Soybean Cultivation on Desert Sand Using Drip Irrigation with Mulch

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Abstract: The growth and yield potential of soybean and the effects of mulching on desert sand were evaluated in relation to N accumulation in nodules. The experiment was conducted in concrete framed plots filled with sand obtained from the Dzungar desert or the normal field soil in Shihezi, Xinjiang, China. Drip irrigation with or without mulch was adopted for the experimental plots. The mean soil temperature in the sand plot with mulch was the highest among the plots during the early growth stages. The relative ureide-N content in the soil plots varied from 23.2% at the full flowering stage (R2) to 37.6% at the beginning of the maturity stage (R7). The sand plots showed higher values than the soil plots ranging from 48.7% at R2 to 80.5% at R7, indicating active N₂ fixation by nodules. Seed yield did not show a significant difference between the soil and the sand plots. It ranged from 394 g m⁻² in the soil plot without mulch to 472 g m⁻² in the sand plots with mulch. The results suggested the possibility of extending soybean cultivation into marginal areas of deserts, provided that adequate water was available for drip irrigation and there was active nodulation.

Key words: Desert sand, Drip irrigation, Mulch, Nitrogen fixation, Nodule, Soybean.

Shihezi is located in Northern Xinjiang, China on the edge of Dzungar desert. The amount of precipitation and evaporation in Shihezi are less than 200 mm and more than 1500 mm per year, respectively. Therefore, crop cultivation relies on irrigation water from melted snow from Tianshan mountains. By devising a method of cultivation on sand using a small amount of irrigation water, soybean cultivation could be extended further to marginal areas of deserts and in arid conditions in other countries in Asia.

Water is more effectively applied to the plant by drip irrigation than by other irrigation systems or by rain-fed cultivation because of the easy control of watering (Dasberg and Or, 1999). The amount of water applied can be reduced drastically as compared with the conventional flood, furrow or basin irrigation (Bresler, 1977; Bucks et al., 1982; Skaggs, 2001; Isoda et al., 2007). Therefore, crop cultivation may be extended even into marginal areas of deserts with adequate water provided by the drip irrigation system. However, crop nutrients are always inadequate due to the low contents and low sustainability in sand. Soybean, a major leguminous crop, can obtain nitrogen by symbiotic fixation of atmospheric nitrogen besides the absorption of inorganic nitrogen from the soil, thereby compensating for the shortage of nitrogen in sand. Sinclair (2004) summarized that N accumulation by either N₂ fixation or soil N uptake is closely linked to C accumulation rate, and that N and C accumulation limits the yield of soybean. Isoda et al. (2006) pointed out that one of the possible reasons for high yields of soybean in Xinjiang was abundant solar energy, besides drip irrigation which can supply frequent and sufficient water. Thus, there is less limitation for C accumulation due to abundant solar energy in the marginal areas of the deserts such as the northern Xinjiang, with a high leaf area index. N accumulation seems to be one of the main limitations for yield increase. High-protein seed production of soybean under field conditions requires a large amount of N fixed by root nodules, and mineralized N and fertilizer from soil. In particular, N₂ fixation by root nodules may play an important role in N accumulation in the sand deficient in N. On the other hand, mulching has been widely used for water conservation and increasing soil temperature in Northern Xinjiang. Several reports showed that mulching would regulate soil temperature (Bristow and Abrecht, 1989; Ghosh et al., 2006; Hou et al., 2010) and conserve soil water (Zhang et al., 2007), leading to vigorous early growth (Li et al., 2004). In this experiment, we examined the growth and yield of soybean on the desert sand and the effect of mulching, in relation to N accumulation in nodules.
Materials and Methods

