Flooding Affects Root Morphology and Photosynthesis in Soybean [*Glycine max* (L.) Merr.]

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Abstract

Flooding is a major problem that reduces soybean [*Glycine max* (L.) Merr.] growth and grain yield in many areas of the world. Two soybean cultivars were flooded during vegetative stage and flowering time for ten days. Root morphological traits, development of adventitious roots were analyzed after flooding. Photosynthesis of soybean cultivars was reduced under the flooding condition in both growth stages. The photosynthesis of soybean was recovered after flooding in vegetative stage while flooding in flowering stage caused severe damage on soybean plants. No aerenchyma was observed in roots of non-flooded plants; however, it was abundant in roots of flooded plants. Aerenchyma development was more abundant during vegetative growth stage than reproductive stage. Lower aerenchyma formation in reproductive stage may cause lower adaptability in flooded condition.

Media Summary

To develop water logging tolerance soybean cultivars, it is necessary to understand morphological and physiological soybean responses on the flooding.

Key Words

Flooding, water logging, photosynthesis, root, soybean

Introduction

Excess water causes water logging or complete submergence of shoot and root. Water logging affects 12% of the agricultural soils in the USA (Boyer, 1982) and is a major limitation to cultivate soybean in paddy field. Soybean is subjected to potential water logging damage in these fields because of poor surface and internal soil drainage. Water logging can greatly reduce soybean yield. Yield can be reduced 17 to 43% if soybean is subjected to water logging at the vegetative growth stage, while yield can be reduced by 50 to 56% if water logging stress occurs at reproductive growth stages (Oosterhuis et al., 1990; Scott et al., 1990). Yield losses from excess soil moisture likely arise from reduced root growth, nodulation, nitrogen fixation, photosynthesis, and plant death due to diseases and physiological stress (Oosterhuis et al., 1990; Sallam and Scott, 1987; Schmitthenner, 1985; Scott el al., 1990). Nitrogen fixation is considerably more sensitive to flooding stress than is biomass accumulation. Additionally, flooding stress severity is less when nitrate is substituted for nitrogen fixation as the primary N source (Bacanamwo and Purcell, 1999a). Flooding acclimation in soybean relying on nitrogen fixation is dependent on adventitious root and aerenchyma formation (Bacanamwo and Purcell, 1999b). Lysigenous aerenchyma contributes to the ability of plant to tolerate low-oxygen soil environments, by providing an internal aeration system for the transfer of oxygen from the shoot. However, aerenchyma formation requires the death of cells in the root cortex (Drew et al., 2000). Flooding at V6 stage, aerenchyma developed only in flooding-tolerant cultivar (Lee and Cho, 2007). Secondary aerenchyma, a white and spongy tissue, forms 30% of porosity in flooded hypocotyl with well-developed cultivars while it forms less than 10% of porosity in flooded but no-aerenchyma-developed cultivars (Shimamura et al., 2003). More adequate supply of oxygen to the root system associated with aerenchyma formation leads to at least partial recovery of N metabolism of the nodulated root system of soybean during a prolonged period of flooding (Thomas et al., 2005). Although several studies have looked into the metabolic and morphological aspects of flooding, these have mostly been carried out in vegetative stages while flooding stresses in reproductive stages are more severe than in vegetative stage. Therefore, the present study was carried out in an attempt to relate flooding response of soybean in vegetative stages with reproductive stages in order to understand the soybean responses under flooding condition.

Methods

The study carried with two soybean cultivar Taekwang and Asoaogari. Plants were planted in 2-L pots (two plants per pot) in soil and grown under well irrigated condition in a greenhouse. When the plants reached V4 and R1, the pots were placed inside 1m3 plastic tank with drain valve and flooded. The water level was maintained 2-3 cm above the surface of the soil. The duration of the flooding treatment was 10 days. Non-flooded controls were also grown in the same condition except flooding. During the treatment, photosynthesis was measured by LCpro+ portable photosynthesis system (ADC Bio., England). After the measurement of photosynthesis, petioles were sampled to analyze ureide content. Roots were sampled periodically and the porosity was measured by a pycnometer method (Jensen et al., 1969).

Result

Photosynthesis and leaf greenness

During V4 stage, photosynthesis and leaf greenness were reduced significantly for both soybean cultivars in the flooding treatment. Photosynthesis was not changed in three days of flooding while it was significantly reduced seven days after flooding. Leaf greenness decreased three days after flooding while the decreasing tendency is moderate than that of photosynthesis. Although cultivar Taekwang showed significantly higher photosynthesis than Asoaogari before the treatment, flooding caused more damage to Taekwang. Greenness of leaves of Taekwang showed bigger decreasing slope than leaf greenness of Asoaogari (Fig. 1.).

