stage was defined based on Fehr et al. (1971).
—●— : CT, —○— : IST.

Table 5. Effects of tillage method on the growth of root at flowering

Tillage Method	2003			2005		
	Root nodule		Root	Root nodule		Root
	(no./plant)	(g/plant)	(g/plant)	(no./plant)	(g/plant)	(g/plant)
CT	49	0.40	1.01	110	0.59	1.48
IST	62	0.47	1.29	149	0.73	1.54
Significance	*	*	*	*	**	ns

Data are from experimental field (Gray lowland soils). * and ** indicate significance at the 0.05 and 0.01 probability levels, respectively (ANOVA, n=3). ns: not significant at the 0.05 level.

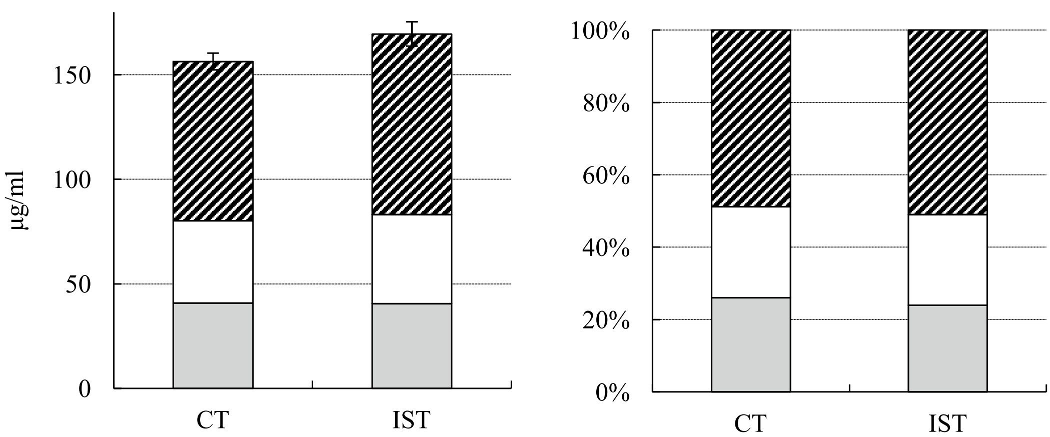

Fig. 5. Effects of the tillage method on ureide-N content and relative ureide in xylem sap
Field experiment. Measurement at R4. Error bars indicate the standard error with 3 replications.
□ : Nitrate-N, □ : Amide-N, ▨ : Ureide-N.

conditions, compared with that in CT. It is assumed that the seeds in IST can achieve uniform seedling emergence because they come into contact with no-tillage soil and absorb water easier than those in CT. The growth stimulation in IST is expected to continue until the later growth period, because the soil property was maintained at the flowering stage, as shown in Table 4.

The activity of root nodules decreased under a drought condition in soybean cultivation (Bennett and Albrecht, 1984; Kirda et al., 1989), while the drought condition also stimulated the decrease in the number of pods, which, in turn, resulted in a yield reduction (Saito et al., 1999).

Thus, it seems that the no-tillage soil in IST is protected from severe drought or excessive moisture, and has advantages in terms of nodulation or the maintenance of nodule activity. The stimulation of nodulation in no-tillage soil following the report of Hughes and Herridge (1989) supports the advantages in IST. Ozawa (1998) reported the flow of water from roots in wet soil to those in dry soil in plants with roots distributed in both, which suggests that drought stress would be alleviated if the roots of plants grown under the drought condition were partially distributed in soil of relatively higher moisture. Thus, the root distribution in soils with different levels of moisture, as occurs in IST, is preferable for the stabilization of growth and yield in UFCP, which tends to experience significant fluctuation of soil water content.