The experiment was conducted at Shihezi Agricultural and Environmental Institute for Arid Areas in Central Asia, Shihezi, Xinjiang, China (86°02' E, 44°18' N, the present name is Urumqi Agricultural and Environmental Institute for Arid Areas in Central Asia) in 2009. Four concrete framed plots (two plots were filled with sand from Dzungar desert, and the other two with the soil from the experimental field which is categorized as light clay) were used. Each plot was 5.4 m × 7.5 m in size with 3 m in depth. The experimental plots were arranged in a split plot design with two replications. Sand or soil with or without mulch were used as the main and sub plot factors, respectively. The soil pH, organic matter and mineral nutrient contents are shown in Table 1. Toyokomachi, a determinate Japanese cultivar, was used. Seeds were treated with Bradyrhizobium japonicum (Mamezou, Tokachi Nokyoren, Japan) for root nodulation before sowing, and sown on 23 April. The planting density was 22.2 and 24.7 plants m⁻² in the soil and sand plots, respectively, due to different distances in pipe laying for each plot. Drip irrigation system with emitters every 20 cm was used. Transparent polyethylene sheet mulch, 0.007 mm in thickness, was applied at the seeding, which was then removed on 24 May. While no fertilizer was applied at sowing, 1 kg urea per plot (6.13 g m⁻² of nitrogen) was sprayed on foliage on 24 May and 7 June. No pest or insect control was performed because there was little crop damage. After emergence, complementary transplanting was carried out for missing stands.

Fourteen plants from each plot were sampled at 14 d intervals from 20 June. The dry weights of roots, stems, leaves and pods from 10 plants, excluding two extremely large and two smallest plants, were measured after being dried in an oven for 48 h at 80°C. Leaf area was measured with an automatic area meter (AAM-7, Hayashidenko Inc., Tokyo, Japan).

Root bleeding sap was collected from 10 plants per plot from the full flowering stage (R2, Fehr et al., 1971) to the beginning of the maturity stage (R7). N₂ fixation by nodules was estimated by the relative ureide method as described by Herridge et al. (1990) and Herridge and Peoples (1990); Relative ureide-N content (%) = ureide-N/(ureide-N + amino-N + nitrate-N) × 100,

where ureide-N, amino-N and nitrate-N were determined by the method of Young and Conway (Young and Conway, 1942), by the ninhydrin method (Yemm and Cocking, 1955) and with a compact nitrate ion meter (B-342, Horiba, Japan), respectively.

Soil temperature was measured using T type thermocouples at two points in each plot during the growing period. The terminals of thermocouples were placed 10 cm below the soil surface. Data were collected at 5-minute intervals with a data logger (Eto-denki Inc., Thermocac E, Japan) connected to a personal computer.

Seed yield and yield components were measured on 20 August. The plants from 1.98 m⁻² were harvested from each plot. Seed were weighed after drying in an oven for 48 h at 80°C.

The data were analyzed using Excel add-on software (Mac Statistical Analysis, ver. 1.5b, Esumi, Japan).

Results

1. Climatic and soil conditions

Fig. 1 shows the mean daily solar radiation, mean air temperature and the amount of water supplied during the growing season. The mean daily solar radiation exceeded 20 MJ m⁻² d⁻¹ every month during the growing season. It was highest in June followed by July. The mean air temperature was similar in April and May, and increased...
up to July, then decreased in August. The amount of irrigation during the growing season was 69% higher in the sand plots than in the soil plots.

The mean soil temperature in the sand plot with mulch was always higher than that in the other plots before 24 May except around 10 May (Fig. 2). The soil plot without mulch had lower soil temperatures during this period. The mean soil temperature in the sand plot with mulch from 25 April to 24 May was higher by 1.4°C and 0.8°C than those in the sand plot without mulch and the soil plot with mulch, respectively. The effect of mulching was greater in the soil plots than in the sand plots. The difference in the mean soil temperature in the plots with and without mulch was 3.1°C on the average during this period.

