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PHYSIOLOGY AND YIELD OF THREE SOYBEAN (*GLYCINE MAX* (L.) MERRILL) CULTIVARS DIFFERENT IN MATURITY TIMING AS AFFECTED BY WATER DEFICIENCY

Oqba Basal
University of Debrecen, Institute of Crop Sciences, Department of Crop Production and Applied Ecology, Debrecen, Hungary
oqba@agr.unideb.hu

András Szabó
University of Debrecen, Institute of Crop Sciences, Department of Crop Production and Applied Ecology, Debrecen, Hungary
szabo@agr.unideb.hu

Abstract

Water deficiency is globally increasing as a direct result of climatic changes, threatening food production stability, especially of drought-susceptible crops, to which soybean (Glycine max (L.) Merrill) belongs. Soybean is mainly important because of its high protein and oil content.

A field experiment was conducted in Debrecen, Hungary in 2017. Three soybean cultivars, different in maturity timing (very early-, early-, and middle-timing cultivars), were grown under two irrigation regimes; non-irrigated (NI) and fully-irrigated (FI) regime, in order to study the effect of water deficiency on the physiology and the yield of the above-mentioned cultivars.

The yield of the three cultivars was increased when irrigation was applied, and though the increase was insignificant, yet the physiological traits were noticeably, and significantly in certain traits, different between the two irrigation regimes.

It was concluded that water deficiency affects the physiology and the yield of soybean, and that the effect output is cultivar-dependent. More traits at different growth stages are needed to best understand water deficiency influence on soybean.

Keywords

Soybean, Water Deficiency, Physiology, Yield

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1. Introduction

Soybean (*Glycine max* (L.) Merrill) is among the 10 most grown crops (He et al., 2016), fourth most important food crop (Li et al., 2013), most widely grown seed legume, providing an inexpensive source of protein (Hao et al., 2013; Mutava et al., 2015) and most widely grown oilseed crop worldwide (Cerezini et al., 2016); moreover, it is an important crop regarding biodiesel production (Fan et al., 2013). Although soybean can be grown in many climatically-different regions (Mutava et al., 2015), it is mostly sown under non-irrigated water regime (Manavalan et al., 2009). Global climate changes have resulted in precipitation fluctuations (Li et al., 2013) and consequently have imposed drought stress, increasing the concern about food supply for the still-growing world population (Vurukonda et al., 2016) which is expected to reach more than 9 billion by the year 2050 (Sto, 2011). Drought stress is one of the most destructive abiotic stresses, and soybean is classified as a drought-sensitive crop, especially at certain growth stages (Liu et al., 2004); the annual soybean yield reductions caused by drought are enormous (Sincik et al., 2008; Sinclair et al., 2007), reaching up to 40% (Manavalan et al., 2009). The response of plants to drought stress is a very complex trait involves multiple mechanisms on the genetic, morphological, physiological, and biochemical levels (Cushman and Bohnert, 2000; Mattana et al., 2005; Rahdari and Hoseini, 2012); for example, light absorption is affected by drought affects through changes in leaf's both chlorophyll content and area index (Dong et al., 2015).

Chlorophyll content is a major physiological trait that reflects the potential of photosynthesis, and consequently, yield. Hao et al. (2013) concluded that water deficiency reduced soybean's chlorophyll content. However, different growth stages respond differently.

Leaf area index (LAI) can be defined as the crop population's canopy density. Its influence on the final yield is noticeable (Liu et al., 2008). Water deficiency can result in less LAI values of certain soybean population.

Plant height reveals soybean ability to produce more nodes on the main stem, and consequently more flowers, pods and seeds. It has been previously reported that plant height is decreased under water deficiency (Kadhem et al., 1985; Korte et al., 1983; Muchow, 1985), with different decrease curves been reported at different growth stages of soybean when water deficiency occurred (Atti et al., 2004; Mak et al., 2014). Decreases in plant height under water deficiency conditions might decrease both leaf area and yield (Monteith and Scott, 1982; Sinclair et al., 1981).

Flower number per plant can give an initial estimation of pod number, consequently, yield potential of the correspondent plant. He et al. (2016) demonstrated the water deficiency to negatively affect the flower number per plant.

