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Effects of water table management and row width on the growth and yield of three soybean cultivars in southwestern Japan

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ABSTRACT

In southwestern Japan, soil water fluctuations from flooding to drought cause unstable soybean yields. Water table management (WTM) with sub-irrigation/drainage systems will overcome the soybean yield instability by inhibiting these fluctuations. Narrow row cultivation is expected to increase soybean yields. The effects of WTM and row width on soybean growth and yield in this region are not clear. We evaluated the effects of WTM with sub-irrigation/drainage systems and row widths (35 or 70 cm) on the growth and yield of one conventional (tall main stem) and two newly developed (short main stem) soybean cultivars. The WTM consisted of (1) fluctuation of the water table between the natural water table depth and that at 30 cm depth according to the growth stage and weather conditions, especially rainfall events (newly developed); (2) maintaining the water table at a 30 cm constant depth throughout the growth period (recommended in Japan); and (3) the natural water table with an underdrain (control). No significant interaction was observed between the WTM and cultivar or row width treatment, indicating that cultivars and row width treatments responded similarly to WTM. WTM 1 and 2 decreased the soybean yield by approx. 5% when the natural water table depth in control existed at 50–60 cm depths throughout the growing period, indicating that the natural water table depth in control was near optimum for soybean growth and yield. Before performing WTM, therefore, the natural water table depth should be measured and considered. The combination of newly developed cultivars with narrow rows had similar or greater yields than conventional cultivation (cultivar and row width), due mainly to an increase in pods m^{-2} and a decrease in yield loss without severe lodging. Thus, yield potential in southwestern Japan could be increased by narrow row cultivation, but cultivars with short main stem lengths should be cultivated.

1. Introduction

Soybean (*Glycine max* [L.] Merr.) is one of the important crops in the world, because of its abundant protein and oil contents. In Japan, more than 80% of soybean crops are cultivated in fields that are converted from paddy fields (MAFF, 2015). Those paddy fields were originally designed to hold irrigation water, and thus the drainage speed in the fields is generally low. In southwestern Japan, the optimum planting date is considered to be early July to mid-July (Uchikawa et al., 2003), but the rainy season (early June to mid- to late July) sometimes overlaps with this period. Thus, growers sometimes cannot plant soybean seeds at the optimum planting period.

In addition, if a rainfall occurs before planting, planting will be delayed because the agricultural machinery cannot be operated at such times. If a heavy rainfall occurs after planting, the soil surface will be flooded, causing the reduction of seedling establishment or early plant growth (Hamada et al., 2007; Nakayama et al., 2004). The rainy season in southwestern Japan sometimes continues until late July, resulting in late (late July to early August) planting which often causes yield reduction due to insufficient vegetative growth (Egli et al., 1987; Fatichin et al., 2013). Therefore, the speed of the drainage of paddy soil should be improved.

In addition to flooding stress during the rainy season in southwestern Japan, the amount of rainfall is relatively small after the rainy season (late July to September). This imposes drought stress on soybean plants, decreasing the seedling establishment or early

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vegetative growth. This may cause a reduction of the seed yield. In this way, the soil moisture fluctuation from flooding to drought inhibits the stability of the soybean yield in southwestern Japan.

Lysimeter and greenhouse experiments demonstrated the existence of an optimum water table for obtaining high soybean yields (Nathanson et al., 1984; Madramootoo et al., 1995; Shimada et al., 1995, 1997), but it may be difficult to control the groundwater level precisely in actual crop fields. To solve these problems, field equipment with a sub-irrigation/drainage system, which is called a farm-oriented enhancing aquatic system (FOEAS), was developed in 2005 (Shimada et al., 2012; Wakasugi and Fujimori, 2009) to manage the water table depth even under the field conditions. When the drainage mode is used, extra surface water that is present during the rainy season is quickly drained, facilitating the field operation with agricultural machinery soon after rainfall. When the sub-irrigation mode is used, the water table can be set at the desired depth between +10 and −35 cm from the soil surface. Thus, paddy rice and upland crops, such as soybean, wheat and barley, can be cultivated in the same fields. For the upland crops, if drought spell continues for several days, the sub-irrigation system can alleviate drought stress.

