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Research Article

INFLUENCE OF WATER DEFICIT ON OIL AND PROTEIN ACCUMULATION IN SOYBEAN GRAINS

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ABSTRACT: A randomized complete block (RCB) design with three replications was arranged to evaluate soybean response to different irrigation treatments (I_1, I_2 and I_3: irrigation after 70, 110 and 150 mm evaporation from A pan, respectively) in 2009. Sowing density was 64 seeds per square meter. All plots were irrigated immediately after sowing and irrigation treatments were applied after seedling establishment. The highest grain filling duration was recorded for plants under I_1, followed by those under I_3 and I_2, respectively. However, grain filling rate under I_2 and maximum grain weight under I_3 were slightly higher than those under other irrigation treatments. High number of grains per plant under I_2 resulted in production of smaller grains. Oil percentage of soybean under all irrigation treatments increased, but protein percentage decreased with proceeding of grain development. Water deficit caused a decrease in oil percentage and increase in protein percentage. Oil and protein yields per unit area had significant positive correlation with grain yield per unit area. Therefore, decreasing oil and protein yields per unit area under severe water stress was attributed to the large reductions in grain yield per unit area.

Keywords: Grain filling, grain yield, oil, protein, soybean, water deficit

INTRODUCTION

Soybean (*Glycine max* L.) is one of the most important protein and oil seed crops throughout the world. Its oil is the largest component of the world's edible oils. Soybean seed contains 18-22% oil and 40-48% protein. The world production of edible oils consists of 30% soybean. It is an ingredient of more than 50% of the world's high protein meal [23, 36, 3, 43]. Grain yield of soybean may be limited by environmental stresses such as water deficit [13, 15].

Water stress is one of the most common environmental stresses that affects growth and development of plants [42, 41, 7]. Drought stress is a permanent constraint to agricultural production in many countries, and an occasional cause of losses of agricultural production [11, 44]. Many researchers believe that amount of crop water use determine plant growth and development. Meanwhile plants may injure under non optimal access of water at any stage [10, 13, 15]. Drought stress severely limits growth and development of plants by affecting different metabolic processes such as CO2 assimilation, oil and protein synthesis [38]. Almost 90% of plant dry weight is resulted from CO_2 assimilation during photosynthesis [5, 39, 24, 22, 34]. The reduction of photosynthesis under drought stress is appeared to be associated with disturbance in biochemical reactions [20]. When stomata are closed due to drought or high temperature, the available CO_2 in intercellular space (Ci) would be reduced, leading to reduced electron transport capacity and restricted assimilation potential [31, 6].

Final grain weight is the result of grain filling rate during the linear phase and the duration of this period. Grain filling rate was described as the accumulation of seed dry matter per unit time, which vary among varieties and had a positive correlation with final grain weight [25, 21]. Shortening of grain filling period due to water stress [17] and decrease of transferring assimilates into grains due to drought stress [33] are two major reasons for reduction of soybean grain weight. Soybean seed protein and oil contents may be also influenced by water stress [37]. Thus, this research was carried out to evaluate variation in grain filling rate and duration, oil and protein accumulation, yield and yield components of soybean in response to different irrigation treatments.

MATERIALS AND METHODS

Seeds of soybean were obtained from Agricultural Research Institute, Khoy, Iran. A randomized complete block (RCB) design with three replications was used to evaluate soybean response to different irrigation treatments (I_1, I_2 and I_3: irrigation after 70, 110 and 150 mm evaporation from A pan, respectively) in 2009. Each experimental unit consisted of six rows with 4.5 m length. Sowing density was 64 seeds per square meter. Seeds were sown at a depth of 3 cm of a sandy-loam soil. All plots were irrigated immediately after sowing. Irrigation treatments were applied after seedling establishment. Weeds were controlled by hand weeding during crop growth and development.