Water deficiency negatively influence soybean growth resulting in yield loss (Bajaj et al., 2008; Dogan et al., 2007; Gercek et al., 2009; Karam et al., 2005; Sincik et al., 2008), moreover, the timing of water deficiency during soybean lifecycle [e.g. at pod formation (Sionit and Kramer, 1977), at seed filling (Maleki et al., 2013; Turner et al., 2005)] results in different amounts of yield reduction. Ishibashi et al. (2011) and Cui et al. (2013) concluded that water deficiency has the most negative effect on soybean if occurred at flowering stage (R_2). However, soybean genotype also plays a role (He et al., 2016).

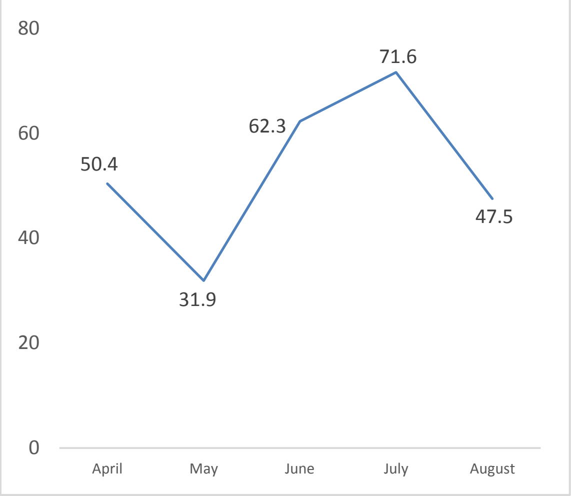
This study aimed at investigating the influence of water deficiency on the physiology and the yield of three soybean cultivars different in maturity timing.

2. Materials and Methods

Three soybean cultivars different in timing of maturity; *'Adsoy'* (very early maturity-timing), *'Johanna'* (early maturity-timing) and *'Bólyi 27'* (middle maturity-timing) were sown in Debrecen University's experimental site (Látókép) (N. latitude 47o 33', E. longitude 21o 27') on April 26th and the harvest was on September 1st for both *'Adsoy'* and *'Johanna'*, and on September 15th, 2017 for *'Bólyi 27'*. The soil type is calcareous chernozem, the average annual precipitation is 565.3 mm, whereas the precipitation between sowing and harvesting dates was 213.3 mm (Fig. 1).

Two irrigation regimes were applied; non-irrigated (NI) (accounting only on precipitation as the only source of water supply) and fully-irrigated (FI) (besides the above mentioned precipitation amount, three irrigation application were supplied with the following amounts and dates; 30 mm on June 6th, 25 mm on June 22nd and 25 mm on July 22nd). Each treatment consisted of four replicates, so the overall plot number was 24 plots (3 genotypes x 2 treatments x 4 replicates).

LAI values were recorded using SS1 – SunScan canopy analysis system (Delta- T Devices, UK). Relative chlorophyll content was measured using SPAD-502Plus (Konica Minolta, Japan). Plant height was measured manually using a 10 meter-ruler. In every measurement, 10 plants were randomly chosen from each plot, and the average was calculated. All the traits were measured at full bloom (R_2) stage (Fehr and Caviness, 1977). The statistical analysis was made using SPSS (ver.22) software (2-way anova).



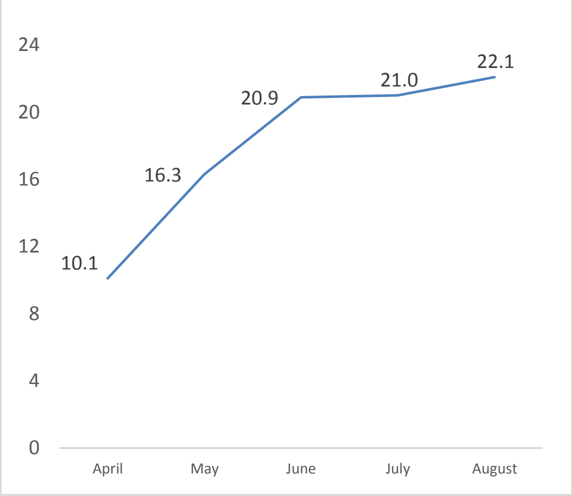


Figure 1: *The Precipitation (mm) and the Temperature (C^o) during the Vegetation Period*

3. Results and Discussion

3.1 Plant Height (cm)

Under both irrigation regimes, the middle maturity-timing cultivar *'Bólyi 27'* resulted in the best plant height (86 and 97 cm for non- and fully-irrigated, respectively), whereas the early maturity-timing cultivar *'Johanna'* was significantly the least (69 and 87 for non- and fully-irrigated, respectively). The very early maturity-timing cultivar *'Adsoy'* was in between, with insignificantly differences (84 and 93 for non- and fully-irrigated, respectively) (table 1). It was previously reported that the early soybean cultivars had lower plant height compared to late-maturity soybean cultivars (Jin et al., 2004_a; Liu et al., 2005). Later, Garcia et al. (2010) reported the different examined soybean genotypes to be significantly different in plant height, which was demonstrated later by Hossain et al. (2014).

