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Rate and duration of seed filling and yield of soybean affected by water and radiation deficits

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ABSTRACT

Seed filling and yield of soybean under water and radiation deficits were investigated during 2011 and 2012. Treatments were irrigations (I_1, I_2, I_3 and I_4 for irrigation after 60, 90, 120 and 150 mm evaporation from class A pan, respectively) in main plots and light interceptions (L_1: 100 %, L_2: 65 % and L_3: 25 % sunlight) in sub-plots. Seeds per plant under I_1 and I_2 decreased, but under I_3 and I_4 increased as a result of radiation deficit. Maximum seed weight and seed filling duration of plants under 25 % light interception (L_3) were higher than those under full sunlight (L_1) and 65 % light interception (L_2). In contrast, plants under full sunlight had the highest seed filling rate, particularly under water stress. Seed filling duration under severe light deficit (L_3) was about 9 days longer than that under full sunlight (L_1), leading to 15.8 % enhancement in maximum seed weight. Decreasing seed yield of soybean under well watering and mild water stress and improving it under moderate and severe water deficit due to low solar radiation are directly related with changes in seed filling duration and consequently in seed weight and number of seeds per plant under these conditions.

Key words: seed filling, shading, soybean, water deficit, yield

IZVLEČEK

POMANJKANJE VODE IN SVETLOBE VPLIVATA NA HITROST IN TRAJANJE POLNENJA SEMEN IN PRIDELEK SOJE

Vpliv pomanjkanja vode in svetlobe na polnenje semen in pridelek soje je bil preučevan v poljskem poskusu v letih 2011 in 2012. Obravnavanja so bila različni režimi namakanja (I_1, I_2, I_3 in I_4 kot namakanje po 60, 90, 120 in 150 mm evaporacije iz razreda A) na glavnih poskusnih ploskavah in različni svetlobni režimi (L_1: 100 %, L_2: 65 % in L_3: 25 % delež svetlobe) na podploskvah. Število semen na rastlino se je pri obravnavanjih I_1 in I_2 zmanjšalo, a se je pri obravnavanjih I_3 in I_4 povečalo kot posledica pomankanja svetlobe. Največja masa semen in najdaljše trajanje polnenja semen sta bila večja pri rastlinah, ki so rastle pri 25 % osvetlitvi (L_3) kot pri rastlinah, ki so rastle na polni (L_1) in 65 % (L_2) osvetlitvi.V nasprotju s tem, so imele rastline pri polni osvetlitvi največjo hitrost polnenja semen, še posebej ob sušnem stresu. Trajanje polnenja semen je bilo pri večjem pomanjkanju svetlobe (L_3) za 9 dni daljše kot pri polni osvetlitvi (L_1), kar je vodilo k 15.8 % povečanju maksimalne mase semen. Zmanjšanje pridelka semena soje pri polnem zalivanju ali blagem sušnem stresu in njegovo povečanje pri zmernem in velikem vodnem deficitu je bilo posledica manjše osvetlitve, kar je neposredno povezano s spremembami v trajanju polnenja semen in posledično s spremembami v masi semen in številu semen na rastlino v teh razmerah.

Ključne besede: polnenje semen, senčenje, soja, vodni deficit, pridelek

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1 INTRODUCTION

Soybean is an important seed legume due to its high protein (35 %), oil and carbohydrate contents (21 % and 34 %, respectively). Nitrogen fixing ability (17-127 kg/ha/year) is another advantage of soybean plants (Messina 1997). Growth, development and yield of soybean are the result of a genetic potential interacting with environment. Soybean seed production may be limited by environmental stresses and minimizing these stresses will optimize seed yield (Mc Williams et al. 2004).

One of the important environmental stresses that affect crop production worldwide is water stress. When the full crop requirements are not met, water deficit in the plant can develop to a point where crop growth and yield are affected. The need for water in soybean increases with plant development, peaking during the flowering and seed filling phases (7-8 mm day^{-1}) and decreasing thereafter (Bertolli et al 2012). So, various growth stages of soybean respond differently to water stress (Egli and Bruening 2004). It has been observed that maximum reduction in yield, due to drought stress occurs during the pod set and seed filling period (Desclaux et al. 2000).

