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Impact of Source, Sink Manipulation on Sunflower Yield Physiology under Different Water Availability Conditions

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Abstract: This study aimed to investigate the effect of source and sink manipulation on the yield of a sunflower hybrid in different water availability conditions. The experiment was conducted during 2015 in Gonabad, Iran in split plot design. Irrigation during the reproductive stage, including optimal irrigation (ETP 100%) and water stress (ETP 50%), was assigned to the main plots. Manipulating of the source and sink, including removing 50% of all leaves at the bottom, 50% of all leaves at the top of the stem, removal of 50% and 25% head seeds, and control treatment (no removal of leaves and seeds) were assigned to the subplots. A 25% reduction in head size in optimal irrigation conditions did not reduce the yield compared to the control, but other treatments caused a decrease in seed yield. The maximum decrease in seed yield (62.2%) was observed in the treatment of 50% removal of the head. Under water stress conditions, none of the defoliation treatments caused a reduction in seed yield, but the removal treatments of 25 and 50% of the seed caused a significant decrease in seed yield by 40.1 and 79.3%, respectively. These results showed that in optimal irrigation conditions, the strength of the source, both at the top and bottom of the canopy, is a limiting factor for yield. Severe sink capacity limitation, however, occurred under water stress conditions

Key words: Defoliation, water stress, source, sink, sunflower.

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Sunflower is often cultivated for vegetable oil due to their adaptability to different weather conditions and high oil content (Adeleke and Babalola *et al.*, 2020). But water is one of the most important limiting factors in sunflower production (Giannini *et al.*, 2022). Water deficiency limits plant growth through inhibitory effects on various physiological processes such as photosynthesis, respiration, absorption of ions and their transport, and metabolism of nutrients. Therefore, it is very important to study the physiological processes affecting the plant's yield under water stress conditions in different genotypes.

Sometimes, in yield physiology research, instead of comparing different cultivars with different leaf surfaces and head sizes, one cultivar is subjected to defoliation and head size reduction treatments to determine which factor physiologically limits seed yield in different soil moisture conditions (Madani *et al*., 2022). This yield limitation may be due to the inability of the leaves in terms of surface area and photosynthesis efficiency to produce the assimilates needed to fill the seeds, which is called "source limitation", or it may be due to the limitation of the place for accumulation of assimilates (number or size of seeds) which is called "sink limitation" (Rodrigues *et al*., 2019).

Our hypothesis was that the limitation of source or sink can be a genetic characteristic that may intensify and even change from source to sink and *vice versa* or a proportion of them may change under water stress. Considering that under water stress conditions, many effective parameters of sunflower yield such as height, leaf area, dry weight, number of seeds, and seed weight are affected by the intensity of stress. Investigating the interactions between water stress and the amount of plant leaf area and seed set can play an important and decisive role in yield, which has been considered and investigated in this research.

Materials and Methods

Soil and climate

A field experiment was conducted in Gonabad city situated at 34° 38′ N latitude, 58° 85′ E longitude and at an altitude of 1105 m. Regarding climate, Gonabad is a hot and dry desert with little rain. The average minimum and maximum temperatures are -7 and 40°C and the average annual rainfall is 141.5 mm. Before conducting the research, chemical and physical characteristics of the soil of the experimental site were determined from a composite sample of 0 to 30 cm depth using standard procedures.

Experimental design and treatments

The experiment was conducted in a split plot design with three replications. In this experiment, two irrigations, i.e., optimal irrigation (ETP 100%) and water stress (ETP 80%) were assigned to main plots. Until the stage of head emergence, all the plots were irrigated equally and stress treatment was applied from this stage onwards. Leaf removal and head size reduction at five levels (no leaf removal, removal of 50% of leaves on the top of the plant, removal of 50% of leaves on the bottom of the plant, removal of 50% of the head size, and removal of 25% of the head size) assigned to the sub-plots. Leaves at the bottom of the plant were considered less important due to being old and being in the shade of other leaves. Leaves were removed using scissors from the fourth leaf above the collar of the plant, randomly toward the head.

Preparation of seedbed

The land preparation operation was done one week before planting on March 21, by plowing, disking, and leveling. 100 kg ha^{1} ammonium phosphate fertilizer was used as a hand spray and a light disc was used to mix the soil and fertilizer. Then the furrows and ridges were separated at a distance of 65 cm and the land was ready for cultivation. Each plot consisted of 5 rows with a length of 4 meters with a row spacing of 65 cm and in-row spacing of 25 cm. Plant density was 75,000 plants ha^{-1}. After preparing the ground on April 1, sunflower seeds of the Iroroflor variety were planted in holes at the depth of three to four centimeters. Thinning was done at the four-leaf stage to reach the desired density.

