Alternative Experimental Method Using a FRP Pot for Evaluating Wet Damage in Soybean and Morning Glory Grown under Excess Soil Water Conditions

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Abstract: A fiber reinforced plastic (FRP) pot, equipped with a slanted pipe through which water is supplied, has been used for assessment of rice herbicides. This pot may also be useful for controlling water table in upland conditions. In this experiment, early growths of soybean and morning glory grown under waterlogging and excess soil water conditions were evaluated. The waterlogging condition was attained by adjusting the top of the slanted pipe to soil surface level, and excess soil water condition (0.2 m³ m⁻³) by adjusting to 15 cm below the soil surface. The water content of the soil did not fluctuate during the treatment. Shoot growths of soybean and morning glory were poorer under waterlogging than excess soil water condition. The present experimental procedures using a FRP pot could be available for evaluation of wet damage of field crops grown under ill-drained field.

Key words: Glycine max, Ill-drained field, Ipomoea, Nitrogen fixation, Water table level, Weed.

Of several growth inhibiting factors for upland field crops on the upland field converted from paddy in Japan, excess soil water content due to ill-drainage of the fields is most critical. Previously, several researchers have reported the effect of different water table levels on growth and nitrogen fixation of soybean plant in pot experiments (Sato et al., 1980; Maekawa et al., 2011) and in lysimeter experiment (Shimada et al., 1995). Different underdrainage systems (Seko et al., 1987) and furrow irrigation conditions (Sugimoto and Sato, 1993) in the field have also been investigated for their effects on soybean yields. Recently, a Farm-Oriented Enhancing Aquatic System (FOEAS) for soybean production has been developed based on these studies (Shimada et al., 2012).

On the other hand, invasion of alien weeds has been reported in the upland field converted from paddy in Japan (Shibuya et al., 2010). In particular, several species of Ipomoea such as pitted and entire leaf morning glories frequently occur in soybean fields (Hiraiwa et al., 2009; Asakura et al., 2012). They also inhibit soybean production. The growth response to high soil moisture conditions, especially during the early growing stage, when morning glories intensely compete with soybean, should be examined.

A fiber reinforced plastics (FRP) pot has been used as an experimental tool for rice herbicides, and several kinds of rice herbicides were evaluated under water leakage or overflow conditions by using this experiment system. The FRP pot is also useful for controlling the water table levels in the upland field conditions through adjusting the slanted pipes attached to the pot. Especially in evaluating early growths of the soybean and morning glory under different soil moisture conditions, such as waterlogging and higher water table level, the experiment using this pot might be convenient. The present study examined the possibility of applying the FRP pots to evaluate wet damage of soybean and morning glory grown under different soil moisture conditions especially in their early growth stages.

Materials and Methods

1. Setup of FRP pots for controlling soil moisture content
FRP pots (W600 × L600 × H640 mm) were prepared as follows (Fig. 1). Seven kg of gravel (1 to 2 cm in diameter) were filled in a mesh bag for a combine harvester of bean (W580 × L800 mm) and the two bags were placed above...
15 cm on the bottom of FRP pot, and then soil was put on it to 10 cm from top of the pot. Soil used in the experiment for soybean was collected from a paddy field of fine gray lowland soil located at Kikugawa, Shizuoka, Japan. The soil was air dried and then passed through a sieve with 10 mm openings. Value of pH and EC of the soil were 5.6 and 0.159 dS m\(^{-1}\), respectively. Soil for morning glory, on the other hand, was a commercial soil for rice nursery production, which was molded as a granular soil (Green soil, Izumo Green Epoch K.K., Japan). The soil contained no fertilizer with a pH and EC of 5.5 and 0.052 dS m\(^{-1}\), respectively.

The time domain reflectometry (TDR) sensors (EC-5 or 5TE; Decagon Devices, Inc., USA) were set at 5 – 10 cm below the soil surface to measure the volumetric water content of the soil. Value of volumetric water content of the soil was calibrated according to the correction factor, which was confirmed before the experiment for each TDR sensor.

2. Soybean

The experiment was conducted outside under a roof of ultraviolet transmitting film at the Life Science Research Institute of Kumiai Chemical Industry Co., Ltd. (Kikugawa, Japan), in June and July, 2011. At 17 June, 16 seeds of soybean (cv. Fukuyutaka) inoculated with rhizobia (Mamezo; Tokachi Federation of Agricultural Cooperatives, Japan) were sown in each pot. The pots were irrigated with 1.25 L tap water, and covered with cheesecloth to maintain the soil moisture. The slanted pipes were adjusted to keep the water table level at 15 cm below the soil surface, which is called excess soil water (ESW) condition in this paper. Seven days after sowing (7DAS), the seedlings were thinned to 9 plants per pot, and the top of the slanted pipe was adjusted to the soil surface level (waterlogging) and 15 cm below the soil surface (ESW condition). Tap water was applied through the pipe at a rate of 1.5 L per minute, and it was stopped when water overflowed through the pipe. The irrigation was done every 2 – 3 days. This experiment was conducted with four replications for each soil moisture condition.