Radiation is another important factor affecting crop photosynthesis, development and yield (Zhao & Osterhuis 1998). Reduction of solar radiation imposes a limitation to biological productivity in plant, although the extent of the limitation varies with shade tolerance of the species and the nitrogen supply (Wong 1991). Shade, regardless of its source, reduces photosynthetically active radiation (PAR) and alters spectral quality, affecting plant photosynthesis (Bel et al. 2000). It has been reported (Kobata & Takami 1986) that inhibition of photosynthesis during the seed filling period, due to environmental stresses like shading, can result in a major reduction in seed yield of rice. At this time the shortage of available assimilate caused by shading during the early seed filling period, restricts final seed weight at the fully ripe stage, even if the shading is removed during the remainder of the seed filling period. In comparison, Nasrullahzadeh et al. (2007) showed that shading increases seed filling duration and seed weight of faba bean.

In most seed crops, individual seed weight is commonly analyzed as the product of the individual seed growth rate by the duration of seed filling. In legume seeds, the active filling period begins when the pod wall has approximately reached its final size. At the end of this phase, cell division stops, linear dry matter accumulation begins in cotyledons and continues until physiological maturity (Ney et al. 1993). Seed filling duration varies with changes in environmental conditions (Dumoulin et al. 1994). Thus, this research was arranged to evaluate variation in seed filling rate and duration and yield of soybean in response to different levels of radiation and irrigation.

2 MATERIALS AND METHODS

Two field experiments were carried out at the Research Farm of the University of Tabriz, Tabriz, Iran (Latitude 38º05´N, Longitude 14º17´E, Altitude 1360m above sea level) during the growing seasons of 2011 and 2012. The soil of the research area was sandy loam with an EC of 0.68 dS/m, pH of 8.1 and field capacity of 28.8 %. The experiments were arranged as split plot on the bases of randomized complete block design in three replicates. Factors were four irrigation treatments (I_1, I_2, I_3, I_4: irrigation after 60, 90, 120 and 150 mm evaporation from class A pan, respectively) in main plots and three levels of light interceptions (L_1: 100%, L_2: 65% and L_3: 25% sunlight) in sub plots. Seeds of soybean (Williams) were treated with Benomyl at a rate of 2 g/ kg and sown in prepared plots on May 2011 and 2012 at a depth of about 4cm. Seeding rate was 64 seeds m^{-2}. Plots were irrigated immediately after sowing, but subsequent irrigations were carried out according to the treatments. Hand weeding was done as required. Shading nets were spread over an iron frame (3m × 3m) 1.5 m above the soil to ensure good ventilation. These nets were large enough to fully cover the corresponding shaded plots immediately after seedling establishment up to maturity. Averages of day length and solar radiation (full sunlight) during plant growth and development were 14.1 hours and 16.9 MJ/m^2/day, respectively.

During seed filling, plants were harvested at 8 stages with 5 days intervals. Seeds of each sample were oven-dried at 130ºC for 17 hours and then seed dry weight was determined. Maximum seed weight and seed filling duration were estimated, using a two piece regression model:

$$w = \begin{cases} a + bt & t < tm \\ a + bt & t \geq tm \end{cases}$$

Where *W* is seed weight, *a* is the intercept, *b* is the slope, *t* is days after anthesis and *tm* is the end of seed filling period (time of mass maturity). Subsequently, seed filling rate (*SFR*) was calculated as:

SFR = *MSW*/*SFD*

Where *MSW* is maximum seed weight and *SFD* is seed filling duration.

At maturity, 10 plants from each plot were harvested and seeds per plant were counted, and then mean number of seeds for each plot was calculated. Finally, 1m^2 in the middle of each plot was harvested and seeds detached from the pods and seed yield per unit area was determined. Statistical analysis was performed with MSTATC and SAS soft-wares and Excel soft-ware was used to draw the figures. Duncan test was applied to compare means of each trait at 5 % probability.

3 RESULTS

Combined analyses of variance (Table1) showed significant effects of year on seeds per plant, rate and duration of seed filling and seed yield, but not on maximum seed weight. Maximum seed weight, seed filling duration and seed filling rate were not significantly affected by irrigation intervals, while the effects of irrigation on seeds per plant and seed yield per unit area were significant. Rate and duration of seed filling and maximum seed weight were significantly influenced by radiation deficiency. Interaction of irrigation × light interception was also significant for seeds per plant, seed filling rate and seed yield, but interaction of irrigation × year was only significant for seed yield (Table 1).