Measurement

To investigate the process of plant growth during the growing season, separate samples were taken from each plot. Sampling was done four times during the growing season, randomly and in a zigzag pattern. The last sampling was done on 12 July. The collected samples were transferred to the laboratory and separated into stems, leaves, and buds (flowers), and after drying in an oven at 70°C for 48 hours, the dry weight of the samples was recorded. Final harvest was done after physiological maturity when the color of the head changed from green to yellow. The heads were dried in the open air and the seeds were separated. After drying, the weight of one hundred seeds, head diameter, and seed yield were recorded. Harvest Index (HI) was calculated as the ratio of seed yield to biological yield.

Statistical analysis

The statistical analysis of the data was carried out using SAS (Version 9.4) computer software, graphs were drawn using Excel 2019, and Duncan's multi-range test at the 5% level was used for comparison of means.

Table 1. Pearson correlation coefficient of the studied traits

Character	Reproductive period (days)	Grain filling period (days)	Total growth period (days)	Grain yield (t ha^{-1})	Biological yield (t ha^{1})	Seed weight (g)	Harvest index (%)
Reproductive Period (days)	1						
Grain filling period (days)	0.92**	1					
Total growth period (days)	0.69**	0.85**	1				
Grain yield (t ha^{1})	0.42**	0.62**	0.62**	1			
Biological yield (t ha^{1})	0.53**	0.75**	0.64**	0.89**	1		
Seed weight (g)	0.72**	0.87**	0.85**	0.58**	0.75**	1	
Harvest index (%)	0.42**	0.62**	0.62**	0.96**	0.75**	0.56**	1

Table 2. ANNOVA for the effect of irrigation, source: sink manipulation and their interaction on studied traits

Seed weight (g)	Harvest index (%)	Biological yield (t ha^{1})	Seeds ($head^{-1}$)	Grain yield (t ha^{1})	Total growth period (days)	Grain filling period (days)	Reproductive period (days)	DF
NS	NS	NS	NS	NS	NS	NS	NS	2 Replication
*	**	*	**	**	*	**	**	1 Water stress level (W)
**	**	**	**	**	**	**	**	Source: Sink (S)
NS	NS	NS	*	*	NS	NS	NS	W x S

*, ** means significant at $p \leq 0.05$

Result and Discussion

Soil of the experimental site was loamy in texture with 24% sand, 52.5% silt and 23.5% clay. Soil pH was 7.7 and organic carbon content was 0.2%. Status of available P and K was 12.6 and 265 mg kg^{-1} respectively.

There was a positive and significant correlation between seed yield and the length of the seed filling period (r= +0.62), the length of the growth period (r= +0.62), biological yield (r= +0.89), and the harvest index (r= +0.96). The hundred seed weight had the most positive and significant correlation with the active period of seed filling (r= +0.87) (Table 1). Water stress significantly affected most of the parameters studied (Table 2)

Water stress reduced yield through sink limitation

Water stress significantly decreased the number of seeds per head (GN) by 71.5% but significantly increased the seed weight (SW) by 19.8% compared to the control. Decrease in number of seeds per head is usually a manifestation of the source strength limitation during the formation of head florets (Andrianasolo *et al.*, 2016). This occurs in water stress treatments depending on the intensity and time of water stress and is usually accompanied by an increase in the weight of seeds due to the greater availability of photosynthetic materials for the seeds remaining in the head (Madani *et al.*, 2022; Yildiz *et al.*, 2018). Probably the abortion of florets in water stress conditions increases the weight of the remaining seeds as was observed in this experiment. Seed weight indicates the partitioning of photosynthetic materials to each seed and is a measure of source power, while the number of seeds is a measure of sink capacity (El-Douby *et al.*, 2021). Therefore, it seems that in this research, water stress at head emergence stage through increasing sink restriction has decreased the seed yield from 2400 to 2200 kg ha^{-1}. The harvest index is a measure of the efficiency of transferring photosynthetic materials to the seed (Rodrigues *et al.*, 2019). The higher value of this index in the optimal irrigation treatment compared to the water stress treatment by 9.6% is due to the higher efficiency of allocation of photosynthetic substances to the seeds, which confirms the increase in sink limitation due to water stress.