During grain filling, seven harvests were made at five days intervals, beginning 33 days after flowering. Grains of each sample were oven-dried at 75°Cfor 48 hours and then grain dry weight was determined. A two piece model was used to describe the pattern of grain filling on mother plant:

$$W = \begin{cases} a + bt & t < t_m \\ a + bt_m & t = t_m \end{cases}$$

Where *w* is the grain dry weight (g), *t* is time after flowering (days), t_m is time of mass maturity (days), *a* is the intercept of the regression line and *b* is the slope of the regression line which determines the rate of grain filling. Duration of grain filling was calculated as:

EFP= MGW/ GFR

Where *EFP* is effective filling period, *MGW* is maximum grain weight and *GFR* is grain filling rate. Percentages of oil and protein for each sample were measured, using a seed analyzer (model: *Zeltex* ZX-50). Regression models were used to describe the grains oil and protein accumulation. At final harvest, grains per plant, grain yield per unit area and oil and protein yield per unit area for each treatment at each replicate were also determined.

Analysis of variance of the data appropriate to the experimental design and comparison of means at p≤0.05 were carried out, using MSTATC software. SAS and Excel softwares were used for regression analysis and drawing figures, respectively.

RESULTS AND DISCUSSION

Mean grain weight of soybean increased with increasing grain filling period up to about 58 days after flowering and thereafter, no changes in grain weight were observed. However, grain filling rate and duration and also maximum grain weight varied among irrigation treatments. The highest grain filling duration was recorded for plants under I_1, followed by those under I_3 and I_2, respectively. In contrast, grain filling rate under I_2 and maximum grain weight under I_3 were slightly higher than those under other irrigation treatments (Figure 1).

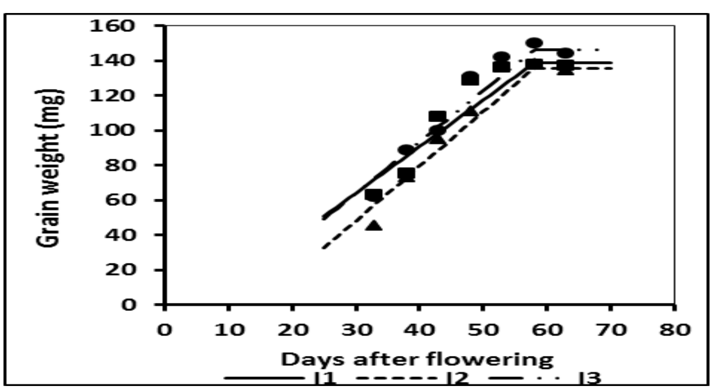

Fig. 1. Changes in mean grain weight of soybean under different irrigation treatments. I_1, I_2 and I_3: Irrigation after 70, 110 and 150 mm evaporation from A pan, respectively.

The highest number of grains per plant was obtained under I_2 (irrigation after 110 mm evaporation) followed by I_1 and I_3 (irrigation after 70 and 150 mm evaporation) (Figure 2). High number of grains per plant under I_2 resulted in production of smaller grains (Figure 1). This is also reflected in significant negative correlation of grains per plant with maximum grain weight (Table 1). Therefore, photo-assimilation directed to more grains under I_2 and resulted in production of comparatively smaller grains (Figure 1). Flowering stage is one of the most sensitive growth stages to environmental stress, especially to water stress. Water deficit stress during the early reproductive development stage increase the flower and pod abortion [19, 28, 32] and decrease grain number per plant, but plant may produce large grains.

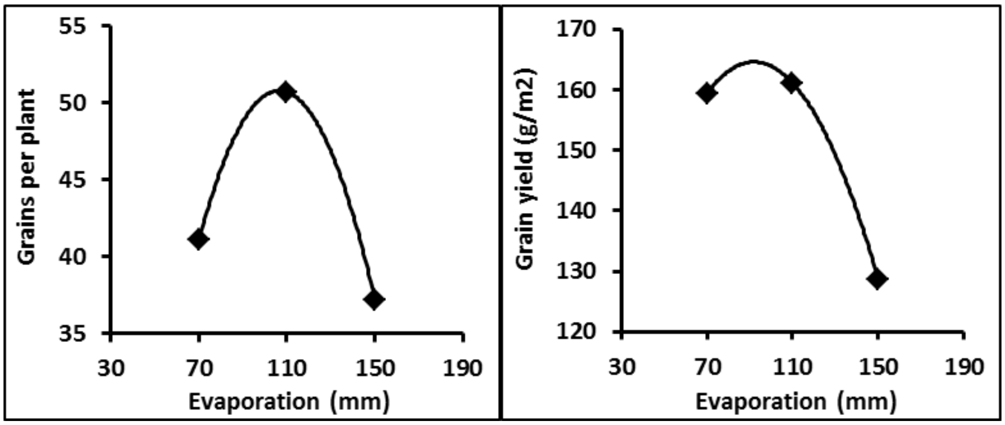

Fig. 2. Changes in grains per plant and grain yield per unit area of soybean under different irrigation treatments. Irrigation after 70, 110 and 150 mm evaporation from A pan.