Table 1: Combined analyses of variance of the effects of different irrigation and shading treatments on soybean

Source	df	Seeds per plant	Maximum seed weight	Seed filling duration	Seed filling rate	Seed yield
Year (Y)	1	341.47**	2.31	5288.23**	47.87**	146148.51**
Rep (Y)	4	94.19	990.3	123.11	3.18	6324.38
Irrigation (I)	3	609.74*	110.68	13.29	0.832	46844.34**
Y * I	3	39.3	851.98	26.29	0.471	4605.87**
Ea	12	26.26	313.81	78.91	0.758	2442.17
Light (L)	2	29.53	3606.51*	718.09*	19.05*	241.67
I * L	6	126.73**	475.99	74.13	5.21*	8157.65*
L * Y	2	8.15	169.89	35.81	0.87	230.31
L * I * Y	6	6.04	217.57	90.45	1.17	1789.64
Eb	32	27.1	438.28	93.37	1.34	1601.53
C.V (%)	-	21.05	16	25.74	29.32	22.54

*'** Significant at p≤0.05 and p≤0.01, respectively

Number of seeds per plant in 2012 was higher than that in 2011 (Table 2). Seeds per plant under I_1 and I_2 decreased, whereas under I_3 and I_4 increased as a result of radiation deficit. The highest number of seeds per plant was obtained from well watered plants under full sunlight. In general, mean numbers of seeds per plant of soybean under I_3 and I_4 were lower than that under I_1 and I_2 (Figure 1).

Maximum seed weight and seed filling duration of plants under 25% light (L_3) were higher than those under full sunlight (L_1) and 65% light (L_2). Mean of seed filling duration in 2011 was significantly higher than that in 2012, while seed filling rate in 2012 was significantly higher than that in 2011. Seed filling rate of plants under full sunlight was higher than that under shading treatments, with no significant difference between L_2 and L_3 (Table 2). Plants under full sunlight had the highest seed filling rate under all irrigation treatments. This superiority was more evident under water stress (Figure 2).

Table 2: Means of maximum seed weight, seed filling duration and rate of soybean under irrigation and radiation treatments in 2011 and 2012

Treatments	Seeds per plant	Maximum seed weight (mg)	Seed filling duration (day)	Seed filling rate (mg day^{-1})
Year				
2011	22.55b	130.66a	46.11a	2.83b
2012	26.91a	131.01a	28.96b	4.52a
Light interception				
L_1	25.4a	125.15b	32.82b	3.81a
L_2	25.34a	122.45b	37.67ab	3.25b
L_3	23.45a	144.91a	42.11a	3.44b

Different letters in each column indicate significant difference at $P \leq 0.05$.
L_1, L_2, L_3: 100 %, 65 % and 25 % light interception, respectively

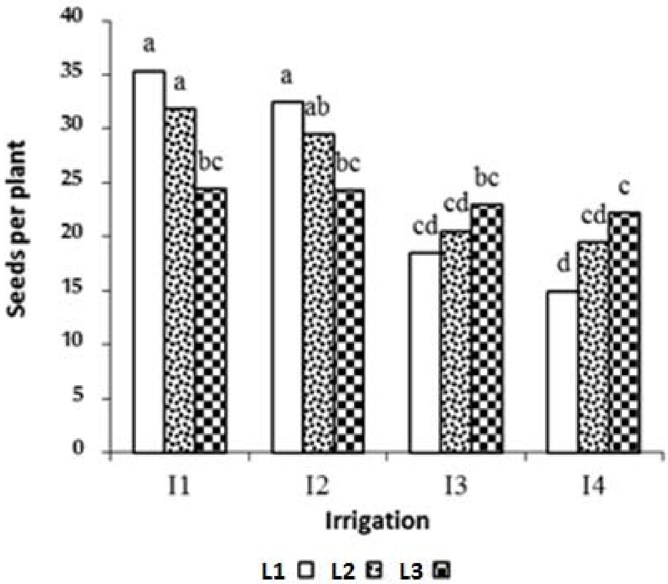

Figure 1: Seeds per plant under different irrigation and shading treatments. I_1, I_2, I_3, I_4: Irrigation after 60, 90, 120 and 150 mm evaporation, respectively. L_1, L_2, L_3: 100 %, 65 % and 25 % light interception, respectively