The length and node number of the main stem were measured every 7 – 10 days. At 17, 27 and 41 DAS, shoot dry weight and total nitrogen (N) content were determined for two plants per pot. Immediately after cutting the shoots at the sampling, xylem sap was collected for determination of ureides, amino acids and nitrate concentrations according to Takahashi et al. (1992). Total N concentration of the shoots was analyzed by a dry combustion method using NC analyzer (Vario MAX CN; Elementar Analysensysteme GmbH, Germany).

3. Morning glory

The experiment was conducted in a plastic greenhouse at the Osaka Prefecture University (Sakai, Japan), in June and July, 2011. FRP pots were prepared as described above, and 16 seeds of pitted morning glory (Ipomoea lacunosa L.) and entire leaf morning glory (I. hederacea (L.) Jacq. var. integrivsula A. Gray) were sown in each pot on 24 June. The pots were irrigated with 1.25 L tap water and the top of the slanted pipes were adjusted to 15 cm below the soil surface to maintain the ESW condition. At 10 DAS, the top of the slanted pipe was adjusted to the soil surface level (waterlogging) or retained at the same level (ESW...
This experiment was conducted with three replications for each treatment. Stem lengths of the plants were measured at 9, 14 and 19 DAS in each treatment.

Results and Discussion

1. Changes in soil moisture contents of FRP pot

During 7 DAS of soybean, no fluctuation of the daily mean soil water content was observed, and it was approximately 0.20 m$^3$ m$^{-3}$ (Fig. 2a). After adjusting the top of the slanted pipe to the soil surface level (waterlogging), the soil water content immediately increased, and it ranged from 0.45 to 0.32 m$^3$ m$^{-3}$ during the early growth stage in soybean. The volumetric water content of the soil in the morning glory experiment was similar to that in the soybean experiment, i.e., it was approximately 0.24 m$^3$ m$^{-3}$ (ESW) during 10 DAS, and increased immediately after setting the top of the pipe to the soil surface level (waterlogging) (Fig. 2b).

Soil used for soybean was gray lowland soil sampled from the paddy field of a grower. Because the soil surface of the pot was covered with fine soil particles derived from clay of the paddy soil, emergence of some seedlings was slightly inhibited. For the morning glory experiment, commercial soil for rice nursery production, which was molded as granular soil, was used to avoid the inhibition of emergence. Although the pH of the soil for rice nursery is generally lower (4.5 – 5.5), pH 5.5 of the soil used in this experiment was not a constraint for seedling growth of morning glory. Clay film was not found on the granular soil surface and then morning glory seedlings normally emerged. As a result, the FRP pot was confirmed to be applicable for setting excess soil water condition in the two different soils.

In the present experiment using the FRP pot with a slanted pipe, the water table level could be easily controlled, therefore, wet condition at each growth stage might be changed and its duration might also be changed by adjusting the slanted pipe. In addition, the amounts of soil filled in the FRP pot can be larger than those of conventional pots. This experimental pot system might be used to evaluate these crop responses to excess soil water conditions. Actually, soybean and morning glory plants grown under excess soil water condition using these pots showed typical wet damage, which has been reported previously. The actual growth responses of those two plants grown under the present experimental conditions are as follows.

**Table 1.** Length and node number of the main stem of soybean plants grown in FRP pots under different soil moisture conditions.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Length of the main stem (cm)</th>
<th>Node number of the main stem</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7 DAS</td>
<td>17 DAS</td>
</tr>
<tr>
<td>0 cm BSS</td>
<td>6.3</td>
<td>12.3</td>
</tr>
<tr>
<td>15 cm BSS</td>
<td>5.9</td>
<td>14.4</td>
</tr>
<tr>
<td>t-test</td>
<td>NS</td>
<td>**</td>
</tr>
</tbody>
</table>

$^a)$ DAS: days after sowing.

$^b)$ BSS: below the soil surface.

$^c)$ * and ** represent significant difference at 5% and 1% probability level, respectively. NS means no significant difference.
2. Effect of soil moisture content on early growth of soybean

The length and number of nodes on the main stem of soybean grown in the FRP pot were significantly lower under the waterlogging condition than the ESW condition (Table 1, Fig. 3). Under the waterlogging condition, the lower leaves were yellowish showing the wet damage (Maekawa et al., 2011).