After the removal of mulch (24 May), the mean and maximum soil temperatures were highest in the sand plot without mulch, followed by the sand plot with mulch. The maximum soil temperature often exceeded 30°C in the sand plot without mulch, probably due to its low thermal capacity. After mid-June, the mean and maximum soil temperatures were highest in the soil plot with mulch followed by the sand plot with mulch, and the soil and sand plots without mulch in this order, for reasons unknown. There was little difference in minimum soil temperature between the soil and sand plots and the plots with and without mulch during the growing season.

Fig. 3 shows the changes in soil nitrate nitrogen with time. The nitrate nitrogen content was higher in the soil plots during the whole growing season. Nitrate nitrogen content in the soil plots fluctuated as compared with the sand plots. There was some change in nitrate nitrogen content in the sand plots with a peak on 29 June and 15 June with and without mulch, respectively. Mulching had a significant positive effect on soil nitrate nitrogen in early June and on 20 July.

2. Dry matter production and leaf area index (LAI)

Fig. 4 shows the total and root dry weights. Total dry weight tended to be heavier in the sand plots than in the soil plots. There was no significant difference between the
plots with and without mulch, though the soil plot without mulch showed the lightest total dry weight throughout the growing season. The sand plots had a heavier root dry weight than the soil plots both with and without mulch during the growing season. The effect of mulching on root dry weight was not clear.

The effect of mulching on LAI in the soil plots was positive, although there was no significant difference between the soil and sand plots, or in the plots with mulch and without mulch (Fig. 5). In the sand plots, the plot without mulch had a higher LAI than the plot with mulch only on 1 July, and there was no difference between the plots on the other dates. In the soil plots, mulching tended to increase LAs on all dates except 1 July.

3. **Nodule dry weight and nitrogen in soil and root bleeding sap**

Nodule dry weight increased with time in both plots (Fig. 6). Nodule dry weight was significantly heavier in the sand plots than in the soil plots throughout the growing season. The effect of mulching was negative in the soil plots and positive in the sand plots except at the beginning of the seed stage (R5, 1 July).

The ureide nitrogen content of root bleeding sap in the sand plots was significantly higher at the 10% level of probability than that in the soil plots throughout the growing season (Fig. 7). The contents of ureide nitrogen did not change much in the soil plots, while it increased at
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Mulching had no significant effect on the nitrate nitrogen content in root bleeding sap.

The relative ureide-N content increased with time in the sand plots, but hardly changed in the soil plots (Fig. 8). The relative ureide-N content ranged from 23.2% at R2 to 37.6% at R7 in the soil plots, and from 48.7% at R2 to 80.5% at R7 in the sand plots, being slightly higher in the latter. Mulching had no significant effect, although the relative ureide-N content in the plot without mulch was significantly higher than in that with mulch at the beginning of the seed stage (R5).

Yield and yield components

There was no significant difference in seed yield between the soil and the sand plots, ranging from 394 g m⁻² in the soil plot without mulch to 472 g m⁻² in the sand plot with mulch (Table 2). Mulching was effective in increasing seed yields in both sand and soil plots. The interaction between soil and mulching also had a significant effect on seed yield. There was no significant difference in pod number between the soil and sand plots, or between the plots with and without mulch. In seed number per pod and 100 seed weight, there was also no difference between the soil and sand plots or between the plots with and without mulch, although mulching tended to have a positive effect on 100 seed weight.

Discussion

The contribution of nitrogen fixation by nodules to yield appears to vary greatly with the soil condition (Rennie et al., 1988; Peoples et al., 1995; Unkovich and Pate, 2000; Nohara et al., 2006). The minimum and maximum values of relative ureide-N contents in the soil plots were observed
at R2 (23.2%) and at R7 (37.6%), respectively, which were similar to the values obtained by Nohara et al. (2006) in the plot with a high nitrate level. On the other hand, the relative ureide-N content was higher in the sand plots than in the soil plots, varying from 48.7% at R2 to 80.5% at R7, with 66.7% and 69.8% on the average in the plots with mulch and without mulch, respectively. The maximum value was similar to that reported by Rennie et al. (1988), and higher than the value reported by Zapata et al. (1987). Bacteroids require relatively large amounts of O2 for respiration, and leghemoglobin apparently not only facilitates O2 diffusion but also maintains low levels of free O2 within the bacteroid, so that nitrogenase activity remains unimpaired (Wittenberg et al., 1974; Rawsthorne et al., 1980). Therefore, the vigorous nodulation in the sand plots might be due to the better ventilation as compared with that in the soil plots.