The effects of water table management (WTM) with a sub-irrigation/drainage system on soybean growth and yield under field conditions were examined in the U.S. and Canada (Cooper et al., 1991; Fisher et al., 1999; Mejia et al., 2000; Nelson et al., 2011). In most of those studies, WTM with a sub-irrigation/drainage system increased the soybean yield compared to that under free-drainage conditions. In Japan, however, there are few reports on the effect of WTM on soybean growth and yield under field conditions. Shimada et al. (2012) reported that WTM with a FOEAS at the constant depth of 20 or 32 cm throughout the growing period significantly increased the soybean (cv. Tachinagaha) yield compared to the yield obtained without WTM (i.e., only open-ditch drainage) in mid-Japan. In contrast, Matsuo et al. (2013) reported that in southwestern Japan, WTM with a FOEAS at a constant depth of 20 cm throughout the growing period tended to decrease the yields of two soybean cultivars compared to the yields obtained under the control conditions (i.e., only an underdrain was used), and the effect of WTM at the constant depth of 35 cm throughout the growing period on the yield was not significant for either cultivar. Thus, the effect of WTM might differ between cultivation areas and cultivars. However, in the above-cited studies in Japan, the water tables were maintained at constant depths throughout the growth period, even though the FOEAS used could freely change the water table from +10 to −35 cm depth at any time. Ayars et al. (2006) proposed the ideal WTM in which the water table is maintained at the position where the root systems exist at an early growth stage and is then lowered as the root systems grow. It is possible that the use of a FOEAS will help develop new techniques for optimum WTM, as proposed by Ayars et al. (2006).

To increase agricultural income, low-cost and labor-saving cultivation techniques are required. To realize low-cost cultivation, the yield should be increased and the usage of agricultural materials, such as agrichemicals, should be minimized. To realize labor-saving cultivation, some agricultural practices should also be minimized. To achieve these purposes, narrow-row cultivation may be one of the desirable techniques. Several studies demonstrated that narrow-row cultivation increased soybean yields (Bullock et al., 1998; Cooper, 1997; Cox and Cherney, 2011; Robinson and Wilcox, 1998). In addition, weed emergence and/or weed growth can be inhibited by narrow-row cultivation, because the aboveground parts of plants grown in narrow-row cultivation cover the ground more quickly than those in wider row cultivation (Matsuo et al., 2015). Thus, the costs for herbicide or the labor for intertillage and ridging, which are conventional agricultural practices used in Japan to control weed population, can be minimized.

The soybean cultivar Fukuyutaka, which is a leading cultivar in southwestern Japan and has long been cultivated for more than 30 yr, has a long main stem. Thus, lodging often occurs with this cultivar under narrow-row cultivation, because intertillage and ridging cannot be performed under this cultivation (Matsunaga et al., 2003). Lodging sometimes makes harvesting by agricultural machinery difficult, and it reduces soybean yields. Thus, new soybean cultivars with a short main stem and lodging resistance even under narrow-row cultivation are needed in order to shift from conventional wide-row cultivation to narrow-row cultivation in southwestern Japan. Indeed, some cultivars with a short main stem and lodging resistance were recently bred in Japan.

The objective of the present study was to evaluate the effects of three types of WTM on the growth, lodging, yield and yield components of three soybean cultivars under narrow (35 cm) and conventional normal row (70 cm) cultivation. We hypothesized that: (1) WTM depending on the growth stage and/or weather conditions (especially rainfall events) may increase soybean growth and yield compared to soybean plants grown under conditions in which the water table is maintained at a constant depth of approx. 30 cm throughout the growing season (recommended in Japan) or not managed under natural water table conditions (i.e., only an underdrain was used), and (2) narrow-row cultivation is suitable for newly developed soybean cultivars with short main stems.

2. Materials and methods

2.1. Site description and plant materials

The field experiments were conducted in 2011, 2012 and 2013 at the Kyushu Okinawa Agricultural Research Center (KARC), Chikugo, Fukuoka, Japan (33° 12′ N, 130° 30′ E, 10 m elevation). There were three FOEASs at the KARC during those years, next to paddy rice fields. Before conducting the experiment, a field was divided into three plots and FOEASs were constructed in each plot. Thus, three WTM treatments could be conducted in a single year. The distance between the WTM treatments examined in the present study was approx. 3 m. The water movement between the treatments and seepage were inhibited by compacting the soil and by burying vinyl sheets down to a depth of >60 cm.

The soil was lowland paddy soil (Typic Endoaquept) and contained 23.0% sand, 36.1% silt and 41.9% clay (light clay). The previous crop was wheat for all three years. The soybean cultivars used were Fukuyutaka (maturity group VI), Sachiyutaka A1 (maturity group V) and Hatsunagaha (maturity group IV). Fukuyutaka is a conventional cultivar, released in 1980 and cultivated widely in southwestern Japan and Sachiyutaka A1 was bred by the Institute of Crop Science, Tsukuba, Ibaraki, Japan and released in 2012. Hatsunagaha was bred by the KARC and released in 2014. Fukuyutaka has a long main stem, whereas Sachiyutaka A1 and Hatsunagaha have short main stems.

2.2. Crop management

Soybeans were grown in the same field for all three years. The planting date was July 11, July 18 and July 16 in 2011, 2012 and 2013, respectively (Table 1). After seedling establishment, the following three WTM treatments were conducted. (1) The water table was manipulated during crop season depending on the growth stage and weather conditions (especially rainfall events) by using both sub-irrigation and drainage modes (FL plot). (2) The water table was set at −30 cm depth throughout the crop season by using only the sub-irrigation mode (30-cm plot). (3) An artificial water table was not set throughout the crop season, by using only the drainage mode with the natural water table (Control plot).