Shoot dry weight of soybean grown in waterlogging condition from 7 DAS was much lower than that grown continuously under the ESW condition (Table 2). The dry weight of both leaves and stems were on the average 40% lower under the waterlogging condition than under the ESW condition. The inhibition of shoot growth at the cotyledonary and primary leaf stages influenced that at the following growth stages. Due to the significantly higher total N concentrations in leaves and stems, except at 27 DAS, the total N content of leaves and stems was significantly lower under the waterlogging condition than the ESW condition (Table 2).

At 17 DAS, the percentage of ureide-N in xylem sap under the waterlogging and under the ESW condition was 26 and 9%, respectively (Fig. 4). These values indicated that the N-fixing activity of root nodules was lower at this growth stage in both waterlogging and ESW conditions. At 27 DAS, several root nodules were observed on adventitious roots formed near the soil surface, and the percentages of ureide-N in xylem sap was 81% under the ESW condition showing a higher contribution of N fixation to total N uptake. On the other hand, the percentage of N in the xylem sap in the waterlogging condition at 27 DAS was not significantly different from that at 17 DAS. At 41 DAS, ureide-N percentage was not nearly the same under the two conditions, but the total N content of shoots was significantly higher in ESW in the waterlogging condition (Fig. 4, Table 2).

The wet damage of soybean grown in the upland field converted from paddy fields in Japan has been studied previously using many leading cultivars such as Tachinagaha, Enrei, and Tamahomare have been evaluated. For example, Shimada et al. (1995) reported that the length of main stem and the shoot dry weight of Tachinagaha grown under lycimeter conditions were definitely inhibited by higher soil moisture contents. These effects were found not only in shoot growth, but also in the growth and development of root systems and nitrogen fixation in Enrei grown in the pot (Ma et al., 2005) and Enrei and Sakukei No. 4 in the field trial (Matsunami et al., 2007). Similar wet damages were observed in the present FRP pot experiments.

![Fig. 3. Soybean plants grown in FRP pots under different soil moisture conditions for 24 days after sowing. a) waterlogging from 7 DAS, b) maintaining the ESW condition.](image1)

![Fig. 4. Percentages of N compounds in xylem sap of soybean plants grown in FRP pots under waterlogging and ESW conditions. DAS: days after sowing.](image2)

### Table 2. Dry weight and total N content of the shoot of soybean plants grown in FRP pots under different soil moisture conditions.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Leaf Shoot dry weight</th>
<th>Stem Shoot dry weight</th>
<th>Total N content of shoot</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>17 DAS*</td>
<td>27 DAS</td>
<td>41 DAS</td>
</tr>
<tr>
<td>0 cm BSS</td>
<td>0.4</td>
<td>2.3</td>
<td>5.8</td>
</tr>
<tr>
<td>15 cm BSS</td>
<td>1.3</td>
<td>4.9</td>
<td>14.2</td>
</tr>
<tr>
<td>Test (1)</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
</tbody>
</table>

a) DAS: days after sowing.
b) BSS: below the soil surface.
(1) * and ** represent significant difference at 5% and 1% probability level, respectively. NS means no significant difference.
3. Effect of soil moisture content on early growth of morning glory

The changes in the length of main stem of morning glory in the early growth stage varied with the species (Fig. 5). Entire leaf morning glory grew slowly even under the ESW condition. Pitted morning glory grew faster than the entire leaf morning glory, and increased the stem length even under waterlogging treatment, though the growth was significantly reduced under the waterlogging condition. In this species, adventitious root formation, which might be one of the responses to excess soil water, was observed near the soil surface after 5 days of waterlogging (Fig. 6).

Sumiyoshi et al. (2010) reported that the survival rate at the cotyledonary stage under the flooded condition was higher in the pitted morning glory than in the entire leaf morning glory. Seo (2011) also reported that the pitted morning glory formed adventitious roots under the flooded condition. In the present experiment using an FRP pot with a slanted pipe to adjust the water table level, the effect of higher soil moisture content on growth of this plant species was also confirmed, showing that the pitted morning glory might be more wet tolerant than the entire leaf morning glory. Thus, the weed damage by the pitted morning glory may be severer than that by the entire leaf morning glory in ill-drained upland field converted from paddy field.

In a further study, the interaction between soybean crop and weedy morning glory could be defined using the FRP pot cultivation system, because the water table level could be readily altered according to the experimental arrangement.

References


* In Japanese with English abstract.
** In Japanese with English summary.
*** In Japanese.