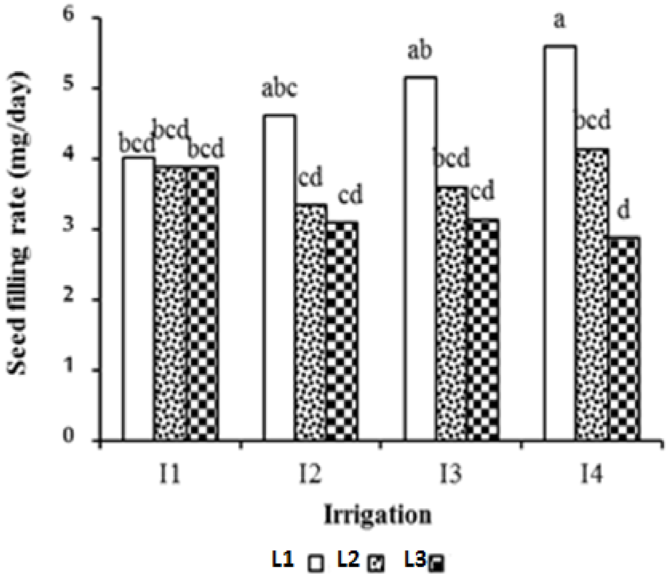

Figure 2: Seed filling rate of soybean under different irrigation and radiation treatments. I_1, I_2, I_3, I_4: Irrigation after 60, 90, 120 and 150 mm evaporation, respectively. L_1, L_2, L_3: 100 %, 65 % and 25 % light interception, respectively

Seed yield per unit area of plants under all irrigation treatments in 2011 was generally lower than that in 2012 (Figure 3). In general, seed yield under I_1 and I_2 was higher than that under I_3 and I_4 in all light interceptions. However, seed yield of plants under I_1 and I_2 decreased, but under I_3 and I_4 increased as a result of shading. The highest seed yield was recorded under well watering with full sunlight (Figure 4).

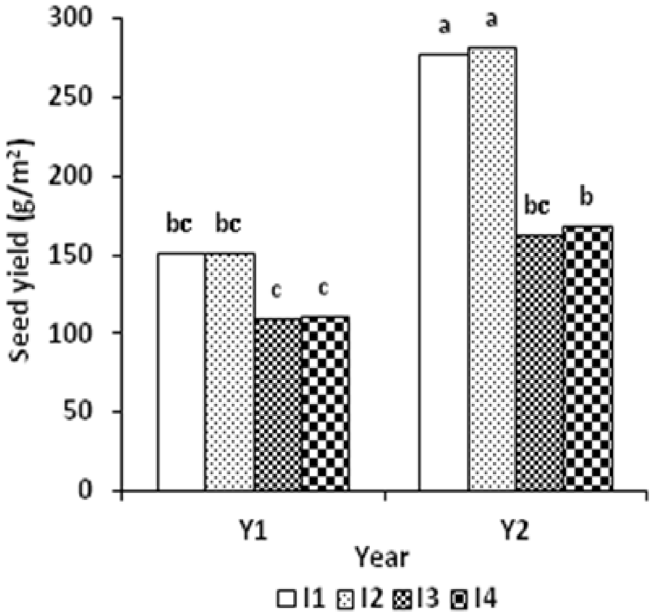

Figure 3: Seed yield of soybean under different irrigation treatments in 2011 (Y_1) and 2012 (Y_2). I_1, I_2, I_3, I_4: Irrigation after 60, 90, 120 and 150 mm evaporation, respectively