Table 1. Correlation coefficients of irrigation treatments and field traits of soybean.

Traits	1	2	3	4	5	6	7
1-Grain filling rate (mg/day)	1						
2-Effective filling period (day)	-0.491	1					
3-Maximum grain weight (mg)	0.625	0.365	1				
4-Grains per plant	-0.078	-0.721*	-0.725*	1			
5-Grain yield (gm^{-2})	-0.093	-0.356	-0.419	0.738*	1		
6-Oil yield (gm^{-2})	-0.256	-0.354	-0.585	0.810**	0.976**	1	
7-Protein yield (gm^{-2})	0.087	-0.325	-0.205	0.640	0.968**	0.900**	1

***, **:** Significant at $p \leq 0.05$ and $p \leq 0.01$, respectively.

Large reductions in number of grains per plant under severe water limitation (Table 1) resulted in considerable decrease in grain yield per unit area (Figure 2). Abortion of flowers and pods due to water stress in flowering and pod set stages are the main reasons for reducing number of pods and grains per plant [16, 27]. Stress, especially in the growing stage, reduces the capacity of the source plants for the source and sink are forced to balance the number of flowers and pods to reduce the stress effects. Reduction in crop yield as a result of water stress has also been reported for soybean [29, 16, 9, 14, 27, 35], wheat [45], faba bean [18] and sunflower [4].
Oil percentage of soybean under all irrigation treatments increased with improving grain development up to a point where maximum value was achieved. In contrast, protein percentage decreased with proceeding of grain development (Figure 3). Similar results were reported by Leninger and Urie [30] for safflower.

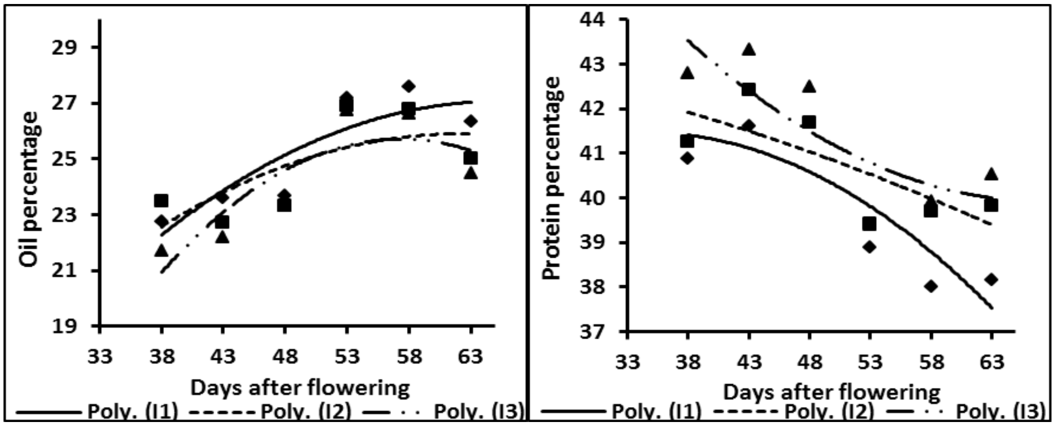

Fig. 3. Changes in grain oil and protein percentage of soybean under different irrigation treatments.I_1, I_2 and I_3: Irrigation after 70, 110 and 150 mm evaporation from A pan, respectively.

Oil percentage was decreased, but protein percentage was increased by decreasing water availability (Figure 3). Reduction of the grain oil percentage due to water deficit has also been reported in sunflower [1, 2]. Increasing grain protein percentage under water stress was also reported in chickpea [8] and wheat [26].
Oil and protein contents per grain of soybean under irrigation treatments increased with progressing grain development (Figure 4). Maximum oil and protein contents under I_1 (well irrigation) were achieved earlier than those under other irrigation treatments. Both oil and protein per grain were higher under severe water deficit (Figure 4). These superiorities were associated with the production of larger grains under I_3, similar with that reported by Rose [40] for soybean.