References

1. Bennett, J. M. & Albrecht, S. L. (1984) Drought and flooding on N_2 fixation, water relations, and diffusive resistance of soybean. *Agron. J.,* **76**, 735–740.
2. Fehr et al. (1971) Stage of development descriptions for soybeans, *Glycine Max* (L.) Merrill. *Crop Sci.,* **11**, 929–931.
3. Hamaguch, H., Nakayama, S. & Umemoto, M. (2004) No-tillage and narrow row spacing soybean cultivation manual. *Misc. Pub. Natl. Res. Cent.,* **5**, 1–21.
4. Heeridge, D. F., Bergersen, F. J. & Peoples, M. B. (1990) Measurement of nitrogen fixation by soybeanin the field using the ureide and natural ^{15}N abundance method. *Plant Physiol.,* **93**, 708–716.
5. Hosokawa, H. (2004) Rotary tilling and ridge-making implement of soybean for avoiding wet injury in clay upland field. *J. Agri. Mechin. Jpn.,* **66**, 14–16 [In Japanese].
6. Hughes, R. M. & Herridge, D. F. (1989) Effects of tillage on yield, nodulation and nitrogen fixation of soybean in far north-coastal New South Wales. *Aust. J. Exp. Agric.,* **29**, 671–677.
7. Kirda, C., Danso, S. K. A. & Zapata, F. (1989) Temporal water stress effects on nodulation, nitrogen accumulation and growth of soybean. *Plant Soil,* **120**, 49–55.
8. Kuwahara, M. (1988) Soil moisture effects on soybean root development and nodulation. *J. Jpn. Soc. Soil Physics.,* **57**, 15–21 [In Japanese with English summary].
9. Matsuzaki, M., Takahashi, T. & Hosokawa, H. (2006) Effects of wet condition and application of coated urea on yield and nitrogen accumulation in soybean grown in the field converted from heavy clay paddy in Hokuriku area. *Jpn. J. Crop Sci.,* **75**, 13–22 [In Japanese with English summary].
10. Ozawa, K. (1998) Regulation of plant water and fertilizer absorption due to roots grown in sub-soil. *Bull. Tohoku Natl. Agric. Exp. Stn.,* **93**, 51–100 [In Japanese with English summary].
11. Saito, K., Mahmood, T. & Kuroda, T. (1999) Effect of moisture stress at different growth stages on flowering and pod set in determinate and indeterminate soybean cultivars. *Jpn. J. Crop Sci.,* **68**, 537–544 [In Japanese with English summary].
12. Seko, H. et al. (1987) Stable high yield cultivation of soybean in underdrained rotational upland field. *Bull. Hyogo Pref. Agric. Center Exp. Ext. Educ.,* **35**, 21–24 [In Japanese with English summary].
13. Shimada, S., Kokubun, M. & Matsui, S. (1995) Effects of water table on physiological traits and yield of soybean. 1. Effects of water table and rainfall on leaf chlorophyll content, root growth and yield. *Jpn. J. Crop Sci.,* **64**, 294–303.
14. Shimada, S. (2006) Strategy for improving soybean productivity in the paddy field under paddy-upland rotation. *Jpn. J. Crop Sci.,* **75**, 394–399 [In Japanese].
15. Sugimoto, H. et al. (1988) Excess moisture injury of soybeans cultivated in a upland field converted from paddy. *Jpn. J. Crop Sci.,* **57**, 71–76 [In Japanese with English summary].
16. Takahashi, T., Hosokawa, H. & Matsuzaki, M. (2006) N_2 fixation of nodules and N absorption by soybean roots associated with ridge tillage on poorly drained upland fields converted from rice paddy fields. *Soi. Sci. Plant Nutr.,* **52**, 291–299.
17. Takahashi, Y. et al. (1992) Evaluation on N_2 fixation and N absorption activity by relative ureide method in field-grown soybean plants with deep placement of coated urea. *Soi. Sci. Plant Nutr.,* **38**, 699–708.
18. Watanabe, T. et al. (2004) Newly developed soybean seeding method by the shallow tillage seeding machine with cutting small ditches. *Jap. J. Farm Work Res.,* **40** (Ext. 1), 39–40 [In Japanese].
19. Yahagi, H. et al. (2002) Effects of excessive soil moisture content on the number of flower and pod, and grain yield of different raceme order in soybean plants. *Jpn. J. Crop Sci.,* **71** (Ext. 2), 150–151 [In Japanese].