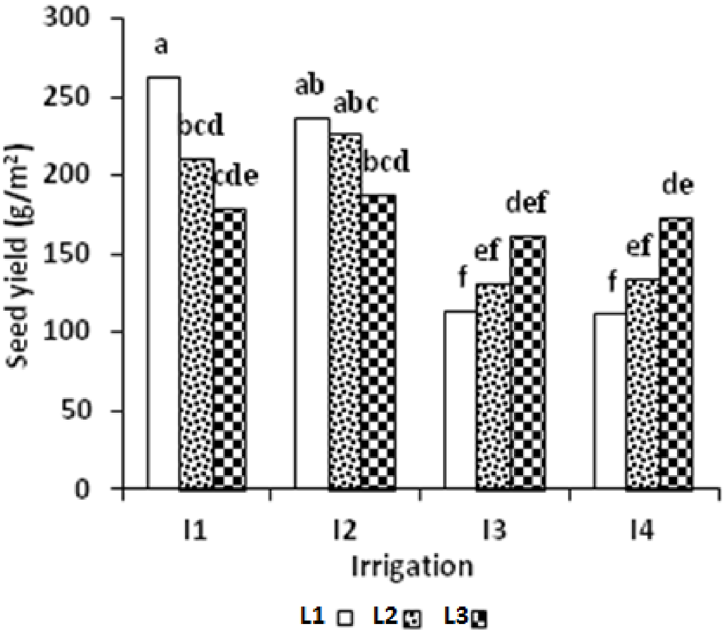

Figure 4: Seed yield of soybean under different irrigation and radiation treatments. I_1, I_2, I_3, I_4: Irrigation after 60, 90, 120 and 150 mm evaporation, respectively. L_1, L_2, L_3: 100 %, 65 % and 25 % light interception, respectively

4 DISCUSSION

Similar maximum seed weight in two years was the result of longer seed filling duration in 2011 and higher seed filling rate in 2012 (Table 2). It has been reported that seed filling rate (Ghassemi-Golezani et al. 2009) and seed filling duration (De Souza et al. 1997) are positively associated with maximum seed weight in soybean.

Although seed filling rate of plants under shade was lower than that under full sunlight, lower radiation increased seed filling duration (Table 2) as a result of decreasing temperature (Ghassemi-Golezani et al. 2013). Seed filling duration under low radiation (L_3) was about 9 days longer than that under full sunlight (L_1), leading to 15.8 % enhancement in maximum seed weight. Similarly, Nasrullahzadeh et al. (2007) reported that delaying physiological maturity under low light increases seed filling duration and consequently mean seed weight of faba-bean. Hadi et al. (2006) also showed that reduction in radiation could increase seed filling duration and mean seed weight of common bean. Seed weight is determined during the seed filling process and duration of seed filling is an important component of maturity (Monpara 2011).

Reduction in seed filling rate due to shading, particularly under severe water stress (Figure 2) may be associated with reduction in cotyledon cell division and cell number of soybean. It has been suggested that both cotyledon cell number and assimilate supply are important in determining seed growth rate (Egli et al. 1989). According to Egli and Bruening (2001), reduction in assimilate availability due to shading decreases seed filling rate and increases effective filling period in soybean. Anyway, variation in seed filling rate under different light interceptions had no significant effect on final seed weight of soybean (Table 2).

Increasing seed filling rate of non-shaded plants with increasing water stress (Figure 2) is the result of early senesces (Bahrani et al. 2009). It has been reported that under water deficit, particularly when there is access to carbohydrates either directly from the leaf photosynthesis or from those pre-stored in stems or leaves, seed filling rate increases (Ahuja et al. 2008). Yang et al. (2001) suggested that an altered hormonal balance in rice seeds by water stress during seed filling, especially a decrease in GAs and an increase in ABA, enhances the remobilization of pre-stored carbon to the seeds and accelerates the seed filling rate.

Since there was no significant difference in maximum seed weight between two years (Table 2), higher seed yield in 2012 (Figure 3) resulted from greater number of seeds per plant under all irrigation treatments (Figure 1). However, decreasing seed yield of soybean under well watering and mild water stress and improving it under moderate and severe water deficit due to light deficit (Figure 4) are directly related with changes in seed filling duration and consequently in seed weight (Table 2) and number of seeds per plant (Figure 1) under these conditions.

5 CONCLUSION

Plants could be subjected to different levels of shading or solar radiation in intercropping, agroforestry and cropping under fruit trees. Water deficit may also occur in these conditions. Therefore, it is very important to understand the interactive effects of water and radiation deficits.

The results of this research clearly showed that shading could reduce the drought impact on soybean plants via enhancing seed filling duration, seed weight, seeds per plant and consequently seed yield per unit area due to reducing temperature. However, soybean is not an appropriate crop to grow under shade, when water supply is sufficient. Similar works on different crops, particularly on shade tolerant plants, can improve our knowledge about these interactions.

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