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Soybean growth traits suitable for forage production in an Italian ryegrass living mulch system

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ABSTRACT

Forage soybean, like alfalfa, is a source of high-protein feed, but expansion of forage soybean cultivation has been prevented by restrictions on the use of herbicides. Although the use of living mulch (LM) is considered as an effective technique for weed control without requiring the use of herbicides, LM sometimes suppresses not only weed but also main crop growth. In the present study, field studies using eight soybean varieties were conducted to evaluate suitable traits and varieties of soybean for forage production in LM systems. Italian ryegrass was sown as a living mulch in April, and soybean was sown without tillage after the ryegrass was mowed in June. The whole-plant yield of soybean was decreased by LM for most varieties, and this yield reduction was larger in early-maturing than in late-maturing varieties. The whole-plant yield in the LM system was higher for late-maturing varieties, but the variety with the highest yield, Fukuyutaka, showed severe lodging, implying that marked yield loss would occur during harvest by farming machinery. In contrast, the variety with the second-highest yield, Tachinagaha, had strong lodging resistance. Whole-plant yield was highly correlated with the vegetation cover ratio of soybean at flowering, which was affected by earliness of soybean and competition with LM. The crude protein content of soybean varieties which reached the beginning of the maturity stage was >20% and was higher than that of imported alfalfa hay ranked as premium grade. Thus, soybean varieties with high whole-plant yield, crude protein content, and lodging resistance are suitable for forage soybean production in LM systems.

1. Introduction

The recently soaring price of imported livestock feed has focused attention on increasing the self-sufficiency rate of feed in Japan. In particular, leguminous forage, namely alfalfa (*Medicago sativa* L.), largely depends on imports. The cultivation of alfalfa has been attempted but has not expanded widely in Japan because alfalfa prefers alkali soil and shows poor growth on acid soils (Rice et al., 1977; Adams, 1984) which are widely distributed in Japan.

As a new leguminous forage crop, soybean (*Glycine max* (L.) Merr.), has been the focus of attention in recent years. In the United States, for example, soybean varieties especially for use as forage have been developed and widely cultivated (Devine and Hatley, 1998; Devine et al., 1998a,b). In other countries, such as Turkey and Taiwan, studies of the productivity and quality of forage soybean have also been conducted (Altinok et al., 2004; Chang et al., 2012; Acikgoz et al., 2013). Soybean has higher tolerance to acid soil than alfalfa (Adams, 1984; Tanaka et al., 1984) and may be more suitable for the environmental conditions in Japan. In addition, soybean that contains crude protein (CP) in high concentrations has an advantage with respect to the flexibility of harvest dates as well as higher tolerance to acid soil because soybean forage quality remains high for a long period (Blount et al., 2009). Balde et al. (1993) reported that the CP content of alfalfa decreased with growth from the early bud stage (25%) to the full flowering stage (18%). In contrast, the CP content of whole soybean plant increased from the flowering stage (18%) to the maturity stage (25%) (Blount et al., 2009).

Restriction of the use of most agrochemicals is a critical limitation for forage soybean production (Blount et al., 2009), which has prevented its expansion. Even in the United States, where forage soybean is cultivated, many herbicides are restricted for use on soybean when used as forage (Scott et al., 2016). In Japan, there is no registered herbicide for forage soybean production. For this reason, weeds must be suppressed by cultural methods such as narrowing rows and increasing crop population (Blount et al., 2009).

We hypothesized that the introduction of a living mulch (LM) into forage soybean production systems would be another effective

Abbreviations: CP, crude protein; DAS, day(s) after sowing soybean; VCR, vegetation cover ratio; LM, living mulch; No-LM, without living mulch treatment; With-LM, with living mulch treatment.

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technique for suppressing weed growth without using herbicides. Our previous studies revealed that weeds could be appreciably suppressed by the use of Italian ryegrass (*Lolium multiflorum* Lam.) as an LM in northern Japan (Kaneko et al., 2011). In this LM system, Italian ryegrass was sown in early April and mowed in mid- to late June. Immediately after ryegrass mowing, soybean was sown directly into the ryegrass sod without tillage and then harvested in October. The Italian ryegrass variety with a strong winter habit continued vegetative growth and covered the soil shortly after the sowing of soybean. Kaneko et al. (2011) also found that the LM suppressed weed growth effectively even in a field with high weed pressure and that 3.2–5.8 Mg ha^{-1} of whole soybean plants could be harvested in 2 years. The fermentation quality and feeding value of the forage soybean silage harvested in this LM system were good (Kawamoto et al., 2013; Touno et al., 2014). Kawamoto et al. (2013) also investigated the effect of the soybean growth stage on the percentage dry-matter of harvested crop: they reported that when soybean reached R7 stage, its dry-matter percentage reached higher than 30% and it could be harvested by the direct cutting systems (i.e., without a wilting process) using a corn harvester to produce high-quality silage. Among the merits of this LM system, the Italian ryegrass, harvested in late June, could also be used as good-quality forage (Touno et al., 2014).

Although the effectiveness of Italian ryegrass LM against weed growth and the utility of the forage soybean harvested in the LM system have been reported as described above, there is limited information on the growth traits of soybean that are ideal in the LM system for stable production of good-quality forage with a high yield without dependence on herbicides. In particular, considering that an LM sometimes suppresses not only weed but also soybean growth (Ateh and Doll, 1996), it is also desirable to investigate the competition between soybean and LM and to identify soybean varieties tolerant of Italian ryegrass LM. To address these needs, the present study evaluated 1) the varietal difference in whole-plant yield and CP content that are important traits for use of soybean as a protein feed, and 2) the effects of soybean—LM competition and the growth traits of soybean on this varietal difference, by comparing the growth of eight soybean varieties widely cultivated for grain production in Japan in fields with and without Italian ryegrass LM. The vegetation cover ratio (VCR), defined as the area covered by vegetation as a percentage of soil surface area, was used to analyze the competition, because it is a reliable index of competition between plants (Rasmussen et al., 2007; Steinmaus et al., 2008; Uchino et al., 2015).