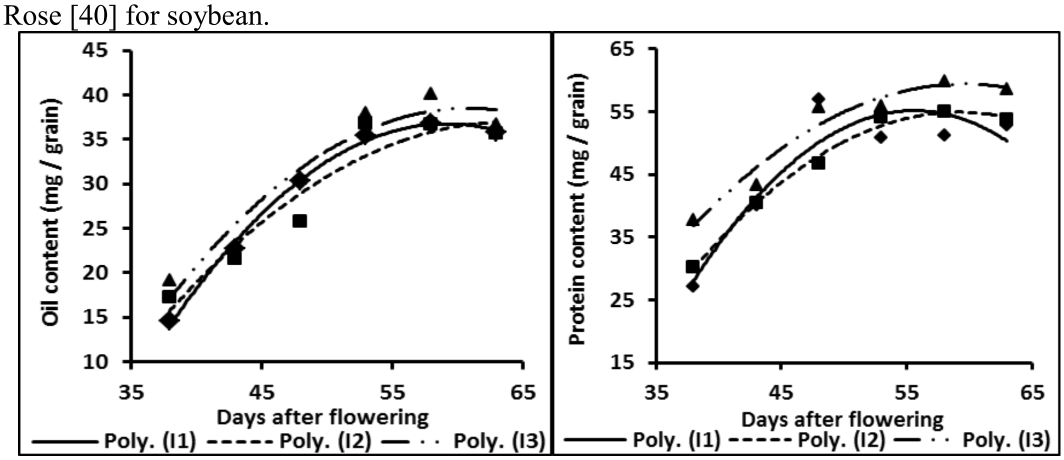

Fig. 4. Changes in grain oil and protein content of soybean under different irrigation treatments. I_1, I_2 and I_3: Irrigation after 70, 110 and 150 mm evaporation from A pan, respectively.

Oil and protein yields per unit area under I_2 (irrigation after 110 mm evaporation) were considerably higher than those under other irrigation treatments (Figure 5). Oil and protein yields per unit area had significant positive correlation with grain yield per unit area (Table 1). Therefore, decreasing oil and protein yields per unit area under severe water stress could be mainly attributed to the large reductions in grain yield per unit area (Figure 2). This result is in general agreement with the results reported by Cober and Voldeng [12] and Behtari *et al* [9]. Since grain yield per unit area under I_1 and I_2 was almost similar (Figure 2), higher protein yield under I_2 clearly is the result of higher protein percentage of grains compared with that under I_1 (Figure 3).

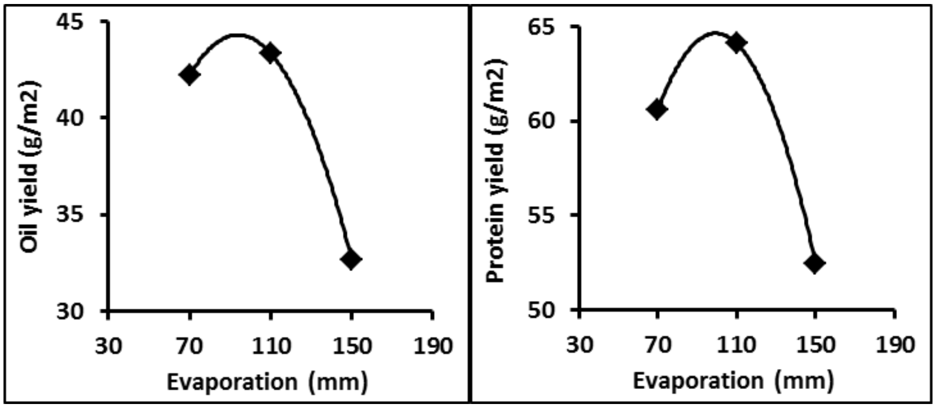

Fig. 5. Changes in oil and protein yield per unit area of soybean under different irrigation treatments. Irrigation after 70, 110 and 150 mm evaporation from A pan.

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