When drought was waived off (FI treatment), the three genotypes were significantly higher, by means of plant height, compared to their non-irrigated counterparts, and the correlation with the irrigation was highly significant ($r = 0.0661^{**}$). Soybean plant height decreases under drought stress (Atti et al., 2004; Brady et al., 1974; Demirtas et al., 2010; Mak et al., 2014; Pang, 1964). Frederick et al. (1989) studied four soybean cultivars; they reported drought stress to reduce plant height, in both years of their study, due to a decrease in the rate at which the stem nodes were produced; this was previously reported in other studies in which an increase in the plant height was observed for several soybean cultivars when irrigation was applied (Kadhem et al., 1985; Korte et al., 1983; Muchow, 1985).

In our experiment, the correlation with the yield was positive, yet not significant (r = 0.1); which is consistent with previous conclusions (Georgiev, 2004; Maleki et al., 2013). Board (1987) concluded that higher seed yields may be obtained if the plant height is enhanced by allowing a greater period for reproductive growth at each node.

3.2 Flower Number (flower plant^{-1})

Under water deficiency conditions, both *'Adsoy'* and *'Johanna'* had very similar number of flowers per plant (23 and 22, respectively), but when water deficiency was waived off, *'Adsoy'* had a significantly higher flower number per plant (29 compared to 25 for *'Johanna'*). The flower number of *'Bólyi 27'* per plant was significantly less for both irrigation regimes compared to the other two cultivars' counterparts (table 1). Pang (1964) reported a different response of the flower number to water deficiency among soybean cultivars.

For cultivar *'Adsoy'*, significant difference between non- and fully-irrigated regimes (23 and 29, respectively) was recorded, whereas the difference was not significant for both cultivars *'Bólyi 27'* and *'Johanna'* (table 1). Bord and Hartville (1998) suggested that drought stress during flower formation can lead to a shorter flowering period and, consequently, produce fewer flowers.

3.3 Relative Chlorophyll Content (SPAD)

Under water deficiency conditions, *'Bólyi 27'* and *'Johanna'* resulted in very similar relative chlorophyll content (38 and 39, respectively); the difference was insignificant, whereas the relative chlorophyll content of *'Adsoy'* was significantly higher (45). Under fully-irrigated regime, the order did not change, however, an insignificant increase, compared to the non-irrigated counterpart, was noticed for *'Johanna'* (40) (table 1). Hossain et al. (2014) found that total chlorophyll content in the leaves of the studied soybean genotypes at vegetative stages (starting from V_2 stage) was lower under water deficit than that of well-watered conditions, which is consistent with previous studies on other crops (Cui et al., 2004; Pagter et al., 2005). Makbul et al. (2011) recorded a significant decrease in chlorophyll content by 28%, and Hao et al. (2013) by 31% of drought-stressed soybean compared to control plants. Similar results were provided earlier by Atti et al. (2004). Drought affects light absorption through changes in leaf chlorophyll content (Dong et al., 2015).

On the other hand, an insignificant decrease, compared to the non-irrigated counterpart, was noticed for both *'Bólyi 27'* and *'Adsoy'* (34 and 42, respectively) (table 1), which might reflects the ability of these two cultivars to adapt with drought stress at flowering stage by enhancing the relative chlorophyll content; however, the yield was significantly-negatively correlated with relative chlorophyll content ($r = -0.712^{**}$); i.e. the increased relative chlorophyll content of the drought-stressed plants did not lead to a better yield.