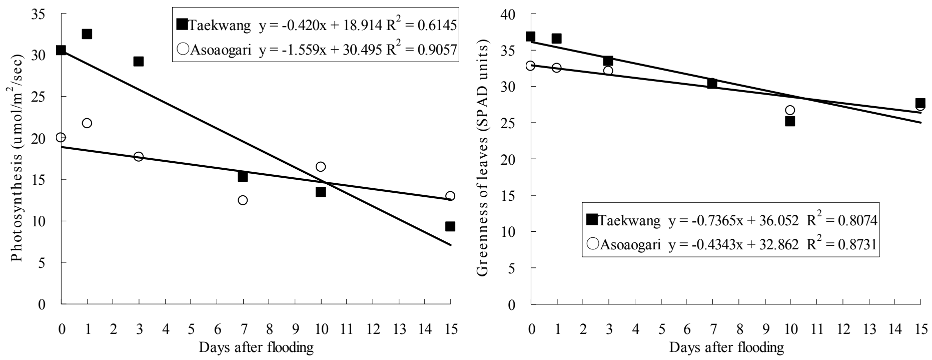

Fig. 1. Effect of flooding on photosynthesis and greenness of soybean plants at V4 stage. Plants were flooded for ten days. The linear equations are significant at the probability level of 0.001 by the SAS regression analysis.

During R1 stage, photosynthesis and greenness of leaves were significantly decreased for both cultivars in the flooding treatment. Although the cultivar Asoaogari showed less decrease of photosynthesis and leaf greenness at V4 stage, the cultivar was withered to death at three days after flooding. Decrease of photosynthesis in the cultivar Taekwang in R1 stage started three days after flooding treatment. Greenness of leaves of the cultivar Taekwang was decreased by flooding treatment and the decreasing tendency was same with the result in V4 stage (Fig. 2.)

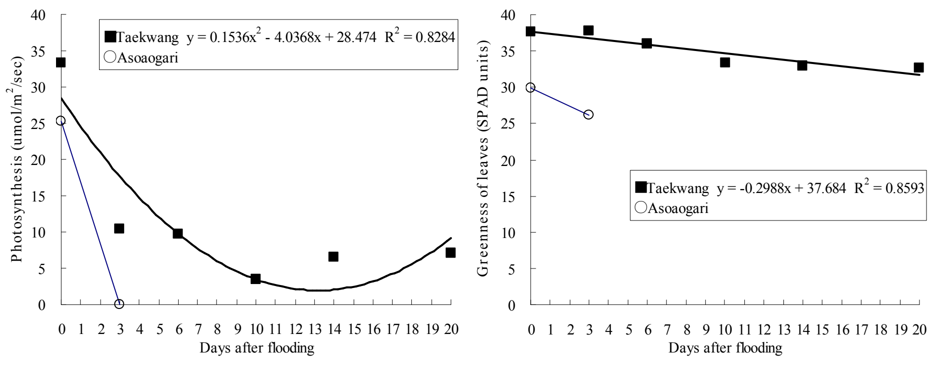

Fig. 2. Effect of flooding on photosynthesis and greenness of soybean plant at R1 stage. Plants were flooded for ten days. Three days after flooding all plants of cultivar Asoaogari were withered to death. The quadratic equation and the linear equation of cultivar Taekwang are significant at the probability level of 0.001 by the SAS regression analysis.

Root porosity and morphology

Flooding greatly increased adventitious root development. Adventitious roots were completely absent in non-flooded plants. Flooding resulted aerenchyma proliferation in the cortex of roots and hypocotyls. After flooding, hypertrophy of lenticels was apparent on the stem-root segment (Photo 1). Aerenchyma formation caused increase of porosity of roots (Table 1). Root porosity of both cultivars was greatly increased by the flooding at V4 stage. After flooding treatment at V4 stage, root porosity of Asoaogari was higher than that of Taekwang 10 days after flooding while only Taekwang maintained higher porosity than control at maturity. Although root porosity increase after flooding treatment at R1 stage increased, the increasing level was far less than the change in V4.