2. Materials and methods

The field experiments were conducted at the Tohoku Agricultural Research Center, NARO (Morioka, Iwate, Japan, 39°45′ N, 141°08′ E) from 2011 to 2012. The soil was light clay (Pachic Melanudand). Eight typical grain-type and determinate-type soybean varieties, Ryuho (categorized as Japanese maturity group IIb), Oosuzu (IIb), Suzukari (IIb), Enrei (IIc), Fukuibuki (IIc), Kinusayaka (IIc), Tachinagaha (IIc) and Fukuyutaka (IVc), were used in this study. The Japanese maturity groups are denoted by Roman numerals, which represent days from sowing to flowering, followed by Arabic characters, which represent days from flowering to maturity (Fukui and Arai, 1951). Currently, these varieties are cultivated mainly for grain production in Japan.

The experiment was arranged as a split-plot design with three replications. The main plots consisted of two levels of LM treatment, with LM (hereafter With-LM) and without LM (No-LM). The subplots were assigned to eight soybean varieties. In With-LM, Italian ryegrass (cv. 'Ace') with a high degree of winter habit was sown as an LM after tillage on April 5, 2011 and April 17, 2012 at a rate of 3 g m^{-2}, and was harvested at a mowing height of 6–7 cm 1 day before sowing soybean. Soybean seeds were sown directly into Italian ryegrass sod without tillage, with a commercial no-till planter (PFLT-275, Minoru Industrial Co., Ltd., Okayama, Japan) on June 17, 2011 and June 19, 2012. A compound fertilizer (N: 14%, P_2O_5: 28%, K_2O: 14%) was broadcasted at a rate equivalent to 5 g N m^{-2} at the time of sowing of the ryegrass LM. Dolomite was also broadcasted at 100 g m^{-2} for soil amendment. Potassium chloride was surface-applied at 15 g K_2O m^{-2} at soybean sowing. In No-LM, soybean seeds were sown after tillage on the same date as With-LM. Magnesium phosphate and potassium chloride were broadcasted at 10 g m^{-2} P_2O_5 and 15 g m^{-2} K_2O, respectively. Dolomite was broadcasted at the same rate as With-LM. For both LM treatments, the sowing density of soybean was 44 seeds m^{-2}, and seedlings were thinned after plant establishment to the target density of 22 plants m^{-2}. Each plot was 3 × 8 m in 2011 and 3 × 6 m in 2012, and consisted of four soybean rows planted 75 cm apart.

Weeds were controlled by herbicides and hand weeding in No-LM: dimethenamid and linuron were applied at 84 and 72 mg a.i. (active ingredient) m^{-2}, respectively, at soybean sowing, and fluazifop-p and bentazone were applied at 17.5 and 60 mg a.i. m^{-2}, respectively, in both years, 5 weeks after soybean sowing. Hand weeding was performed 8 and 7 weeks after soybean sowing in 2011 and 2012, respectively. No herbicides or weeding were applied in With-LM. Neither intertillage nor molding was performed in either LM treatment.

Italian ryegrass LM in a 1 × 1-m quadrat in each plot was cut at a height of 6–7 cm above ground level at the June harvest, and dry weight was recorded after drying at 70 °C for >72 h. Days from sowing soybean to R1 (beginning flowering) and R7 (beginning maturity) growth stages were recorded according to Fehr et al. (1971). The VCR of soybean, LM, and weed was recorded at weekly intervals from sowing soybean to ca. 80 days after sowing (DAS). VCR measurement was performed as described by Uchino et al. (2009) and Uchino and Iwama (2010). Briefly, near-infrared images were acquired from 2 to 3 m above ground using a cover ratio camera (Kimura Oyokogei, Saitama, Japan). Italian ryegrass and/or weeds were removed from the images with an image processing program (GIMP 2.8, http://www.gimp.org/), and the VCR for each of soybean, Italian ryegrass, and the weeds was estimated separately with software for calculating VCR (Kimura Oyokogei, Saitama, Japan). The number of soybean plants inclined more than 45° from the vertical was determined at the R7 stage, and the lodging ratio (%) was calculated as 100 × the number of inclined plants in the two center rows/the total number of plants in the two center rows.

At 7–10 days after the R7 stage of each variety, lodged plants were raised manually and soybean was harvested at a height of 10 cm from a 2-m length of the two center rows. Harvested soybean plants were separated into grain and other parts (stem + leaf + pod wall), and dry weight was measured after drying at 70 °C for more than 72 h. Weeds were harvested from the inter-row space between the two soybean rows, and their dry weight was recorded. The dried samples of soybean were ground, and the nitrogen content of each plant part was determined by the Kjeldahl method. The CP content was computed by multiplying the nitrogen content by the nitrogen-to-protein conversion factor, 6.25.

Statistical analysis was performed using Statistix software (version 10, Analytical Software, Tallahassee, FL, USA). Analysis of variance (ANOVA) was performed using a combined model where year, LM treatment, and soybean varieties were treated as fixed factors and replication as a random factor (McIntosh, 1983). Differences between treatments were tested by the Tukey–Kramer method when ANOVA *F*-test was significant.