3.4 Leaf Area Index (LAI)

LAI was the same (with an average of 6) (table 1) for the three cultivars under water deficiency conditions. However, when fully-irrigated regime was applied, the three cultivars resulted in better LAI (with a highly-significant correlation with irrigation; $r = 0.707^{**}$); the increase was significant for *'Johanna'* (with an average of 9) and insignificant for both *'Bólyi 27'* and *'Adsoy'* (7 and 8 on average, respectively) (table 1). Sinclair and Serraj (1995) reported drought stress to reduce leaf area, consequently, protein synthesis was decreased and yield was less (Purcell and King, 1996).

In our experiment, the correlation with the yield was positive, yet not significant ($r = 0.13$), moreover, it was positive with both plant height ($r = 0.37$) and flower number ($r = 0.49^{*}$). Dong et al. (1979) reported LAI to be positively correlated with grain yield of eight soybean cultivars. Growth stage plays a role in the relationship between LAI and yield; Jin et al. ($2004_{a,b,c,d}$) concluded that high LAI during reproductive stages was correlated with high soybean yield. Chang (1981) recorded a significant correlation coefficient ($r = 0.603^{*}$) between total LAI at R_2 stage and yield in a 7-year experiment.

Soybean genotype also plays a role in LAI value and the correspondent yield (Liu et al., 2005); which is consistent with our results.

3.5 Yield (kg ha^{-1})

For cultivar *'Adsoy'*, the yield was very similar under both non- and fully-irrigated regimes (2062 and 2067 kg ha^{-1}, respectively), which was significantly less than *'Johanna'* (2907 and 3178 kg ha^{-1}, respectively) and *'Bólyi 27'* (3024 and 3668 kg ha^{-1}, respectively) (table 1). Garcia et al. (2010) reported that the genotypes significantly differ in yield production under drought stress conditions and also within the interaction between the drought stress and the genotype; similar conclusions were reported by many researchers (e.g. Bellaloui and Mengistu, 2008; Brown et al., 1985; Maleki et al., 2013).

Although the yield was higher under fully-irrigated compared to non-irrigated regime for the three cultivars, yet the increase was not significant, and the correlation with irrigation was also non-significant (r = 0.24). Many previous researchers reported soybean seed yield to decrease under drought stress conditions (e.g. Ashley and Ethridge, 1978; Bajaj et al., 2008; Doss et al., 1974; Gercek et al., 2009; Heatherly and Elmore, 1986; Karam et al., 2005; Kokubun, 2011; Rose, 1988; Sadeghipour and Abbasi, 2012).

Table 1: *Flower Number. (flower plant^{-1}), plant height (cm), relative chlorophyll content (SPAD), leaf area index (LAI) and yield (kg ha^{-1}) for soybean cultivars 'Adsoy', 'Bólyi 27' and 'Johanna' under non-irrigated (NI) and fully-irrigated (FI) regimes.*

	Flower Number		**Plant height**		**SPAD**		**LAI**		**Yield**	
	NI	*FI*	*NI*	*FI*	*NI*	*FI*	*NI*	*FI*	*NI*	*FI*
'Adsoy'	23^{b1}	29^{a1}	84^{b1}	93^{a12}	45^{a1}	42^{a1}	6^{a1}	8^{a12}	2062^{a2}	2067^{a2}
'Bólyi 27'	19^{a2}	19^{a3}	86^{b1}	97^{a1}	38^{a2}	34^{a2}	6^{a1}	7^{a2}	3024^{a1}	3668^{a1}
'Johanna'	22^{a1}	25^{a2}	69^{b2}	87^{a2}	39^{a2}	40^{a1}	6^{b1}	9^{a1}	2907^{a1}	3178^{a1}

- Same letter indicates no significant difference at .05 level between irrigation regimes within a certain trait.
- Same number indicates no significant difference at .05 level between cultivars within a certain irrigation regime.

4. Conclusions

It was concluded that water deficiency at full bloom (R_2) stage has a noticeable influence on soybean physiology and yield; though the influence was not significant on the yield, yet the yield was reduced as a result of water deficiency for all studied cultivars. Moreover, some important physiological traits (e.g. plant height) were significantly decreased under water deficiency conditions. Different soybean genotypes, by means of maturity-timing, acted differently in response to water deficiency; this could be caused by different length of full bloom stage for every cultivar, especially under water deficiency, as each cultivar may increase or decrease certain growth stage's length as a method of coping with this abiotic stress.

Further studies are needed to better evaluate the different soybean cultivars' response to water deficiency on more levels; production trait and seed quality levels, to name few, and at different growth stages.

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