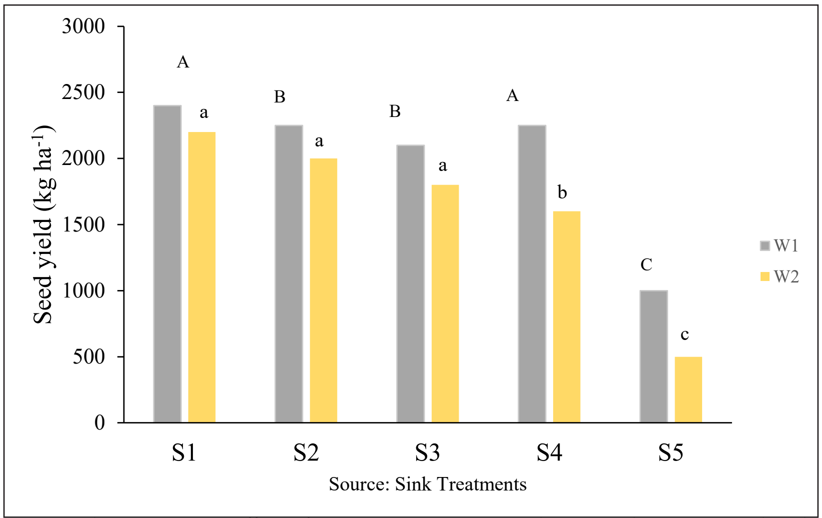

Fig. 1. The interaction effect of irrigation × source-sink manipulation on seed yield of sunflower.

S1: control treatment (No removal of leaves and seeds); S2: removing 50% of all leaves at the bottom; S3: removing 50% of all leaves at the top of the stem; S4: removal of 50% of head seeds; S5: removal of 25% of head seeds. W1: without water stress; W2: water stress.

Negative feedback control on source caused by small (decreased) sink demand

A 50% reduction of leaves in one half of a stem (top or bottom) means 25 defoliations in the canopy, which is expected to result in the same amount of seed yield reduction. However, removing 50% of the leaves on the top of the stem led to a decrease in the number of seeds per pod by 35% and an increase in seed weight by 35.5%, which ultimately resulted in a 17% decrease in seed yield (Fig 1). The rate of seed yield reduction in the treatment of removing 50% of the lower leaves of the canopy was 11%. It can be concluded that the efficiency of the upper leaves of the sunflower stems in yield is higher than other leaves because these leaves have more photosynthetic activity than the lower leaves of the stem (Madani *et al.*, 2022). Results also suggested that after defoliation, photosynthetic activity of the remaining leaves did not increase (Madani *et al.*, 2022; Alimohammadi and Azizov, 2019). Therefore, it seems that the studied variables do not have a significant limitation of source strength.

Since, the source activity decreases as the sink demand decreases (Andrianasolo *et al.*, 2016), by removing 50% of the seeds per head, the power of the source was greatly reduced. Although the number of seeds in the head was expected to decrease by 50% compared to the control, it decreased by 79%, and despite the increase in the weight of 100 seeds from 23.5 to 37.3, it could not compensate for this decrease in yield (Table 2). In other words, the yield of the control plants was 2320 kg ha^{-1} and it is expected that by halving the head, it reduced by half, i.e., 1115 kg ha^{-1}, while it decreased by 33% more than expected (740 kg ha^{-1}). In the studied cultivar, the yield-limiting factor was the sink size, but with the increase of the severity of this limitation through the negative feedback of the sink size on the source power, the source power should also be reduced.

In favorable water conditions, the yield was limited by source, and in water stress conditions, by the sink

A 25% reduction in head size in favorable irrigation conditions did not reduce the yield compared to the control, but other defoliation treatments and a reduction in head size in favorable irrigation conditions caused a decrease in seed yield. The maximum of seed yield was observed in 50% seed removal by 62.2%. The leaf removal treatments at the top and bottom of the head were not significantly different in terms of seed yield, and on average, they had 14.2% less yield than the control. Under water stress conditions, none of the defoliation treatments on the lower and upper leaves of the head caused a reduction in seed yield, but the removal treatments of 25 and 50% of the head caused a significant decrease in seed22 yield by 40.1 and 79.2%, respectively. These results showed that the main yield–limiting factor in favorable irrigation conditions was the size of the source, but in the conditions of water stress, it was the size of the sink.

Conclusion

The results showed that in optimal irrigated conditions, the size of the sink is not the limiting factor of the yield, but the size of the source, both at the top and bottom of the canopy, are the limiting factors for the yield. In the condition of water stress, the result was different in such a way that source limitation was not seen in any part of the canopy, but severe sink limitation occurred.

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