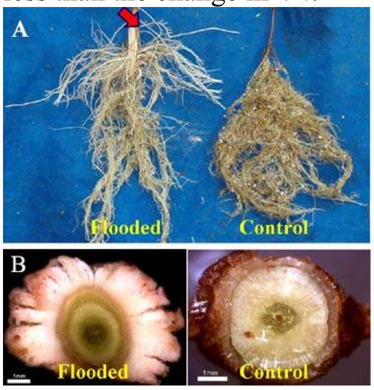

Photo 1. Change of root morphology after flooding treatment at V4 stage of a soybean cultivar Taekwang.

Table 1. Root porosity change after flooding in two growth stages of soybean

Cultivar	Treatment	Root porosity after flooding at V4			Root porosity after flooding at R1		
		0 day	10 day	Maturity	0 day	10 day	Maturity
Taekwang	Flood	2.0	12.6^{b}	7.4^{a}	1.4	5.9^{a}	4.6
Taekwang	Cont	2.0	2.0^{c}	4.0^{b}	1.4	1.8^{b}	4.0
Asoaogari	Flood	2.8	17.3^{a}	3.0^{b}	-†	-	-
Asoaogari	Cont	2.8	1.7^{c}	2.2^{b}	-	-	-

†Asoaogari was excluded because all the flooded plants were withered to death 3 days after flooding.
‡Numbers in same column followed by same characters are significantly different by LSD (*P*=0.05).

Dry matter accumulation and seed yield

Dry mater accumulation was decreased by flooding in both treatment stages, V4 and R1. Flooding at the V4 growth stage (Fig. 3A) resulted in an inhibition of dry matter accumulation, after which growth resumed and the slopes of the dry matter accumulation curves became nearly parallel to those of the controls. However, at the R1 stage (Fig. 3B); the dry weight of cultivar Taekwang was not increased for 10 days and cultivar Asoaogari was even withered to death. The dry weight at 10 days after flooding was not increased, and the growth was not fully recovered. The reductions in dry matter accumulation were reflected in final seed yields. Yields were significantly reduced by the flooding treatment irrespective of the growth stage at which the flooding occurred (Table 1). There was no different flooding effect on yield between cultivars, while flooding at R2 stage affected significantly higher impact on grain yield than flooding at V4 stage.

Table 2. Seed yield after flooding treatment at two growth stages in two soybean cultivars.

Cultivar	Flooding time		Non-flooded control
	V4	R1	
Taekwang	26.7^{b}	6.9^{c}	32.4^{a}
Asoaogari	25.5^{b}	-‡	31.6^{b}

†Numbers followed by different character are significantly different (*P*=0.05) by the LSD.
‡All flooded plants were withered to death.

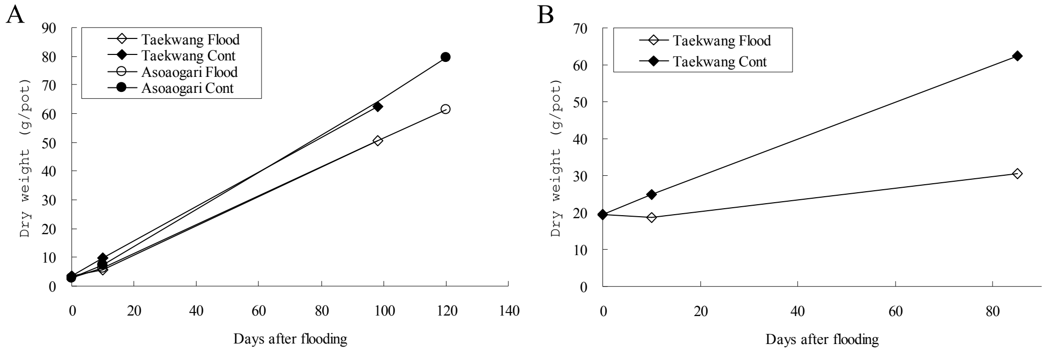

Fig. 3. Dry matter accumulation of two soybean cultivars in flooding treatment. Flooding treated at V4 stage (A) and R1 stage (B). Third dry matter was measured at maturity in both experiments.

Conclusion

The observed morphological changes concerning the formation of adventitious roots and aerenchyma that occur in the submerged roots showed the mechanism of soybean flooding tolerance. But the changes were not enough to fully adapt to flooded condition. Especially, the ability of adaptation was different between genotypes and also with different growing stages. As concluded in previous reports (Oosterhuis et al., 1990; Scott et al., 1990), grain yield decrease is grater when they flooded in reproductive stage rather than flooded in vegetative stage (Table 2). Changes of root porosity successfully explained the change of dry matter accumulation and grain yield in flooded soybean.

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