The reduction of N2 by nitrogenase is a highly energy-consuming process (Serraj et al., 1999), although the photosynthate does not limit N2 fixation (Sinclair, 2004). The reduction of dinitrogen requires an energy source (ATP) and a reductant, which are both supplied by respiratory catabolism of carbohydrates produced by the host plant (Rawsthorne et al., 1980). Photosynthates are also required to generate the carbon skeleton for amino acid or ureide synthesis during the assimilation of ammonia produced by bacteroids within the nodule tissue. Inevitably, competition for photosynthates would occur between the bacteroids and sinks of the host plant. This experiment, however, suggested that such competition did not occur because of the abundance of solar energy available for photosynthesis during the growing season in Northern Xinjiang (Fig. 1).

The seed yields both in the sand and soil plots with mulch were significantly higher than in those without mulch. The soil temperature in the soil plot without mulch during the early growing period was lower than that in the other plots (Fig. 2). Consequently the total dry weight and LAI were lower in the soil plot without mulch than in the soil plot with mulch just after the end of mulching treatment. On the other hand, the effects of mulching on LAI and total dry weight in the sand plots were not clear, and the increase of yield in the sand plot by mulching was smaller than that in the soil plot. The activity of nodules has been reported to increase with the increase in soil temperature up to about 30°C (Munévar and Wollum, 1981; Sinclair and Weisz, 1985). The maximum soil temperatures often exceeded 30°C in the sand plot without mulch after mid May and in the soil plot with mulch after mid June (Fig. 2). The nodule dry weights tended to be lower for the sand plot without mulch and the soil plot with mulch after mid June. Therefore, nodule growth might be restricted by higher soil temperatures in the sand plot without mulch and in the soil plot with mulch during these periods.

Symbiotic nitrogen fixation decreased in response to water deficit prior to many other physiological processes (Durand et al., 1987; Sinclair et al., 1987; Sall and Sinclair, 1991; King and Purcell, 2001). In this experiment, the drought stress was not severe in the sand plots during the growing season, because the nodule volume was larger in the sand plots than in the soil plots. The total amount of irrigation in the sand plot was about 70% larger than that in the soil plot. Such a condition not apply to actual cultivation. However, the drip irrigation can save much water as compared with the furrow irrigation. Isoda et al. (2007) reported that the amount of water for irrigation could be reduced approximately 50% when supplied by drip irrigation than by furrow irrigation in their experiment with a sugar beet crop. Though the conditions may vary with the crop, it may be possible to grow soybean in sand plots using a drip irrigation system. On the other hand, a yield of 472 g m⁻² was obtained in the sand plot with only foliage spraying of nitrogen. The results of the present study imply the possibility to extend soybean cultivation in marginal areas of deserts provided that an adequate water supply for drip irrigation is available.

| Treatment             | Seed yield (g m⁻²) | Pod number (m⁻²) | Seed number (pod⁻¹) | 100 seed weight (g) |
|-----------------------|--------------------|------------------|---------------------|---------------------|
| Soil with mulch       | 452.9              | 710              | 2.2                 | 29.1               |
| Soil without mulch    | 394.1              | 708              | 2.2                 | 25.1               |
| Sand with mulch       | 471.7              | 707              | 2.3                 | 28.9               |
| Sand without mulch    | 434.4              | 664              | 2.4                 | 27.5               |

* *, ** and ns indicate 5%, and 1% level of significance and no significance by F-test, respectively.

Table 2. Yield and yield components.
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